Optimal EPI parameters for BOLD sensitivity dropout reduction: a whole brain map

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Introduction

Blood oxygen level-dependent (BOLD) gradient echo echo-planar imaging (GE-EPI) is commonly used for functional magnetic resonance imaging (fMRI). One problem with EPI is that inhomogeneities in the static magnetic field (B_0) at air-tissue interfaces can cause local signal dropout. Various studies have shown that the signal dropout depends on: the imaged object, and on the imaging sequence and its parameters (e.g., TE, slice tilt, readout time). Dropout increases with increasing B_0. Several components of the basic EPI sequence can be modified to minimize signal dropout: a) Excitation. Radio-frequency pulses with quadratic phase profiles for reducing through-slice dropout [1]. b) Pre-readout. Additional gradient pulses for counteracting susceptibility gradients [2-4] (e.g., through-plane z-shimming [5]). c) Readout. E.g., inverting the phase encoding (PE) gradient polarity, spiral-in/-out acquisition [6].

The goal of this study was to create a 3D map showing the optimal imaging parameters for different brain regions. The parameters investigated were the moment of the z-shimming pulse, the slice orientation, and the PE polarity. These parameters were optimized with respect to the local BOLD sensitivity (BS) calculated according to [2].

Methods

We implemented an EPI sequence on a 1.5 T whole body scanner (Siemens Sonata) and a 3 T head scanner (Siemens Allegra) which allows for the free choice of the slice orientation, the z-shimming gradient, and the PE polarity. Other imaging parameters were 48 slices, slice thickness = 2 mm, slice gap = 1 mm, FOV = 192 mm, matrix size = 64x64, PE in A-P direction, TE = 35 ms/50 ms, TR = 4.4 s/3.1 s (for 1.5 T/3 T), flip angle = 90°.

For BS mapping we scanned three volunteers (with written informed consent). The moment of the z-shimming pulse was varied from M_{Gz} = -2 mT/m*ms to +2 mT/m*ms (in steps of 1 mT/m*ms), the slice tilt from β = -45° to +45° (in steps of 15°), and the PE gradient was set to pos./neg. polarity, resulting in 70 measurements with 5 repetitions each. Further analysis was based on the 5th repetition to allow for T_1 saturation. Images with prepulse magnitudes > 2 mT/m*ms can be omitted because they reduce the BS in well-shimmed areas by more than 10% [2,4]. For distortion correction and anatomical reference, a field map (double echo GRE, voxel size = 3x3x3 mm^3) and a 3D T_1w image for spatial normalization (MDEFT [7], voxel size = 1x1x1 mm^3) were recorded.

BS maps were calculated from the complex k-space data [2]. Images were spatially normalized using SPM2 [8] after correcting geometric distortions using the FieldMap toolbox [9]. We calculated a BS_0, which is the mean BS across all parameter settings, and a BS_m, which is the maximal achievable BS. The BS gain was then defined as $(BS_m\text{-}BS_0)/BS_0$.

Results

The choice of imaging parameters strongly influenced the BS in several areas affected by field inhomogeneities. The BS gain exceeded 100% in parts of the ventromedial prefrontal cortex (VMPFC, Fig. 3). We delineated four major regions in which the BS gain exceeded 20% at 3 T (Figs. 1-3): 1) VMPFC (β = +45°, M_{Gz} = -2 mT/m*ms, pos. PE), 2) posterior VMPFC (β = -30°, M_{Gz} = -2 mT/m*ms, pos. PE), 3) temporal poles (β = -40°, M_{Gz} = +2 mT/m*ms, pos. PE), 4) inferior temporal lobes (β = +40°, M_{Gz} = -2 mT/m*ms, pos. PE). Optimal parameter settings and regions were similar at 1.5 T and 3 T. However, regions showing significant BS gains were larger and maximal BS gains were higher at 3 T. Optimal prepulse moments were similar for pos. and neg. PE, but the slice tilt was inverted. BS of the two PE polarities differed only minimally (< 20%) except for small parts of the amygdala-hippocampal region, brainstem, and inferior prefrontal cortex. As expected no significant BS gains were discovered in areas not affected by susceptibility gradients.

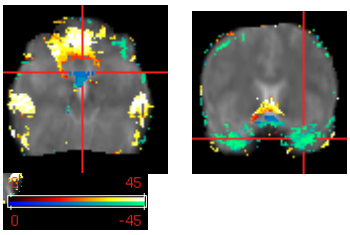

Fig. 1: Optimal tilt angle [°] from axial plane

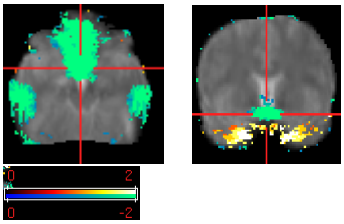

Fig. 2: Optimal z-shim prepulse [mT/m*ms]

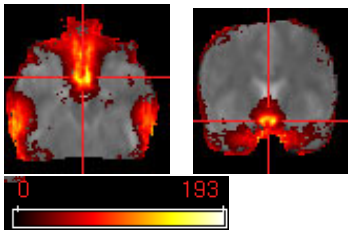

Fig. 3: Relative percent gain in BOLD sensitivity

Discussion

Signal dropouts were significantly reduced both at 1.5 T and 3 T using optimal z-shimming gradients and slice tilts in accordance with previous reports [2,4]. We identified four brain regions in which the BS could be increased significantly using a specific set of parameters (> 20%, see Fig. 3). If the slice tilt and the z-shimming gradient are optimized, the PE gradient polarity seems to have relatively little influence on the BS, which may be due to echo time shifting [2]. Parameter maps at 1.5 T and 3 T were qualitatively similar. However, regions exhibiting BS gain were more extended at 3 T and maximal gains were higher. This study concentrated on three parameters: z-shimming gradient, slice orientation, PE polarity. In future studies, additional parameters could be investigated. The goal is to create a 3D atlas providing researchers with information on optimal fMRI sequence design and an estimate of functional sensitivity.

References

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