Susceptibility-induced BOLD Sensitivity Variation in Breath Hold Task

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INTRODUCTION

Magnetic field inhomogeneity exist near the interface of air/tissue in the ventral brain (i.e. orbitofrontal cortex), which leads to susceptibility artifacts in fMRI including geometric distortion and signal loss [1-6]. In gradient echo acquisition, the induced susceptibility gradients will also cause echo time shift resulting to BOLD sensitivity changes, especially in the areas contain high susceptibility gradients. We examined the susceptibility-induced BOLD sensitivity variations in a breath hold task among subjects.

THEORY

For gradient echo fMRI, the magnitude of BOLD signal has a strong dependence on the echo time [7]. Therefore, echo time shift (induced by susceptibility gradients) will cause BOLD sensitivity changes [8]. The breath hold fMRI experiment invokes a BOLD-like response throughout the gray matter in the brain and provides a controlled, whole-brain look at BOLD signal intensities. Thus examining the BOLD sensitivity change (due to susceptibility gradients) in breath hold task provides valuable investigations.

METHODS

Simulation: Estimated BOLD sensitivity signal from effective echo time due to linear susceptibility gradients is shown in Fig. 1 for EPI down (anterior to posterior) trajectory, as described in our previous work [8]. It shows that the BOLD signal induced by susceptibility gradients changes seriously in phase encode direction (Y-direction).

In vivo: The experiment was performed on a head-only Siemens Allegra 3T MRI scanner. Twenty-one healthy subjects (ten older adults aged 61-72, eleven younger adults aged 19-32) participated in an fMRI breath hold scan and field inhomogeneity map acquisition. The breath hold task was designed as seven repetition of alternating breath holding and self-paced breathing in 18 sec blocks, as described in [9]. The subjects were scanned with an EPI acquisition with phase encoding direction down, 32 slices with 4 mm slice thickness, TE of 30 ms, TR of 2 sec, and matrix size of 64×64. The field map acquisition was a multi-echo gradient echo scan with echo times of 10 and 12.46 ms and a doubled matrix size as 128×128. The BOLD maps (converted to percent signal change) and susceptibility gradient maps were normalized to standard MNI space prior to analysis, as would be done in a typical fMRI experiment.

We examined two subject-specific ROI's defined by the susceptibility gradient ranges, shown in Fig. 1 as two shadowed region. We restricted our analysis to 5 slices near the base of the brain to ensure similar BOLD signal properties. For ROI1, the susceptibility gradients in the phase encode direction (Y-direction) from 10 to 30 Hz/cm were targeted in the gray matter (defined as having a percent signal change of 1% or more). For ROI2, we defined the ROI to be gray matter that had susceptibility gradients in Y-direction from -30 to -10 Hz/cm. As can be seen in Fig. 1, for EPI with phase encode down, ROI1 is expected to have larger BOLD signal change and ROI2 is expected to have smaller BOLD signal change.

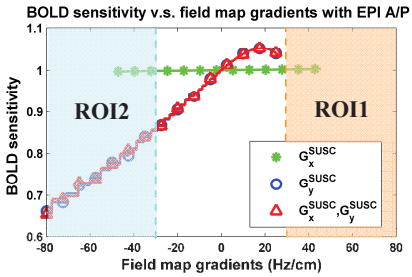

Fig. 1 The estimated BOLD sensitivity signal from effective echo time shift due to a linear susceptibility gradient using EPI A/P. The green line with star and the blue line with circle represent the BOLD signal due to susceptibility gradients in X-direction (readout) and Y-direction (phase), respectively; and the red line with triangle represents the BOLD signal due to susceptibility gradients in both X- and Y- direction simultaneously. ROI1 (10~30 Hz/cm) is in light blue and ROI2 (-30~-10 Hz/cm) is in light orange.

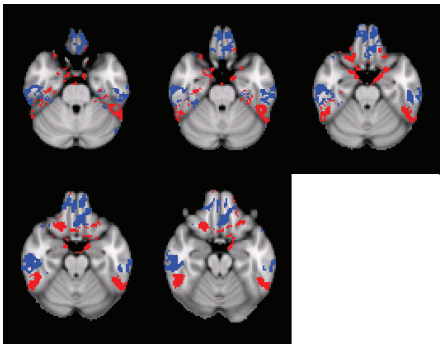

Fig. 2 Regions of interest is defined by susceptibility gradients in Y-direction in one subject. ROI1 (10~30 Hz/cm) is in red and ROI2 (-30~-10 Hz/cm) is in blue.

RESULTS and DISCUSSION

Fig. 2 shows the ROIs in a typical young subject, while ROI1 (with susceptibility gradients 10~30 Hz/cm in Y-direction) is in red and ROI2 (with susceptibility gradients -30~10 Hz/cm in Y-direction) is in blue. Table 1 gives the resulting comparison for the subject shown in Fig. 2. As shown in the table, ROI1 gives a higher percent signal change with the difference being very significant ($p=1.2\times10^{-36}$). The average percent signal change for the 21 subjects is shown in Table 2. Similar significant higher activations in ROI1 were seen in 17 of 21 subjects with p-values ranging up to 6.8×10^{-103}. 4 subjects (2 young adults and 2 old adults) did not show significant differences at the p=0.05 level, of which 2 subjects showed non-significantly higher BOLD signal in ROI2. Despite these outliers, the effect is very robustly showing a highly significant relationship between susceptibility gradients and BOLD signal in 81% of the subjects, additional experiments will seek to control other susceptibility artifacts that are present in the data, including through-plane signal loss and geometric distortions that were not addressed in this preliminary study.

Table.1 Signal Change in ROI1 and ROI2 for one subject (The data is corresponding to Fig. 2)

Regions of Interest	Number of voxels in ROI	Mean percent signal change	Standard deviation
ROI1 (10~30 Hz/cm)	1039	3.56	1.96
ROI2 (-30~-10 Hz/cm)	1307	2.67	1.40

Table.2 Average Signal Change in ROI1 and ROI2 for 21 subjects

Regions of Interest	Number of voxels in ROI	Mean percent signal change	Standard deviation
ROI1 (10~30 Hz/cm)	814	3.60	2.55
ROI2 (-30~-10 Hz/cm)	908	2.81	1.95

CONCLUSION

The breath hold fMRI experiment analyzed to determine if susceptibility gradient induced BOLD sensitivity changes are observable within susceptibility regions in subjects. The results show the BOLD sensitivity changes significantly due to magnetic field inhomogeneity gradients in 81% subjects.

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