Automated slice-dependent z-shim for fMRI: user-independent reduction of BOLD sensitivity losses

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Introduction: Most functional magnetic resonance imaging (fMRI) techniques are based on the blood oxygen level-dependent (BOLD) effect. Heavily T2* weighted gradient-echo echo-planar imaging (GE-EPI) sequences are frequently used because of their high BOLD sensitivity (BS). However, inhomogeneities of the static magnetic field near air-/tissue-interfaces can cause severe signal losses, in particular in the basal brain [1;2]. Recently, a method has been developed which allows for optimizing the BS in those dropout regions by specifically adjusting the slice tilt, the polarity of the phase-encoding (PE), and z-shim preparation with constant gradient moment across the brain [2-4]. The latter will effectively reduce the BS loss in the areas it is optimized for. However, it may underperform in other areas requiring different z-shim gradient moments or even exacerbate the BS loss. Here, we propose a novel compensation technique that optimizes the slice tilt, PE polarity and slice-dependent z-shim moments for a combination of specific regions of interest (ROIs). The method does not require user input, because the optimal parameter set for an average normalized brain is stored and applied to each subject after automatically accounting for variations in the head size and position in the scanner.

Methods: ***Calibration:*** Based on previous BOLD sensitivity measurements [4], we determined the optimal slice tilt, PE direction, and slice-dependent z-shim moments maximizing the BS in a given set of regions of interest: medial orbitofrontal cortex (mOFC) combined with either amygdala, hippo-/parahippocampus, or temporal pole. As an example, Fig. 1 shows the dependence of the optimum z-shim moment on the slice position for simultaneous investigation of the mOFC and the temporal pole. Since the original BS measurements were determined for a group of 5 subjects after transformation of the individual single subject data to the MNI stereotactic space [5], the optimal parameters given in the stereotactic space had to be transformed to the individual subject's space before application. An automatic procedure was implemented that spatially normalizes an EPI pre-scan of the subject before the fMRI run. Using the same transformation, the optimal parameters for the individual can be determined from the optimal parameters of the group. The spatial normalization and the optimization were performed in Matlab using SPM2 (Wellcome Dept. Imaging Neuroscience, London, UK) and custom-made programs.

Validation: To assess the effectiveness of the slice-dependent z-shim, the mean BS achieved in the ROIs was compared to the mean BS that was achieved by using the previously published technique using optimal slice tilts and PE direction, but a constant z-shim moment [4], and by using a standard EPI (axial orientation, PE polarity pos., no z-shim). Seven subjects were scanned (with informed consent) in a 3 T Allegra head scanner (Siemens Medical, Erlangen, Germany) using the standard birdcage head coil (single-shot GE EPI, resolution 3x3x2mm^3, TE 30 ms). BS maps were estimated from the complex EPI raw data according to [6] as the product of the local TE and image intensity. The BS values were normalized to the mean BS (= 100%) in a well-shimmed brain area according to [4]. All images were spatially normalized and smoothed (FWHM 6 mm) using SPM2 after correcting geometric distortions using the FieldMap toolbox [7] on the basis of acquired fieldmaps. The mean BS was determined for each combination of ROIs and acquisition type (slice-dependent, constant z-shim, and conventional EPI).

Results: The mean BS increase caused by the slice-dependent z-shim compared to the constant z-shim / conventional EPI acquisition was: mOFC+amygdala: 1.1% / 5.1%; mOFC+temporal pole: 5.0% / 6.5%; mOFC+hippo-/parahippocampus: 4.7% / 4.8%. The local BS increases well exceeded the mean BS increases, yielding increases of more than 30% in many voxels of the ROIs. As an example, Fig. 2 shows maps of the increases achieved in the mOFC or the temporal pole.

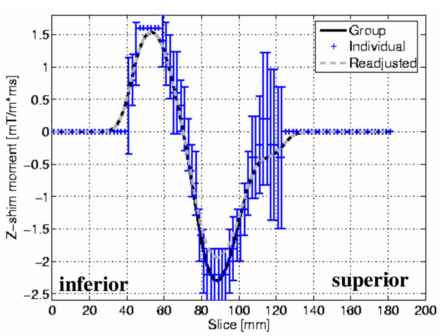

Figure 1: Optimal z-shim gradient moments for imaging of the mOFC and temporal pole. Optimal values for the group and individual subjects are similar. Values were smoothed and readjusted to moments < 2 mT/m*ms to avoid spatial discontinuities and excessive signal loss in well-shimmed areas. Slice tilt = +30°, neg. PE polarity.

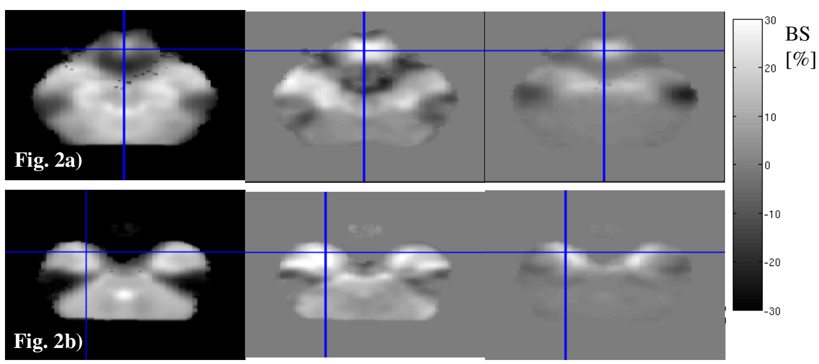

Figure 2: BOLD sensitivity (BS) map of the EPI acquisition with slice-dependent z-shim (left), difference between the slice-dependent z-shim and the conventional EPI (center) or the constant z-shim (right). Maps are based on the mean BS across the group. a) mOFC, b) temporal pole.

Discussion: We have presented a method that effectively compensates BOLD sensitivity losses by optimizing the slice tilt, PE polarity and slice-dependent z-shim without requiring user input. Previous slice-dependent z-shim methods required user input [8] or did not optimize the slice tilt and PE polarity [9]. Moreover, the approach outperforms previous compensation approaches based on a constant z-shim [2-4].

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