Evaluation of spiral imaging variants for high-resolution fMRI in human superior colliculus

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Introduction. The superior colliculus (SC) is a brain region with critical functions for eye movements and the orientation of attention. The small size of human SC (<1 cm) make high-resolution functional magnetic resonance imaging (fMRI) essential. Self-navigated multi-shot spiral-out acquisitions have been used previously for various fMRI studies[1,2]. However, high-resolution fMRI requires long readouts that are affected by off-resonance distortions and T2* signal decay. To mitigate off-resonance distortions, a linear field map correction technique was implemented[3]. To counter T2* signal decay effects, we examined the use of dual-echo spiral. Dual echoes capture different spatial-frequency content of the BOLD contrast. Spiral in-out is a popular dual-echo variant[4]; but it acquires best contrast when the trajectory is acquiring low spatial frequencies. Spiral out-out and in-in[5] acquire both the low and high frequencies in the middle of acquisition period and thus could yield higher BOLD contrast for high-resolution studies. Here, we evaluate dual- and single-echo spiral sequence variants to determine optimal echo times and functional signal-to-noise ratios (fSNR) for SC imaging.

Methods. Functional images were obtained on a Siemens Skyra 3T scanner using an interleaved spiral readout (3-shots, 35 ms/echo), 1.2-mm isometric voxels, 8-10 quasi-axial slices, TR = 1s, and a 32-channel head coil. Subjects (N = 3) viewed a moving-dot stimulus that alternated between left and right visual hemifields with a 24-sec period; the alternation was repeated 9.5 times to create 228-s runs. The first 12 sec of data was discarded to reduce onset transients. Subjects fixated while performing a speed-discrimination task upon the stimuli. In separate sessions for each subject, high-resolution (0.7-mm) T1-weighted anatomical images were acquired, and the tissue of the brainstem was segmented. A smooth surface was then constructed at the CSF-tissue interface. This surface provides a means to visualize and analyze the functional data. FMRI data were aligned and resampled to this reference volume, then averaged over a 0—1.8mm depth range corresponding to SC superficial layers where the visual response is strong.[6]

For each run, a sinusoid at the stimulus repetition frequency was fit to this data to measure response amplitude. Because fMRI noise is not normally distributed, fSNR was calculated using a run-by-run bootstrapping procedure. On 10,000 iterations, amplitude data from 6—8 runs were resampled with replication, then averaged. The resulting bootstrapped amplitude distributions were used to calculate 68% confidence intervals, which are analogous to the standard-error-of-the-mean for normally distributed data. FSNR was then defined as the ratio of the mean amplitude to the magnitude of these confidence intervals.

Experiments began with a baseline session for each subject using standard single-echo spiral-out fMRI at TE = 40 ms to define retinotopic regions-of-interest (ROIs) based on peak response amplitudes. Amplitude thresholds were adjusted to create a contiguous region with an area predicted by SC retinotopy[6] (Fig. 1). Multiple tuning sessions with different echo times (6 runs/condition) were acquired for each spiral variant on two subjects. Finally, comparison sessions on multiple subjects (N = 3) were run for each spiral variant at its optimized echo time. Each session included 7 runs with the spiral variant, and 7 runs of single-echo spiral out as a reference. Performance was then expressed as a relative fSNR, the ratio of the variant's fSNR to the reference fSNR.

Results. Fig. 2 shows sample tuning for spiral in. Tuning of the variants yielded the following echo times: spiral-in, 59 ms; spiral in-in, 56 ms; and spiral out-out, 32 ms. At optimal TE, two dual-echo variants showed a performance boost over the single-echo spiral reference. Dual spiral out was best, with a relative fSNR of 1.57, slightly better than the in-out variant with a relative fSNR of 1.29. Dual spiral in and single-echo spiral in both performed poorly compared to the reference.

Conclusions. Preliminary results indicate best performance for dual spiral out, which offers a large boost over single-echo spiral out. Purely spiral-in trajectories performed relatively poorly. Further measurements are in progress to establish the statistical significance of these results.

References: [1]Glover,G.H. *Magn Reso Med* **44**, 412-415 (1999); [2]Pfeuffer *et. al. Magn Reso Med* **47**, 344-353 (2002); [3]Irrazabal *et. al. Magn Reso Med* **35**, 278-282 (1996); [4]Preston *et. al.* J. *Cogn Neurosci* **22**, 156-173 (2010); [5] Li *et. al. Magn Reso Med* **55**, 325-334 (2006); [6] Katyal *et. al. J Neurophysiol* **104**, 3074-83 (2010). [7]Glover et. al.*Magn Reso Med* **51**, 863-868 (2004).

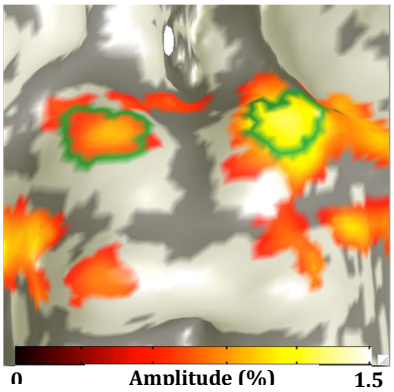

Fig. 1: Significant SC response amplitudes for a spiral-out baseline session. Green lines are retinotopic ROIs.

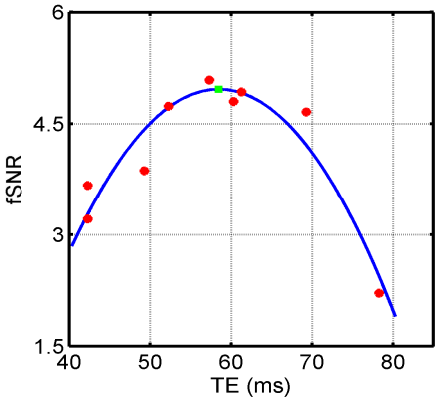

Fig. 2: Echo time tuning for spiral in; ROI data is in red, parabolic fit in blue.

fSNR→ variants	Test Seq. (μ_1)	Spiral out (μ_2)	Ratio (μ_1/μ_2)
in	3.9	6.2	0.63
in-in	4.8†	5.98‡	0.80
out-out	9.4†	5.98‡	1.57
in-out	7.7†	5.98‡	1.29

† - based on tuning sessions
‡ - based on baseline sessions

Table: sequence performance, showing fSNR for each variant and spiral-out reference.