Distortion-Corrected High Resolution Zoomed fMRI at 9.4 T

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Target audience: Researchers interested in functional imaging, ultra-high field applications and distortion correction methods.

Introduction: Echo-planar imaging often suffers from distortions and signal dropouts in regions with strong susceptibility differences. These artifacts scale with field strength as well as readout duration. One method to reduce distortions is the correction of the pixel shift in image space based on a point spread function (psf) map [1-3]. However, for an optimal BOLD contrast at high field strengths a reduction in time to k-space center is often required. For Cartesian trajectories, the most common approach is the combination of partial Fourier sampling with large parallel imaging factors. Another possibility to shorten the echo train is to reduce the field of view (FOV) in phase encoding direction combined with a suppression of signals from outside of the volume of interest, also called zoomed imaging [4, 5]. Whereas the psf technique allows for the correction of distortions, zoomed imaging can be used to obtain high resolution data from a spatially limited region with high SNR. In this work, the two methods were combined allowing high resolution functional imaging with reduced distortions and relatively low parallel imaging factors.

Methods: Measurements were performed on a 9.4 T MRI scanner (Siemens Healthcare, Erlangen, Germany) using a home-built 16 channel transmit array combined with a 31 channel receive helmet [6]. For outer-volume signal suppression a 30 ms SKEWED pulse [4, 7] was implemented in a GRE-EPI and a psf mapping sequence. Two experiments were performed with an isotropic resolution of 0.8 mm and 0.65 mm. Further imaging parameters were: TE = 23 ms, TR = 3120 ms, 24 slices, FOV 70 x 141 mm², matrix = 88 x 176, for the 0.8 mm dataset and TE = 25 ms, TR = 3120 ms, 24 slices, FOV 49 x 98 mm², matrix = 75 x 150, for the 0.65 mm dataset. For both sequences partial Fourier of 6/8 and GRAPPA = 2 was used. The point spread function was measured in a separate scan before each fMRI experiment using the same sequence settings. Visual stimulation during the 100 measurements of the fMRI scans was performed by presenting a rotating, flashing checkerboard (7 Hz; 7 TRs ON vs. 7 TRs OFF). Activation maps of the uncorrected and the distortion corrected images were obtained using the FEAT algorithm of FSL (FMRIB, Oxford, UK).

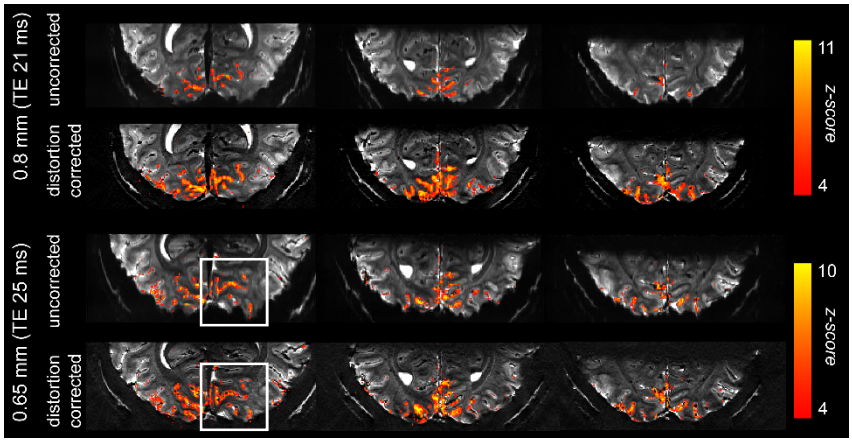

Figure 1: Activations maps for three example slices of the 0.8 mm and 0.65 mm datasets overlaid on the corresponding mean images. The white boxed region is magnified in Figure 2.

Results: Figure 1 shows the activation maps of three example slices of one example subject overlaid on the mean of the EPI images with and without point spread function distortion correction for the two different resolutions. Stronger activations and a higher number of activated voxels were found for both sequences for the distortion corrected datasets. In Figure 2 a more detailed representation of the 0.65 mm isotropic measurement (white box in Figure 1) is given together with the same region of an anatomical gradient echo scan. The psf corrected image allows a more accurate localization of the BOLD response and a better differentiation of cortical structures due to higher sharpness but also shows an increase in noise level when compared to the uncorrected image.

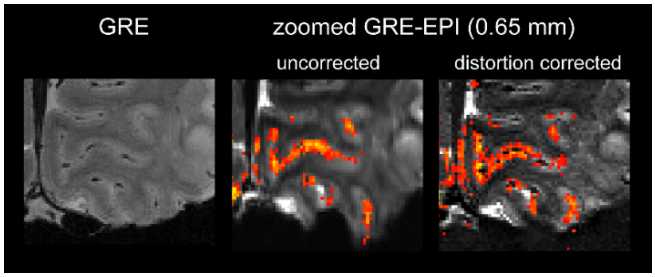

Figure 2: Detail view of the activation map. As an anatomical reference, a gradient echo (TE = 12 ms, 0.5x0.5x0.6 mm³) acquired at the same position is shown.

Discussion & Conclusion: The combination of point spread function correction with the zoomed technique enables high resolution fMRI with reduced distortions. Furthermore, it was possible to keep TE in the range for the optimal BOLD contrast at 9.4 T without requiring high parallel imaging acceleration due to the 50% shorter echo train. However, this approach comes along with a higher specific absorption rate due to the additional saturation pulses and the need for a separate reference scan. The stronger activations found in the psf corrected datasets may be explained by reduced partial voluming of signal from activated voxels with signal from regions with smaller response to the stimulus than in distorted images. Furthermore, the undistorted functional activation maps may be easier to co-register to anatomical images or standardized models for group studies. The most reasonable explanation for the higher noise level in the distortion corrected images is that the psf map was calculated based on data with a less than optimal SNR due to the high resolution. Thus, it is not directly related to the apparent resolution increase. However, additional experiments are required to investigate this effect in detail.

References: [1] Zeng H and Constable RT. MRM (2002); 48(1):137-46. [2] Zaitsev M, et al. MRM (2004); 52(5):1156-66. [3] In M-H, et al. MAGMA (2012); 25(3):183-92. [4] Pfeuffer J, et al. NeuroImage (2002); 17:272-86. [5] Heidemann R, et al. MRM (2012); 68(5):1506-16. [6] G. Shajan, et al. MRM (2014); 71:870-79. [7] Hwang T-L, et al. JMR (1999); 138(1):173-77.