Improvements in sweep scans for frequency adjustments in SSFP fMRI using coarse sampling with cubic spline interpolation

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Introduction

Steady-state free-precession (SSFP) method has been shown to exhibit strong potential for distortion-free fMRI at high spatial resolution [1]. One major challenge of transition-band SSFP fMRI is the narrow functional frequency band, leading to native sensitivity to spatial and temporal field instability, even with careful shimming [1, 2]. Previous studies have proposed methods to overcome temporal field instability [3, 4]. Spatial field inhomogeneity, on the other hand, has also been addressed in a regional manner by a slice-dependent frequency adjustment method [5]. However, in the original design of the slice-dependent frequency adjustment method, fine increment in the SSFP angle is needed for the sweep scan, which prolongs the scan time. In this study, we proposed a modified processing method based on cubic spline fitting to substantially shorten the scan time of the sweep scan with frequency adjustment values estimated with sufficient accuracy. Transition-band SSFP fMRI experiments were performed to demonstrate its effectiveness.

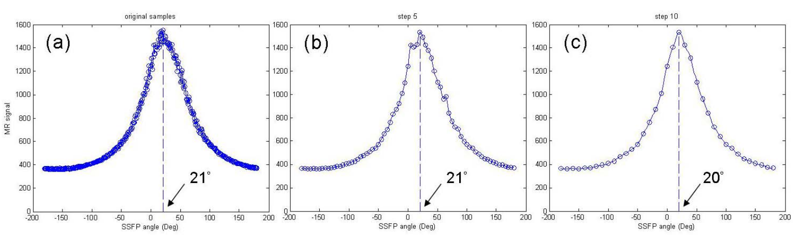

Fig. 1 Sweep scans at 1- (a), 5- (b), and 10- (c) degree increments of the SSFP angle. Dashed lines stand for the off-resonance frequencies corresponding to the maximum signal intensity.

Methods

The software for processing the sweep scan data was developed using the Matlab software. To verify the effectiveness of this method, the sweep scan was first performed with 1 degree of increment per frame in the SSFP angles from -180 to 180 degrees (total 361 frames, 206 sec per slice). Mean signal intensity for each image frame was then plotted as a function of the SSFP angle. Simulated data for coarser increments (5 degree increments, 73 frames; 10 degree increments, 37 frames) were generated from the same set of data. The three data sets were smoothly interpolated with the use of the cubic spline fitting technique [6]. Regional off-resonances corresponding to the amounts of frequency adjustment were then determined by finding the peaks of the fitted curves, with results compared among different SSFP angular increments. The calculation of signal intensity was done on pre-selected region of interest (i.e., occipital lobe), where shimming was optimized in this study.

Imaging was performed on a 3.0T Philips Achieva system using an 8-channel head coil. Shimming was targeted to the occipital lobe for visual stimulation SSFP fMRI experiments. The image parameters were 220 mm FOV, 64 by 64 matrix size, 4 mm slice thickness, 4° flip angle and TR/TE = 8/4 ms. IIR-filtered frequecy stabilization was applied to compensate for temporal frequency drifts. Two sets of SSFP fMRI images were acquired to compare conditions without and with slice frequency adjustment. The stimulus was a 5 Hz flashing checkerboard visual stimulus in 3-on/4-off blocks. Analysis was performed using SPM5 software. The sweep scans were performed with 10-degree SSFP angle increments from -180 to 180 degrees (total 37 frames, 24 sec per slice, TR/TE/flip angle: 8ms/4ms/4°), inserted before fMRI experiments and positioned exactly the same as in SSFP fMRI, such that frequency adjustments for each slice could be determined after cubic spline interpolation.

Results

Figure 1 shows three sets of the sweep scan. The circles represent the original samples, and the solid lines represent the interpolated result of cubic spine fitting. The dotted lines point out the maxminum value of the fitting curve, corresponding to the off-resonance in unit of degrees of the SSFP angle. Fig.1(a) is the original data, showing sufficiently smooth profile suitable for cubic spline interpolation at coarser samplings. Figs.1(b) and 1(c) are the sweep scans with 5- and 10-degree increments, respectively. The off-resonance in SSFP angles are found to be 21°/21°/20° (7.29/7.29/6.94 Hz) for step1/step5/step10, respectively. The minor difference of 0.35 Hz between the finest step 1 and the coarsest step 10 is around the level of system fluctuations (~0.5 Hz) found in our system, which is hence well acceptable. Fig.2(a) and 2(b) show the activation maps without and with slice-dependent frequency adjustments at 10-degree SSFP increments, respectively. With slice frequency adjustments following cubic spline interpolation, more activated voxels could be observed in Fig.2(b) compared with the activation maps shown in Fig.2(a), demonstrating effectiveness of slice frequency adjustements by using sweep scan with 10-degree increments per frame.

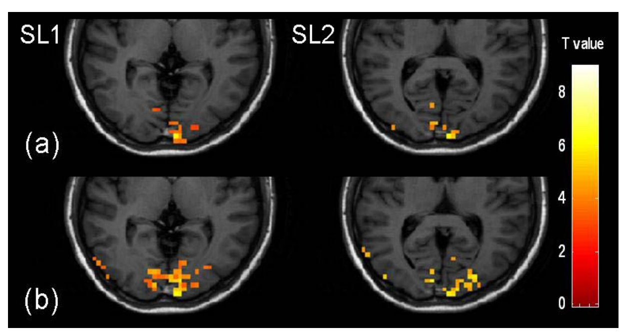

Fig. 2 SSFP fMRI activation maps without (a) and with (b) frequency adjustment using coarse 10-degree increment in the sweep scans.

Discussion and Conclusion

Results from our study show that with cubic spline interpolation for the sweep scans, appropriate frequency adjustment value for each slice can be found with good accuracy with 10-time reduction in the number of samples. The shortening of the sweep scan is advantageous in increasing the reliability of sweep scan in the presence of system instability and physiological fluctuations. The proposed technique thus has potential for efficiently improving transition-band SSFP fMRI experiments.

References

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