Interleaved Spiral In/Out b-SSFP Acquisition for Functional Imaging

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INTRODUCTION

Balanced-steady-state free precession (b-SSFP) sequences provide an advantageous approach for functional imaging. Passband b-SSFP (pbSSFP) fMRI utilizes rapid RF excitations that reduce susceptibility artifacts such as image distortion and signal dropout frequently encountered in conventional gradient echo images [1]. To reduce the sensitivity of pbSSFP fMRI to physiological noise contamination it is desirable to have $T_E \approx ½\ T_R$ for complete refocusing of spins [2]. Segmented echo planar imaging (EPI), which is often used for pbSSFP [3], is designed to have its echo at the center of the T_R interval. Spiral trajectories can provide greater acquisition efficiency than EPI, but the traditional spiral out sequence is less efficient when $T_E \approx ½\ T_R$. We propose an interleaved spiral in/out approach that has its echo time at the spin refocusing time and maintains its high acquisition efficiency.

METHODS

Figure 1 shows the pulse sequence diagram and 2 interleave k-space diagram for the proposed interleaved spiral in/out acquisition. Each red interleave in (b) is from the spiral in portion, and the 180° rotated blue interleaves are the corresponding spiral-out portions. This allows for twice as many effective interleaves for the spiral in/out case. The arrangement of all spiral in interleaves sequentially and all spiral out interleaves sequentially can reduce the increase in artifacts due to off resonance effects and k-space deviations associated with interchanging k-space trajectories.

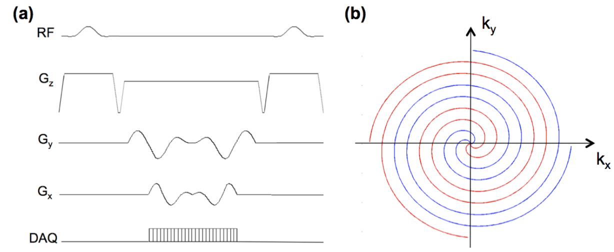

Figure 1. (a) Pulse sequence diagram for spiral in/out. Gz provides phase encoding through the slice direction for 3D stack of spirals acquisition. **(b)** 2D k-space trajectory with two interleaves shown for spiral in/out sequence, where red corresponds to spiral in and blue to spiral out.

We compared visual activation for a spiral out acquisition with minimum T_E and the proposed interleaved spiral in/out method. Two block design scans (10s on, 3 cycles of 15s on/15s off; 8-Hz flickering checkerboard visual stimulus) were performed. These scans were acquired using a GE 3T Signa HDx system and a standard 8 channel head coil with (1) spiral out with T_E=1ms and (2) spiral in/out with T_E=4ms, 3D stack of spirals pbSSFP trajectories. Additional scan parameters included: T_R = 8.46ms, FOV = 24cm, 128x128 matrix, 10 slices, 4mm slice thickness, and 16 interleaves (32 effective interleaves for spiral in/out). The 4ms echo time for the in/out case was chosen based on our simulation of the refocusing time in white and gray matter. The functional data were coregistered and spatially smoothed (3mm full width at half maximum Gaussian filter). Physiological noise correction was performed using respiratory data collected during the scan and constant and linear trends were removed. Activation maps (p <0.05) were generated using a general linear model analysis. Average time courses were obtained from the commonly activated voxels in both the spiral out and spiral in/out runs.

RESULTS AND DISCUSSION

Figure 2(a) displays significant (p <0.05) visual activation for one subject over two neighboring slices. The two maps in the left column show the activation from the spiral out data overlaid on the averaged spiral out images. The same slices are shown in the right column with the activation from the proposed spiral in/out sequence overlaid on the averaged spiral in/out images. The quality of the images is comparable for both acquisition methods. As expected, however, the extent of visual activation is reduced for the spiral in/out case. Spiral-out acquisition shows slightly more activation due to its T_2* sensitivity for short T_E<½T_R. The spins in spiral in/out acquisition can potentially yield better localized activation maps because they are refocused at the given echo time. The graphs in Figure 2 plot the average time courses versus time from the spiral out acquisition (b) and spiral in/out acquisition (c). The corresponding periods of visual stimulation are displayed as black bars on the graphs. The spiral in/out time course shows less sensitivity to physiological noise contamination.

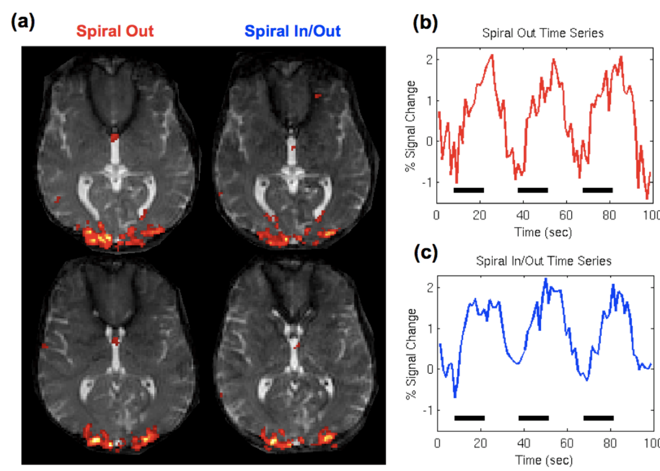

Figure 2. (a) Visual activation maps for spiral out and spiral in/out. Average time courses for **(b)** spiral out acquisition and **(c)** spiral in/out acquisition, extracted from the common activation region for the two slices shown.

We have implemented an efficient acquisition technique with an echo-time at spin refocusing. Our proposed method gives comparable results to spiral out acquisition without any compromise in image quality due to interleaving.

REFERENCES

[1] Miller et al. MRM, 55:161-70, 2006. [2] Scheffler et al. 49:395-7, 2003. [3] Lee et al. MRM, 59:1099-110, 2008.