SIMULATION OF OPTIMAL ECHO TIMES TO MAXIMIZE BOLD SENSITIVITY IN THE ORBITOFRONTAL CORTEX FOR FMRI

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Introduction

The orbitofrontal cortex (OFC), important for decision-making and reward processing [1], is affected by susceptibility gradients (SG) causing signal drop outs and image distortions in fMRI using EPI [2]. In subcortical brain areas, BOLD sensitivity (BS) depends critically on echo time (TE) [3]. EPI with short TE of 27 ms have been used in previous fMRI studies [4-5] to mitigate SG-effects in the OFC and maintain acceptable BS in the rest of the brain. Stöcker et al. proposed slice dependent TE to optimize BS in subcortical and cortical brain areas seperately [6]. The goal of this work is to calculate optimal TE for single EPI slices via BS simulations considering local T2* and SG values to maximize BS in the OFC.

Material & Methods

All measurements were performed on a 3 Tesla whole-body MR-system (Magnetom Trio, Siemens Healthcare, Erlangen, Germany) equipped with a 12-channel head coil. Phase maps were acquired from six healthy subjects (27±1 years) with a multi-gradient echo 3D-FLASH sequence at five different TE between 2.45ms and 13.13ms with AC-PC section orientation and the following sequence parameters: 40 slices; 64x64 matrix; TR=30ms; flip angle α=12°; FOV=220^{2}mm^2; slice thickness Δz=2.5mm. T2* weighted intensity images were acquired adjacently using the same MR-sequence at twelve different TE between 5ms and 140ms and α=25°. SG in slice (Gss) and phase encoding (blip) direction (Gsp) were computed from the phase images [7] and T2* maps were computed from the intensity images using an sinc-exp fit [8]. The parameter maps were then registered to the T2* weighted intensity images, spatially normalized to MNI space and resampled to a 96x96x40 matrix size using SPM 8 (http://www.fil.ion.ucl.ac.uk/spm). BS depends on local T2* and SG values and can be expressed as **(1)** $BS = TE/Q^2 \exp[-TE/(QT2^*)]\, sinc[\gamma G_{ss} TE \Delta z/2]$, with $Q = 1-\gamma \Delta t FOV G_{sp}/(2\pi)$ [9]. Here γ denotes the gyromagnetic ratio and Δt the time between successive gradient echoes. BS is zero if **(2)** $TE\,|1-1/Q| > TA/2$ [9]. That is if the gradient echo is shifted outside the signal acquisition window of duration TA. Optimal TEs were calculated numerically using equation **(1)** and **(2)**.

Results

T2* (SG) values are clearly decreased (increased) in the lowest part of the OFC compared to other brain areas (Figure 1). T2* relaxation times were in the range of 8±3ms and 31±7ms. For reference, T2* measured in the caudate nucleus was 43±3ms and agrees well with the literature [8]. In (through)-plane SG were in the range of -202±57µTm^{-1} (-230±56µTm^{-1}) and 288±63µTm^{-1} (214±17µTm^{-1}). These values correspond to the 5 and 95 percentiles averaged over all subjects and agree with the findings of DePanfilis et al [10]. The standard deviation denotes the variation between the subjects. Figure 2 shows BS for all possible combinations of in- and through-plane SG. It can be seen that BS loss is effectively recovered at TE of 20ms for SG of negative but not of positive polarity. Given the imaging parameters above and assuming T2* of 25ms, BS is lost (i.e. BS/BS0<0.1) in 37% (44%), 32% (43%), and 8% (40%) of all voxels in the left (right) hemisphere of the Gsp/Gss plane at TE of 40ms, 30ms, and 20ms. Considering the magnitude of the BS, it shows that BS affected by through-plane SG (Gsp=0) increases at shorter TE. The situation is more complex if BS is affected by in-plane SG (Gss=0). In the case that BS is not totally lost, BS can also decrease at shorter TE. For example, given an in-plane SG of Gsp= -100µTm^{-1} leads to 14% (26%) BS reduction when TE is decreased from 40ms to 30ms (20ms). Figure 3 shows that for SG in the range of [-250...250] µTm^{-1}, signal loss is successfully prevented for negative Gsp values (i.e. anti-parallel to the blips) when TE is about 25ms. On the contrary, signal loss is unavoidable for positive Gsp values above 75µTm^{-1} since TE cannot be arbitrarily shortened using a standard EPI sequence with typical imaging parameters. Figure 4 shows that TE reduction significantly increases BS in the OFC when short TE is used. In average, the percentage of dead voxels decreased from 81±9% to 67±15%, 39±16%, and 16±4% in all subjects using TE of 50ms, 40ms, 30ms, and 20ms. In ascending direction, maximal BS in the OFC was reached at increasing TE values (Figure 5). In foot-head direction, mean optimal TE in all subjects increased from 17±2ms to 39±2ms using AC-PC section orientation. In areas not affected by SG, maximal BS was reached at TE of 46±3ms in agreement with cortical values [11].

