Refinements in Reconstruction of Spiral-In Imaging Improve fMRI of the Frontal and Hippocampal Areas

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Introduction:

BOLD contrast arises from the T2* effect, which is the same effect that causes MR signal loss in the frontal lobe and hippocampus, the regions that are critical in epilepsy. The signal loss is large with single-shot techniques, such as the Echo Planar Imaging (EPI) and conventional Spiral imaging (Spiral-out). It has been demonstrated [1] that spiral imaging from outer to the center of k-space (Spiral-in) improves resolution by reduced T2* decay of the signal at the outer regions of k-space and increases overall SNR. The BOLD contrast remains the same (same TE) but signal loss is reduced in Spiral-in images because all data are acquired prior to the TE time, and therefore the off-resonance dephasing is relatively small. However, errors in the gradient trajectory accumulate during the readout period and are greatest near the center of k-space where the MRI signal is the largest. We present a spiral-in sequence with new techniques in reconstruction to improve the T2* signal in susceptibility-challenged cortical areas. To demonstrate the improvement, we compared EPI, Spiral-out and Spiral-in techniques on subjects in fMRI to examine the signals in temporal lobe and hippocampal areas.

Method:

Spiral-in Sequence A spiral-in trajectory is generated at run-time based on the gradient hardware constraints and the choice of FOV and resolution. In a separate imaging session, a phantom is used to measure the actual k-space trajectory produced by the hardware and is stored for use during reconstruction. The time between the excitation pulse and the echo time of 40msec is long enough to acquire a 90x90 image matrix with our gradient hardware. This extra k-space data is used with a Hanning filter to reduce Gibbs ringing in the final images. The receiver is kept open for a short time after the spiral trajectory ends to collect some B0 information used to correct for time varying fluctuations induced by the subject's respiration.

Image Reconstruction Images are reconstructed by standard convolution gridding. However, the measured k-space trajectory is supplied, linear shim terms are determined from delayed-echo phase difference maps, Voronoi areas are used as a weighting function and a Hanning filter is applied to the gridded data before Fourier transformaton. A multi-frequency reconstruction as described by Noll et al. [2] is used in regions with significantly varying susceptibility.

FMRI experiment The single-shot GRE Spiral-in technique was applied on five healthy volunteers and an epilepsy patient with 24 MRI-compatible EEG leads attached. The fMRI studies were performed at 1.5T (TE/TR = 40ms/2s, 24-cm FOV, 90×90 matrix, 24 4.4-mm slices) by using verb generation paradigm and visual scene encoding paradigm [3]. The former invokes activation in Broca's area in temporal lobe, whereas the latter stimulates the memory encoding area located in the posterior hippocampus.

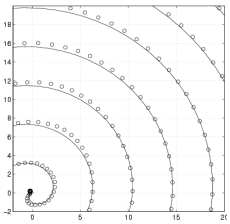

Figure 1

Results:

The measured spiral-in trajectory (circles in Fig.1) shows significant distortion from the ideal trajectory (solid line) near the origin of k-space where the errors due to gradient fidelity tend to accumulate. These distortions lead to large fluctuations of the Jacobian weighting function (ripples in Fig.2) even when the origin of the spiral is shifted by less than 0.5% of the trajectory diameter. The Voronoi areas (dashed line) are completely insensitive to shifts of the origin of the trajectory. The weighting function should reflect the local sampling density rather than the absolute location of the origin of the spiral trajectory and hence the Voronoi areas are a better choice.

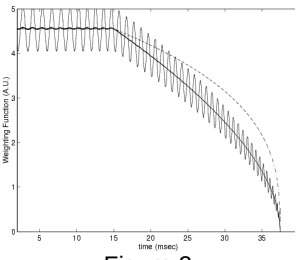

Figure 2

The Spiral-in T2* images have much less signal loss near the frontal sinus and auditory canals (Fig.3 as labeled), and in hippocampus (dotted box) than the EPI and Spiral-out images. The EEG leads on the patient's skull do not affect the T2* image (Fig.4a) and reasonable language activation (color for p<0.001) appears in Broca's area. Bi-lateral hippocampal activation (Fig. 4b) of memory encoding is observed in the healthy subject.

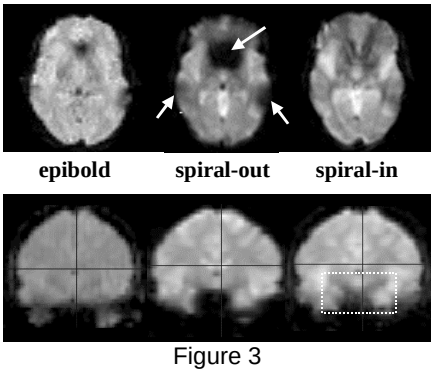

Figure 3

Discussion and Conclusion:

With measured k-space trajectories, an improved weighting function, off-resonance correction and an apodization filter to reduce Gibbs phenomenon, the spiral-in technique is a good choice for imaging in regions with significant susceptibility differences like the frontal and hippocampal regions.

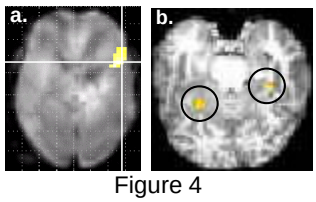

Figure 4

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