K-space Density Weighted Functional Magnetic Resonance Imaging

Mario Zeller[1], Andreas J. Bartsch[2,3], Alexander Müller[1], Marcel Gutberlet[4], Dietbert Hahn[1], and Herbert Köstler[1]
[1]*Institute of Radiology, University of Würzburg, Würzburg, Germany,* [2]*Department of Neuroradiology, University of Heidelberg, Heidelberg, Germany,* [3]*FMRIB Centre, Oxford University, Oxford, United Kingdom,* [4]*Institute for Interventional and Diagnostic Radiology, Hannover Medical School, Hannover, Germany*

Purpose: K-space density weighting [1] is a technique, which has already been applied to a variety of pulse sequences to achieve a prospectively defined point spread function (PSF) [2-4]. This is achieved by acquiring the k-space using a non-Cartesian trajectory. In contrast to retrospective filtering typically applied to Cartesian data, an optimal signal-to-noise ratio (SNR) is maintained, as the sampling can be optimized for an SNR matched filter [3,5]. Echo planar imaging (EPI) time series acquired in functional magnetic resonance imaging (fMRI) experiments are often spatially smoothed retrospectively using a Gaussian filter prior to statistical analysis. Density weighting allows yielding an identical filter function while maintaining, at the same time, an optimal SNR. The purpose of this study was to evaluate potential benefits of density weighting over Cartesian imaging with retrospective filtering in fMRI experiments.

Materials and methods: Measurements were performed on a 3 T scanner equipped with a 12-channel head coil. Cartesian and k-space density weighted EPIs [5] were acquired using a single-shot EPI sequence (64x64 matrix, FOV 220x220 mm², slice thickness 3.0 mm, 40 slices, TE=30 ms, TR=2.2 s, echo spacing ES=0.54 ms, GRAPPA factor r=2). Four healthy volunteers performed a left-handed finger tapping task consisting of 5 on/off block cycles starting with rest. Volumes (150 in total) were acquired alternatingly in Cartesian and density weighted fashion. In addition to the EPI scan, a three-dimensional T_1 weighted gradient echo scan (for anatomical registration) as well as a multi-echo reference scan [6] (to allow for off-resonance correction [7]) were acquired.

For higher-level analysis, the k-space density weighted sampling was chosen to reproduce a Gaussian filter with full width half maximum FWHM=6.6 mm in image space. This leads to a Gaussian shaped modulation transfer function (MTF) in phase encoding direction, while taking into account a mean T_2^*= 50 ms. As the approximate signal decay $S_n=\exp(-ES \cdot n/T_2^*)$ is known (with n=0…31 being the respective echoes of the echo train), this is achieved by varying the k-space density ρ_n during acquisition according to [4,5]: $\rho_n = 1/\Delta k_n = MTF_n/S_n^2$. Two constraints were set for the calculation of the sampling: 1. The minimum k-space density was limited to a factor of 0.75 to allow for efficient parallel imaging reconstruction. 2. The echo time was kept identical in density weighted and Cartesian acquisition to allow for direct comparison. Image reconstruction was performed using a non-Cartesian GRAPPA/PARS algorithm [2]. To ensure identical PSFs, the Cartesian data was smoothed with an appropriate Gaussian filter in phase encoding direction. Both datasets were also smoothed in read-out direction with an identical FWHM.

The reconstructed data was subsequently preprocessed and analyzed using FSL (www.fmrib.ox.ac.uk/fsl/) [8]. After motion correction, brain extraction and high-pass temporal filtering, time-series statistical analysis was carried out according to the General Linear Model (GLM) using FEAT and FILM (both part of FSL) with local autocorrelation correction. Upon registration to the MNI152 template, higher-level analysis across the n=4 subjects was carried out by a Fixed-Effects (FE) model using FEAT. After pre-threshold masking using a sphere (15mm radius) centered to the right hand knob, Z- (i.e. Gaussianised T-) statistic images were thresholded using clusters determined by Z>2.3 and a FWER-corrected cluster significance threshold of p≤0.05.

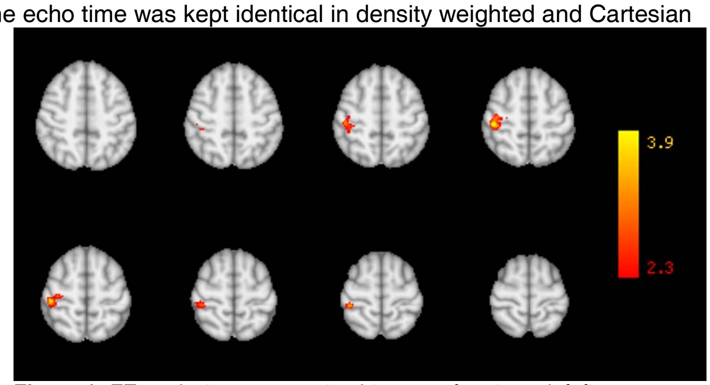

Figure 1: FE analysis across n=4 subjects performing a left finger tapping task reveals significantly higher activations of k-space density weighted fMRI compared to conventional Cartesian fMRI in the right sensorimotor cortex innervating the contralateral hand (cluster-corrected p≤0.05).

Results: Figure 1 shows the cluster around the right hand knob in which k-space density weighted fMRI revealed significantly higher activation levels for left finger tapping than the conventional Cartesian acquisitions (image in 'radiological convention' with right hemisphere on the left image side). Increased response levels of activation within that area are plotted in Figure 2. Density weighted datasets demonstrated higher activation magnitudes for each of the four subjects, and the averaged response strength of the density weighted data was 33±17 % above the Cartesian data.

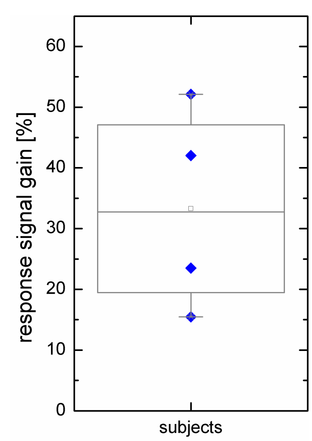

Figure 2: Box plot of increased sensorimotor fMRI responses [%] of k-space density weighted over conventional Cartesian recordings in n=4 subjects performing a finger tapping task.

Discussion and Conclusions: K-space density weighted fMRI significantly increases the measured activations evoked by finger tapping compared to conventional Cartesian imaging. This is achieved while maintaining identical echo time as well as identical total acquisition time. In this study, interleaved acquisition of Cartesian and density weighted data avoided any potential bias of recording two different time courses in separate experiments. Density weighting can be implemented into existing sequences very easily, as it only requires a modification of the amplitudes of the phase blip gradients. The improved efficiency of k-space density weighted sampling can be beneficial, for example, to shorten measurement times required for fMRI studies.

References: [1] Greiser MRM 2003;50:1266-75 [2] Geier MAGMA 2007; 20:19-25 [3] Gutberlet MRI 2010:28;341-350 [4] Zeller JMRI 2012;in press [5] Zeller Proceedings ESMRMB 2012;510 [6] Schmithorst IEEE MI 2001;20:535-539 [7] Man MRM 1997;37:785-92 [8| Woolrich NeuroImage 2009;45:173-186