Recovery of susceptibility induced signal loss in reduced field-of-view EPI-BOLD using z-shim

W. Scott Hoge[1], Hong Pan[1], Ravi Teja Seethamraju[2], Keith A Heberlein[2], and Emily Stern[1]
[1]Radiology, Brigham and Women's Hospital, Boston, MA, United States, [2]Siemens Healthcare, Boston, MA, United States

Introduction: Gradient-echo EPI is used extensively in BOLD fMRI to assess neurological functionality, because it can provide whole-brain imaging at a reasonable temporal resolution despite its limited spatial resolution at low TRs. One approach to improve spatial resolution is to provide functional images of the brain in a reduced field-of-view (rFOV). Although this can increase temporal and spatial resolution, rFOV-EPI BOLD continues to suffer from the inherent drawbacks of traditional EPI: Nyquist ghosting, geometric distortion, and signal loss due to magnetic susceptibility.

Magnetic susceptibility is particularly pronounced in regions of the brain near air-tissue interfaces, such as the nasal sinuses and ear canals. Magnetic susceptibility changes the phase accumulation rate, which pushes the spin signal in such areas outside the region excited by slice encode gradients. Z-shim methods [1,2] are one approach to correct this signal loss, where a *z*-gradient is applied across the slice prior to the EPI echo train—effectively modifying which regions of the image are "bright" and which are "dark". Most z-shim compensation methods acquire each slice twice, using complementary z-shim compensation gradients for each pair of images. The final image is then formed by combining the two complementary z-shimmed images, to recover regions of the slice that would be dark in EPI images without z-shim compensation.

rFOV is effective in reducing in-plane distortion due to susceptibility, but it does not mitigate signal loss due to local through-plane field gradients. This work presents a method that combines rFOV-EPI and z-shim compensation. The addition of z-shim compensation to rFOV enables a comprehenive solution to susceptibility artifacts in EPI, and will extend the applicability of rFOV-EPI to regions of the brain that suffer from magnetic susceptibility induced signal loss. The aim is to enable high-resolution functional imaging of the amygdala, pituitary, and other frontal-limbic structures.

Methods: We employed a rFOV EPI sequence [3] to limit the field of view within the brain. To this we added z-shim compensation gradients along k_z between the three Nyquist ghost correction navigator lines and the EPI echo train, which required a 190 μsec lengthening of the echo time.

To calibrate the z-shim compensation gradients, 16 images of each slice were acquired uniformly across the range of possible z-shim values. From this set, we identify a pair of images for each slice that most closely match the maximum-intensity-projection (MIP) across the calibration images. Once these image pairs are determined, the z-shim gradient values associated with the image pairs are employed in subsequent fMRI experiments by alternating the z-shim gradient value on every other volume repetition. Once all of the data is acquired, a MIP mask is generated from the first pair of images for each slice. This mask then determines which voxel from each z-shim pair of images in the temporal series contributes to the functional image. The combined z-shim image pairs are then realigned to correct for slight head motion based on intracranial voxels, and spatially smoothed with an isotropic Gaussian kernel (FWHM=4.5mm).

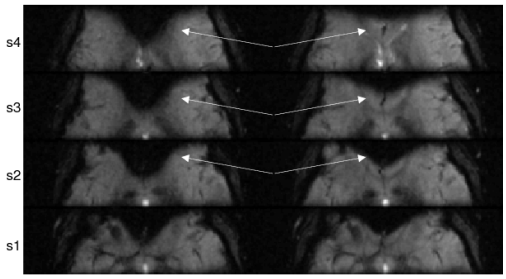

Fig 1: Individual rFOV-EPI images (left) without and (right) with z-shim compensation.

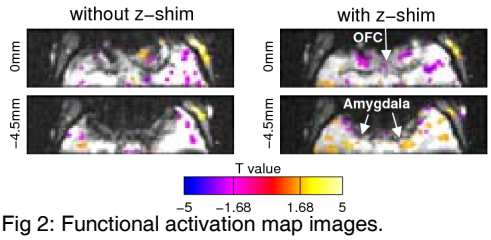

Fig 2: Functional activation map images.

Volume of activated voxels (mm^3) / peak z-scores for frontal-limbic circuit

	Amygdala		Posterior mOFC
2nex	43(L)/2.26	326(R)/3.20	67/-2.88
0nex	10(L)/1.74	24(R)/2.23	0 / no signal/stats

Images from a healthy volunteer were acquired under informed consent and IRB oversight, covering the brain regions of both bi-lateral amygdala and the posterior medial OFC. The imaging protocol sampled 9 slices over an area 19.2cm x 5.4cm x 3mm per slice with a 1.5mm gap, using a matrix size of 192x54 per slice (1mm x 1mm x 4.5mm / voxel). The imaging parameters were TR/TE = 871ms/44.7ms. The volunteer viewed a paradigm designed to elicit an emotional response in the frontal-limbic region of the brain.

To analyze the functional data, a voxel-wise multiple linear regression model was employed to examine the effect sizes of the key condition contrasts in an ANCOVA setting, where the regressor of interest consists of the stimulus onset times convolved with a prototypical hemodynamic response function, and the covariates of no interest consist of the temporal first-order derivative of the principal regressors, realignment parameters, and their higher-order effects. Effects at every brain voxel were estimated using the EM (expectation maximization) algorithm, and regionally specific effects were then compared using linear contrasts between two different stimulus conditions.

Results: Fig 1 shows 4 (of 9) slices of pre-analysis rFOV-EPI images acquired just above the nasal sinuses. Comparing the standard images (left) with the z-shim compensated images (right) one observes a significant recovery of MR signal from the frontal-limbic region. Fig 2 shows the resulting statistics map after post-acquisition processing and analysis. Of particular note is the activation/deactivation present at the amgydala and OFC, labeled in the z-shimmed images on the right of Fig 2. This activation is notably diminished in the no z-shim images. The table confirms this observation by showing a dramatic increase in detection power in the regions of interest.

Discussion: The goal of rFOV EPI methods is to simultaneously provide high-spatial and high-temporal resolution for functional imaging. We have demonstrated that the combination of z-shim compensation with reduced field-of-view EPI allows one to image functional neural activities in the structures at the base of the brain that are both particularly important in the study of affective disorders and also highly susceptible to geometric distortion and signal loss due to magnetic susceptibility.

References: 1. Frahm, et al, *Magn Reson Med* 1988;32:474-480. 2. Constable. *J Magn Reson Imag* 1995; 5:746-752. 3. Rieseberg, et.al., *Magn Reson Med* 2002;47:1186-1193