New Interleaved Spiral In/Out fMRI Method

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Introduction. The spiral in/out imaging sequence has been shown to reduce susceptibility signal drop-out and increase fMRI sensitivity in frontal and lower temporal regions [1]. Each half (in & out) is sufficiently sampled to produce an alias-free image which causes readout time to be long, thereby increasing signal dropout. We propose a new sequence using a two-interleaf spiral trajectory with the first interleaf gathered as spiral-in and the second as spiral-out (Fig. 1). The entire sequence critically samples the desired k-space. This proposed sequence allows fMRI of the frontal and lower temporal regions with better spatial or temporal resolution, and reduced susceptibility induced signal drop-out.

Methods. Compared with standard spiral-out, the proposed sequence is equal in readout duration covering the same k-space but in two interleaves (Fig. 1). The spiral-in trajectory covers the first interleaf, and is immediately followed by the spiral-out half (the second interleaf). Images reconstructed using data from this new proposed sequence typically suffer from artifacts due to eddy current, off-resonance, and trajectory imperfection. Two methods for image reconstruction are used to eliminate these artifacts. In the first method, direction of the trajectory is reversed in alternate frames. Images are reconstructed using both interleaves and filtering in the temporal domain [2,3] (Fig. 2). In the second method, we separately reconstruct an image from each interleaf. Since each is undersampled, we use UNFOLD [4] to remove aliasing artifacts. These two images are then combined according to their relative signal strength and correlation coefficient ratio [1,5] (Fig. 2). We compare these two methods of reconstruction using the proposed sequence with the standard spiral-out having temporal filtering identical to that in the first method of reconstruction. The result is an alias-free image with reduced susceptibility drop-out compared to standard spiral-out.

A breath-holding activation experiment was carried out at a GE 1.5T. This task consists of 15s normal breathing and 15s breath-holding after inspiration, visually cued and repeated for 8 cycles. This causes a systemic hypoxia and results in BOLD signal modulation, independent of cognition, having a trough during breath-holding epochs [6]. Ten oblique slices (96 X 96) were gathered using a standard head coil (TR/TE/α /TH/FOV = 1s, 30ms, 70°, 5mm, 20cm). Eight volunteers participated, each scanned four times: twice with standard spiral-out, and twice with the new spiral in/out sequence. The sequence order used for each volunteer was counter-balanced to reduce biasing.

Results. Although only two imaging sequences are used, four image sets are created using data processing procedures mentioned above (Fig. 3): images using (a) new spiral in/out sequence with standard reconstruction technique, (b) spiral-out sequence, (c) new spiral in/out sequence reconstructed with the second method: combination of spiral-in half image and spiral-out half image with signal magnitude weighting, and (d) same as (c) but with correlation coefficient weighting. Correlation analysis is performed on each set of images.

Figure 3 (left) shows these four sets of images near frontal and parietal regions from one volunteer; notice, more signal is recovered with the new spiral in/out than with standard spiral-out. Figure 3 (right) shows the activation maps corresponding to those in the left. The new spiral in/out reveals activation area that spiral-out misses. Figure 4 shows the median number of activated pixels in an ROI in Fig. 3.

Discussion We developed a new spiral in/out sequence that allows fMRI in susceptibility sensitive regions. Unlike EPI where these susceptibility-induced drop-out regions suffer from geometric distortion, this new technique is superior, only suffering from the more tolerable blurring artifacts [7]. While the existing spiral in/out is also susceptibility-tolerant, this new sequence allows image acquisition with higher resolution and the same amount of data acquisition-time. Where temporal resolution is critical, one can therefore take advantage of shorter sequence duration (as compared to spiral-out) to reduce repetition time.

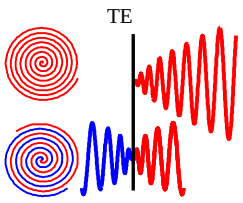

Fig. 1. k-space trajectory and its corresponding real part of (top) standard spiral-out, and (bottom) proposed spiral in/out.

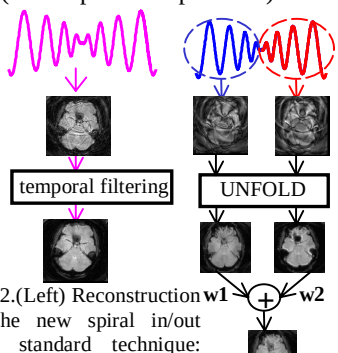

Fig. 2.(Left) Reconstruction of the new spiral in/out with standard technique: artifact is removed by temporal filtering. (Right) Using UNFOLD to un-alias images from spiral-in half and spiral-out half. Each is multiplied by its weight and the two are added.

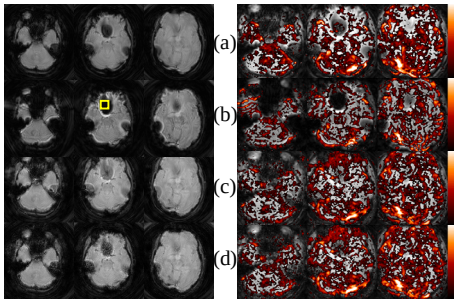

Fig. 3. Left: Images using (a) new spiral in/out, (b) spiral-out, (c) combination of spiral-in half & spiral-out half using signal weighting, (d) same as (c) but with correlation weighting. Right: Correlation coefficient maps corresponding to those in the left.

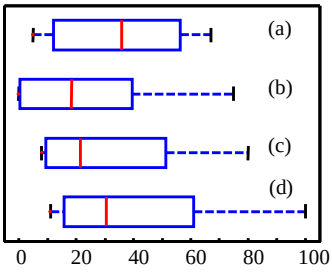

Fig. 4. Number of activated pixels inside frontal & parietal regions corresponding to those in Fig 3. The box outlines the lower & upper quartile, and the red is the median. The dotted lines show the extent of the rest of the data.

Reference. 1. Glover GH, Law CS, Magn Reson Med. 2001; 46(3):515-22. 2. Madore Magn Reson Med. 2002; 48(3):493-501. 3. Chen NK, Yoo SS, Chou YH, Oshio K, Panych LP, Proc Intl Soc Magn Reson Med. 2004; 11:514. 4. Madore B, Glover GH, Pelc NJ, Magn Reson Med. 1999; 42(5):813-28. 5. Glover GH, Thomason ME, Magn Reson Med. 2004; 51(4):863-8. 6. Kastrup A, et. al. Magn. Reson. Med. 1999; 42(3):608-611. 7. Nishimura DG, Irarrazabal P, Meyer CH, Magn. Reson. Med. 1995; 33(4):549-56.

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