Optimizing EPI for Functional MRI using Multi-directional Shimming in a Single Shot Acquisition

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INTRODUCTION

Susceptibility-induced field inhomogeneity is a major cause of signal loss near air/tissue interface in functional MRI based on blood oxygenation level dependent (BOLD) contrast. The signal loss has often compromised the quality of fMRI studies of the orbital frontal cortex (OFC) and the medial and inferior temporal lobes. Z-shimming has been widely used to offset the field inhomogeneity in the slice selection (SS) direction [1-5]. Shimming has been attempted in the phase encoding (PE) direction with a fixed amplitude [1],which may not achieve the optimal signal recovery of whole brain [5]. As another approach, slices were prescribed in an oblique position to minimize the susceptibility-induced field inhomogeneity in the PE direction in combination with Z-shimming [2, 3]. However, the oblique acquisition may reduce the brain coverage and only certain slices may produce the optimal signal recovery with the oblique slice scheme [3]. A single-shot Z-shimming sequence [4] was introduced for the acquisition of a z-shimmed image and a standard image in a single repetition both of which virtually maintain the similar BOLD contrast. In this work, we describe a method that can optimally compensate for the susceptibility-induced field inhomogeneity in both SS and PE directions with the single shot EPI approach.

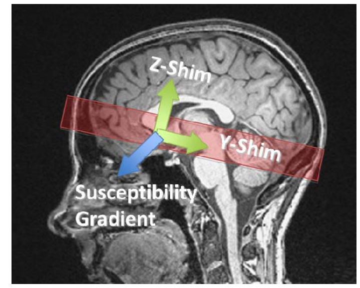

Figure 1. Illustration of compensation by multi-directional shimming gradient

METHODS

A dual-echo EPI sequence with YZ-shim, as depicted in Fig 2, was implemented on a 3T MR scanner (Siemens Medical Solutions, Malvern, PA). The sequence forms a gradient-echo EPI image followed by an asymmetric spin-echo EPI image both of which have a similar BOLD weighting. The YZ-shimming gradients are applied before the acquisition of the second echo. The sequence was tested on normal volunteers to investigate its performance. Axial imaging was performed, covering the OFC and the medial and inferior temporal lobes. The imaging parameters were: 20 contiguous 4-mm slices, TE1/TE2/TR =30/66/2000 ms, FA=90°, FOV =22 cm, 3.44×3.44×4 mm^3, and BW = 2442 Hz/pixel. The compensation gradient was applied from -140 μT/m to 140 μT/m for Y-shimming and from -240 μT/m to 240 μT/m for Z-shimming in increments of 20 μT/m. The composite image was reconstructed by computing the square root of the sum of squares (SSQ) of the two acquired images. Signal recovery was quantified by the sum of supra-threshold intensity increment of the shimmed-echo compared to the 2^{nd} echo with no shim. The optimal selection of YZ-shimming gradients was based on this measure and was verified by visual inspection.

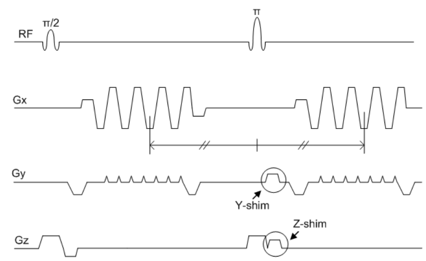

Figure 2. Pulse sequence diagram for the dual echo YZ-shim EPI sequence. The arrows denote the Y-shim and Z-shim gradients to compensate for susceptibility-related field inhomogeneity before an asymmetric spin-echo.