Discussion and Conclusion

The goal of this work was to estimate optimal TEs to maximize BS in the OFC. We simulated the effects of TE reduction on BS for typical T2* and SG values observed in the OFC. It showed that reducing TE significantly increases BS in the presence of through-plane SG. But on the other hand, if the signal is not totally lost at longer TE, shorter TE can also decrease BS in the presence of in-plane SG with negative polarity and medium strength. Furthermore, a TE reduction is very ineffective to recover signal loss caused by in-plane gradients with positive polarity. Therefore, TE should not be too small to ensure uncompromised BS in homogeneous parts of the brain. BS computations in the OFC showed that a TE of about 20ms effectively recovers BS loss in the lower part of the OFC typically affected by stronger SG than upper parts. The theoretical values of optimal TE increased approx. linearly from 17±2ms to 39±2ms for AC-PC section orientation and showed good consistency over all subjects. In conclusion, we recommend using increasing TE from about 20ms to 40ms for whole-brain fMRI using EPI with focus on the OFC. In future work, an EPI with slice dependent TE will be implemented and tested in fMRI.

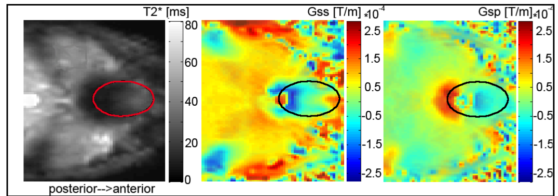

Figure 1. T2* and SG maps, in slice/phase encoding direction, depicted for slice 1. The OFC is indicated by the circle. This data was obtained from subject 1.

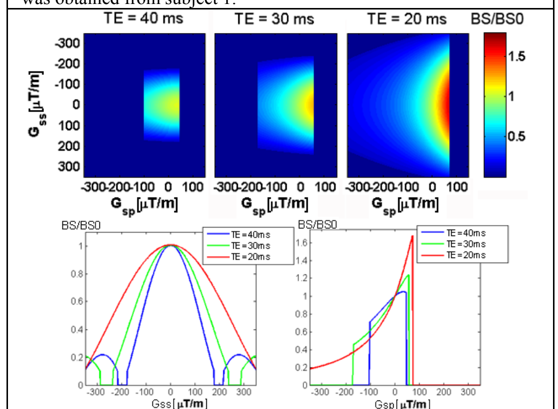

Figure 2. Normalized BS maps (top row) in the Gsp/Gss plane simulated for different TE according to equation **(1)** and **(2)**. BS profiles along Gsp=0 (left) and Gss=0 (right) are depicted below. BS/BS0 values below 10% were set to zero. T2* was 25ms.

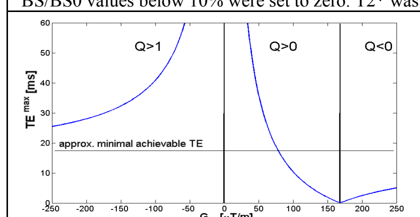

Figure 3. TE values before total signal loss occurs according to equation **(2)**.

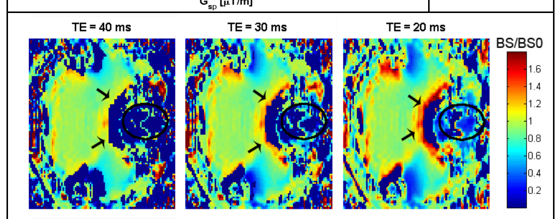

Figure 4. Normalized BS-maps of slice 1 simulated for different TEs. The OFC is indicated by the circle. The two arrows mark an area with signal loss occurring at any TE. This data was obtained from subject 5.

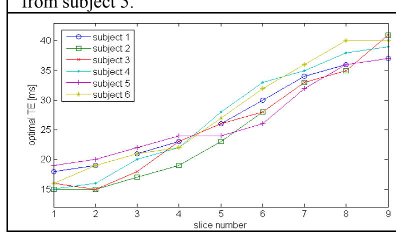

Figure 5. Optimal TEs calculated for different axial slices in the OFC. This data was obtained from six healthy subjects.

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