Automatic slice-dependent frequency adjustments for SSFP fMRI

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Introduction

SSFP fMRI has been reported to have potential for distortion free and high resolution functional imaging [1]. Based on balanced SSFP imaging with a small flip angle, whose magnitude peaks at the narrow band of phase transition [1], SSFP fMRI is suitable for detecting small functional changes in blood oxygenation, which however also leads to native sensitivity to field instability [1,2]. Previous studies have proposed methods to remedy temporal field instability during consecutive scans of fMRI [3,4]. However, spatial field inhomogeneity, from either tissues with heterogeneous susceptibility or systematic imperfect shimming, remains to be improved. In this study, we proposed a slice-dependent frequency adjustment method to compensate for regional off resonance such that all areas of interest in the brain have optimized functional sensitivity. SSFP fMRI were also performed to evaluate the effectiveness of our method.

Materials and Methods

Two volunteers (one male and one female, 24-30yrs) underwent SSFP fMRI in this study (matrix 64x64, TR/TE/flip angle: 8ms/4ms/5^0, 5 transverse slices). All images were acquired on a 3.0 Tesla system (Philips Achieva, Best, the Netherlands), with an 8-channel volume coil and shimming covering occipital lobe. IIR-filtered frequency stabilization was applied to compensate for temporal frequency drift [4]. Tight foam padding was applied to prevent head motion. Visual stimulus (5Hz checkerboard, 4 on, 5 off, 8 frames/block, 2.56 sec/frame) was given in 72 dynamic scans. fMRI analysis was done by using T-test implemented in SPM5 software.

To measure regional off resonance frequency, a sweep scan with varying SSFP angle was inserted before each SSFP fMRI trial. All sweep scans (SSFP angle: from -180 to 180 degree, 6 degree of increment/frame, 61 frames, TR/TE/flip angle: 8ms/4ms/5^0, half-Fourier acquisition) were positioned exactly the same as in SSFP fMRI. For each slice, regional off-resonance was determined by finding the peak of an averaged curve over a selected region of interest (ROI), which is occipital lobe in this study. Frequency adjustments were, therefore, set for individual slices.

Results

Figure 1 showed results from two sweep scans. Averaged curves over selected ROIs were plotted to determine regional off-resonance frequency. Without frequency adjustment, Fig.1(a) showed that none of the selected ROIs were on resonance. The off-resonance could be as large as 48 degrees (equivalent to 16.7Hz when TR = 8ms). Averaged ROI curves were better centered after adjustment and off resonance was reduced to be within ±12 degrees, as shown in Fig.1(b). In Figure 2, two sets of SSFP fMRI were demonstrated to show effects of the proposed method. Figs.2(a) and 2(b) were SSFP images from the first dynamic scans of fMRI trials without and with frequency adjustment, respectively. It has to be noted that SSFP bright bands, corresponding to sensitivity band of SSFP fMRI, were more focused on occipital lobe in Fig.2(b) than in Fig.2(a), suggesting effectiveness of slice frequency adjustments. Statistical maps from both fMRI trials were shown in Figs.2(c) and 2(d). With slice frequency adjustments, more activated voxels could be found in Fig.2(d), especially for the first 3 slices, as compared with activation maps without adjustment as shown in Fig.2(c).

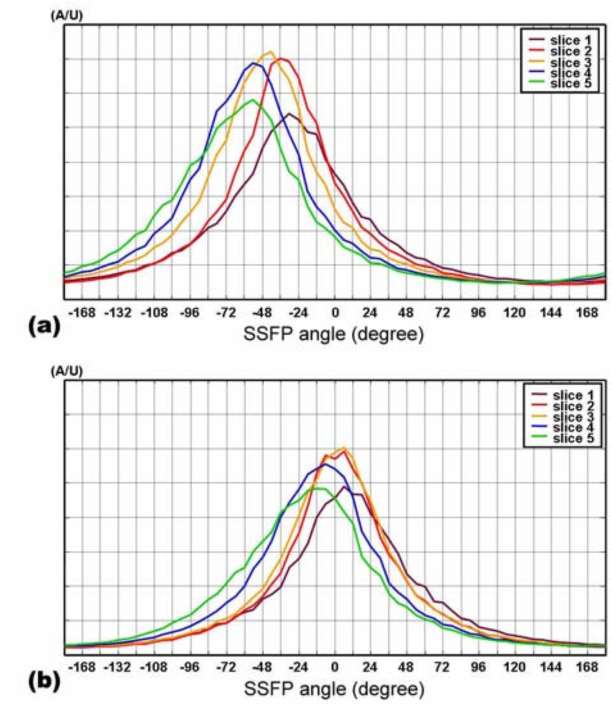

Figure 1. Averaged curves of selected regions from sweep scans without and with frequency adjustment in (a) and (b), separately. Fig. 1(a) showed that off resonance was as large as 48 degrees (equivalent to 16.7Hz) before adjustment. Averaged ROI curves were better centered after adjustment and off resonance was reduced to be within ±12 degrees, as shown in fig.1(b).

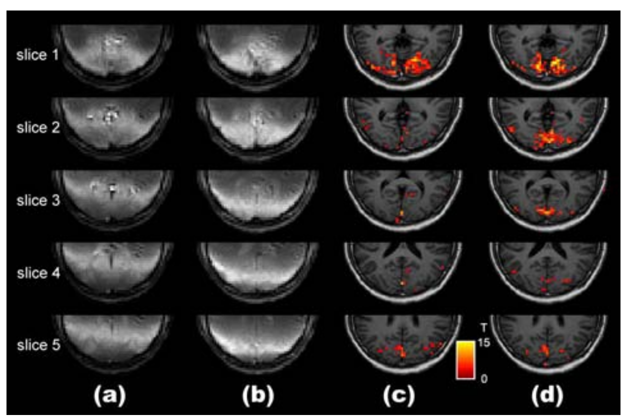

Figure 2. Two SSFP fMRI trials were demonstrated to compare conditions without and with slice frequency adjustments. The first dynamic scans of both trials were shown in fig. 2(a) and 2(b). With slice frequency adjustment in fig. 2(b), SSFP bright bands, corresponding to functional sensitivity band, were more focused on occipital lobe than in fig. 2(a). Besides, more activated voxels were found in activation maps with slice frequency adjustments in fig. 2(d) compared with fig. 2(c).

Discussion

Because the sensitivity band of SSFP fMRI could be as narrow as a few hertz, any field inhomogeneity might result in less optimized fMRI results. In this study, we proposed a method which allows adjustments of reference frequency in a slice-by-slice manner. At the cost of around 1.5 mins for a sweep scan, off resonance frequencies of each slice were measured and, therefore, corrected. From our preliminary results, it seemed that better SSFP fMRI could be obtained with slice frequency adjustments. Previous studies combining multiple fMRI trials, with different frequency settings to obtain a broadened sensitivity over frequency spectrum, would compensate not only for temporal field drift but also for spatial field inhomogeneity. It has to be noted that the proposed method in this study was not intended to replace the multiple acquisition method but, on the contrary, to improve it in a complimentary manner. By aligning the sweep curves as in Fig.1(b), a frequency shift applied in an additional trial could have more consistent effects on all selected ROIs. In addition, since it is less possible to reach perfect shimming over the entire brain parenchyma, a localized optimization might be a practical strategy when planning an SSFP fMRI experiment.

Reference

1. Miller KL et al., MRM 2003;50:675. 2. Miller KL et al., MRM 2006;55:161. 3. Lee JH et al., MRM 2006;55:1197. 4. Wu ML et al., ISMRM 2006:#2815.