RESULTS and DISCUSSION

Images of the inferior frontal lobe are shown in Fig 3. From left to right, images of a standard EPI image, an optimally Z-shimmed (180 μT/m) image and an optimally YZ-shimmed (80, 120 μT/m) image, respectively are presented. Significant signal recovery is observed in the OFC with the optimal YZ-shimming (indicated by yellow and red box in the zoomed-in images). With the optimal Z-shimming only, signal recovery is achieved at 38% of the optimal YZ-shimming acquisition. It has been shown that signal loss still remains in the OFC after Z-shimming has been optimized [3]. Thus, it is important to optimize the multi-directional shimming for reducing signal loss. In Fig 4, the signal recovery distribution along YZ-shim plane is unimodal and smooth, suggesting online calibration scan can be implemented in a time-efficient manner. The single shot approach based on spiral in/out acquisitions [6] could also be used for the 2-dimensional shim method introduced here. Compared with multiple-shot approaches, a single-shot technique described in this work can achieve improved temporal resolution. For more efficient imaging, the 2^{nd} echo may be only acquired for a selected volume where the susceptibility-induced signal loss is severe. In conclusion, multi-directional shimming may have significant advantage over Z-shimming alone for recovering susceptibility-induced signal losses in fMRI.

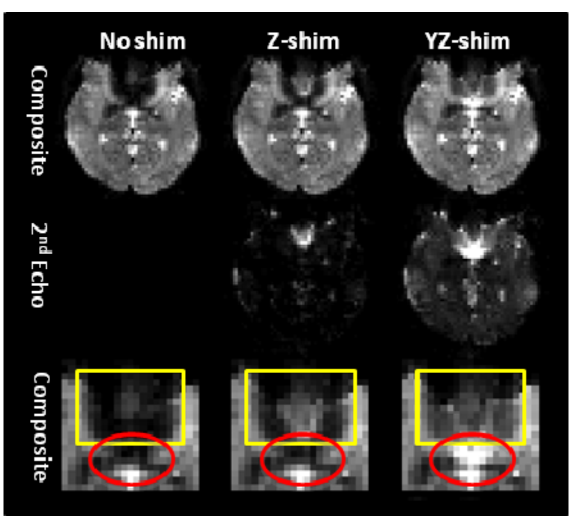

Figure 3. Resulting images from a YZ-SAGA pulse sequence. The left image is the standard EPI image and the center image is the optimal Z-shim image. The right image is the optimal YZ-shim image. The top row is sum of squares (SSQ) composite images and the center row is asymmetric spin echo image. The bottom row corresponds to zoomed-in images of top row

REFERENCE

[1] R. Deichmann et al., *NeuroImage* 2002,15:120-135
[2] R. Deichmann et al., *NeuroImage* 2003,19:430-441
[3] N. Weiskopf et al., *NeuroImage* 2006,33:493-504
[4] K. A. Heberlein et al., *Magn. Res. Med.* 2004,51:212-216
[5] J. Rick et al., *Magn Reson Mater Phy* 2010,23 :165-176
[6] G. H. Glover., *Magn. Res. Med.* 2001,46:515-522

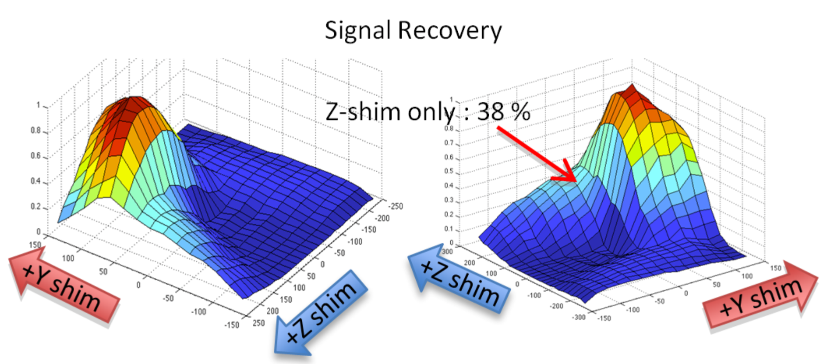

Figure 4. Signal recovery distribution along YZ-shim plane for the same slice as Fig 3.