

Variable density spiral fMRI

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Introduction: In the original variable-density (VD) spiral trajectory[1], the sampling density varies throughout the k-space trajectory; i.e., $k(\tau) = \lambda\tau^\alpha e^{i\omega\tau}$, where the parameter α controls the rate of density variation. Here, we propose a k-space trajectory consisting of an Archimedean spiral[2] from the origin out to a given radius k_1 , and extending beyond k_1 with a variable-density spiral of $\alpha > 1$ (Eq.1, Fig.1). This design allows for a reduction in readout time at the expense of under-sampling only the high spatial frequencies, which may provide flexibility for improving the performance of either normal- or high-resolution fMRI. We introduce the use of this trajectory in fMRI of the human brain, demonstrating that the VD spiral permits the use of a single-shot spiral-in/out[3] trajectory for high (128x128) resolution.

To obtain high-resolution (128x128) functional images, a conventional (fully Archimedean) spiral takes 59.8 ms to traverse k-space; note that an EPI trajectory would take even longer (60.1 ms for partial k-space). Such a long readout exacerbates signal dropout, particularly in susceptibility regions. Thus, one typically uses an interleaved (2-shot) spiral-in/out acquisition in which half of the k-space trajectory is gathered in each interleave. However, the interleaved acquisition suffers a loss of temporal resolution and allows fewer time frames to be acquired within the same total scan time, and in addition may experience aliasing due to gradient imperfections. We therefore hypothesized that a spiral-in/out with our proposed VD trajectory, which would permit a shorter TE and more rapid readout without interleaving, might yield improved BOLD sensitivity and statistical power compared to both the conventional spiral-in/out and interleaved spiral-in/out acquisitions.

Methods: The proposed VD spiral trajectory, parameterized by k_1 and α , is given by

$$k(t) = \begin{cases} \lambda_1 \omega \tau(t) e^{i\omega \tau(t)}, & 0 \leq |k| \leq k_1 \\ \lambda_2 (r_o + (\tau(t) - \tau_o)^\alpha) e^{i\omega \tau(t)}, & k_1 \leq |k| \leq k_{\max} \end{cases} \quad (\text{Eq. 1})$$

where r_o and τ_o are chosen so that the trajectory and its first derivative are continuous at $k=k_1$. The gradient waveforms were designed for the slew-rate limited and amplitude-limited cases following procedures described in [2]. The VD spiral was implemented in a 2D spiral-in/out pulse sequence with control variables for easily modifying k_1 and α .

Three volunteers were scanned at 3T (GE Discovery 750) while performing a block-design sensory task with stimuli consisting of visual checkerboards, auditory tones, and passive finger stimulation. The following three protocols (Fig. 2) were compared: (A) interleaved (2-shot) conventional spiral in/out, (B) single-shot conventional spiral-in/out, and (C) single-shot VD spiral in/out. In each protocol, the spatial resolution was 1.7 mm in-plane (matrix size 128x128, FOV=22cm) with 4 mm slice thickness, 24 axial slices were acquired, and the total scan duration was fixed at 256 sec. The VD parameters ($\alpha=2.1$, $k_1=0.5$) were selected based on preliminary experiments, yielding a readout duration of 47.9 ms (which is ~80% of the conventional readout). For each scan, activation maps (t-scores) and temporal signal-to-fluctuation-noise ratio (SFNR) were generated.

Results: Figure 3 shows, for 1 subject, the activation maps resulting from each of the 3 protocols. Here, VD (Fig. 3C) demonstrates stronger activation in visual and auditory cortices, and with no apparent effects of displaced activation due to undersampling of high spatial frequencies. Similar results were observed for a second subject; the third subject, however, showed stronger activation in visual cortex using the conventional interleaved protocol relative to the VD spiral. Fig. 4 shows increased SFNR in frontal regions using VD spiral-in/out compared to the conventional single-shot spiral-in/out.

Conclusions: The VD spiral-in/out demonstrates advantages over conventional methods in detecting activation in high-resolution fMRI, and the impact of undersampling the high frequencies appears to be minor. Advantages of the VD spiral include (1) feasibility of including a spiral-in component for single-shot high resolution imaging, which mitigates susceptibility dropout, and (2) faster acquisition, which reduces off-resonance artifacts, permits a greater number of slices per TR, and reduces the overall scan time. Current work includes a more detailed examination of the possible impact of the high-frequency aliasing in the VD trajectory, which may depend on the task and brain structures of interest.

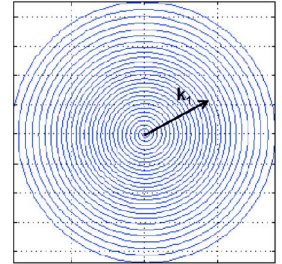


Fig. 1. VD spiral trajectory

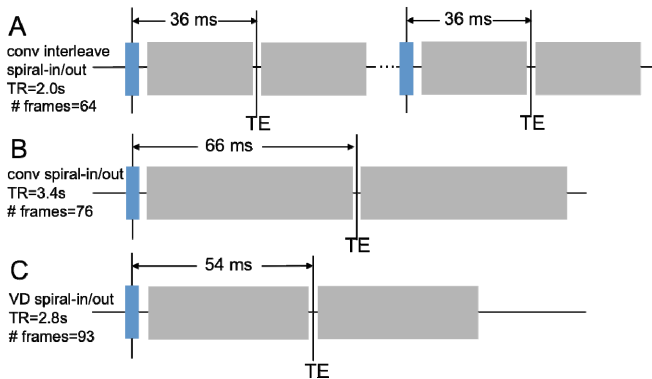


Fig 2. Two conventional (“conv”) protocols (A,B) were compared with the VD spiral-in/out (C). Values of TE/TR for are the minimum allowable values for the respective readout duration & equal brain coverage (24 slices). The # frames in each comparison are maximal for constant scan time of 256 s.

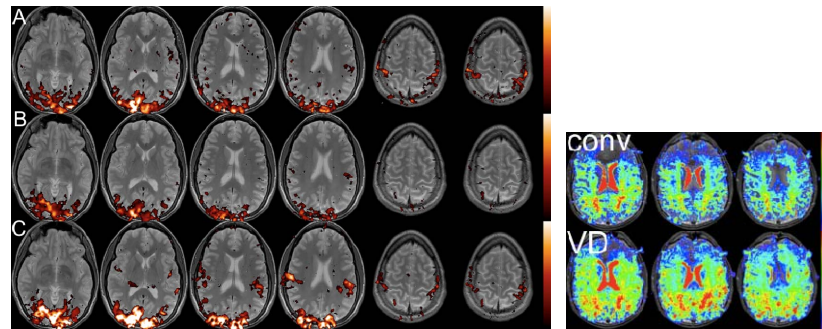


Fig. 3 (above left). Activation (t-score, left) in 1 subject, for comparisons shown in Fig. 2. Fig 4. (above right). SFNR maps for one-shot conventional and VD spiral-in/out, showing less signal dropout in frontal regions using the VD trajectory.

References: [1]Kim et al, MRM 50:214-219(2003). [2]Glover, MRM 42:412-215(2000). [3]Glover & Law, MRM 46:515-522(2001). [4]Preston et al, Neuroimage 21(1):291-301 (2004). **Acknowledgments:** NIH P41 RR009784, NIH F31 AG032168I, GE Healthcare.