Dynamic Updates of R_2^* and Field Map in fMRI Using a Spiral-In Quick-Spiral-Out K-Space Trajectory

V. Olafsson[1], J. A. Fessler[1], D. C. Noll[2]

[1]EECS, The University of Michigan, Ann Arbor, MI, United States, [2]BME, The University of Michigan, Ann Arbor, MI, United States

Introduction

Collecting fMRI data using a spiral-in k-space trajectory is more robust to susceptibility related signal dropouts common in BOLD-weighted images. However, this is at the cost of lower functional contrast that the more commonly used spiral-out provides. It has been proposed to collect a fully sampled spiral-in spiral-out data [1], where the signal dropouts decrease by the data collected during the spiral-in, while the additional BOLD-weighting comes from the spiral-out data. This increased the activation volumes relative to using only the spiral-out data [2,3]. Another method for spiral-in spiral-out imaging used nonlinear joint iterative reconstruction of the image and a field map for every time point [4]. The long readout, which resulted in improved field map estimates, and the field map updates again increased the activation volume. This improvement came at a cost of increased compute time for the reconstruction.

Here, we propose to collect a fully sampled spiral-in and a quick-spiral-out which has a 4-fold reduced FOV relative to the spiral-in but equal resolution. This trajectory should offer increased temporal resolution and additional BOLD-weighting compared to only collecting spiral-in. We also use this collected data to reconstruct R_2^* and field maps for each time point [5], requiring a computational complexity on the order of current fast linear iterative reconstruction methods.

Theory

The k-space trajectory used here is a fully sampled spiral-in quick-spiral-out, where the quick-spiral-out has equal resolution but FOV reduced 4-fold relative to the spiral-in as shown in Fig 1. This makes the readout shorter relative to a full spiral-in spiral-out, thus potentially increasing temporal resolution of the functional time series.

The reconstruction used here is a joint reconstruction of dynamic changes in R_2^* and field map in neighboring time points for the time series. Since these dynamic changes are assumed to be small, the MR signal equation can be made linear. This allows for reconstruction to be performed using a fast linear iterative algorithm, where the conjugate gradient algorithm is used to minimize the following quadratic penalized least-squares cost function [5]:

$$\hat{\mathbf{d}}_j = \underset{\mathbf{d}_j}{\arg\min}\left\{\frac{1}{2}\left\|\tilde{\mathbf{y}}_j - \mathbf{A}(\hat{\mathbf{z}}_{j-1})\mathbf{d}_j\right\|^2 + \mathrm{R}(\Re(\mathbf{z}_j)) + \mathrm{R}(\Im(\mathbf{z}_j))\right\}, \text{ where } \begin{cases}\tilde{\mathbf{y}}_j = \mathbf{y}_{j-1} - \mathbf{y}_j \\ \mathbf{z}_j = \mathbf{z}_{j-1} + \mathbf{d}_j\end{cases} \text{ and } \left[\mathbf{A}(\hat{\mathbf{z}}_{j-1})\right]_{mn} = m_{0_n} e^{-t_m \hat{z}_{j-1_n}} t_m e^{-i2\pi(k_m r_n)}.$$

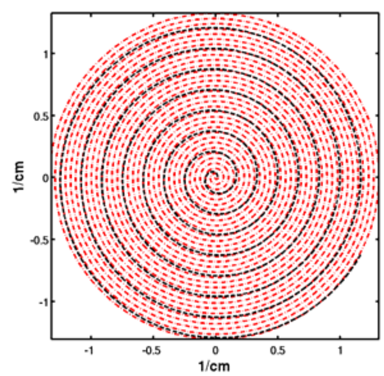

***Fig. 1*: The k-space trajectory for the spiral-in quick-spiral-out**

where $\mathbf{d}_j$ is the complex valued spatial map of the dynamic changes from time point *j-1* to *j* in R_2^* (real part) and field map (imaginary part), $\mathbf{z}_j$ is the complex valued spatial map of R_2^* (real part) and field map (imaginary part), $\mathbf{y}_j$ is the MR data for the j^{th} time point, and $\mathbf{m}_0$ is the magnetization after applying the RF pulse. The penalty is a roughness penalty that separately penalizes R_2^* and field map. To initialize the algorithm, $\mathbf{z}_0$ and $\mathbf{m}_0$ needs to be estimated. For the initial field map, 2 images were collected, one with a delayed echo relative to the other, and for the initial R_2^* map magnitude images of multi-echo MR data were fitted to an exponential decay. Using these maps, $\mathbf{m}_0$ was estimated for the first time point in the functional time series and used for all estimates of $\mathbf{d}_j$.

Methods

We collected *in vivo* functional data on a 3T GE Signa scanner. A block designed paradigm was used, 20 sec of finger tapping using a flashing checkerboard and 20 sec of rest, 6 blocks in total. Here we collected the data using the spiral-in quick-spiral-out, with acquisition parameters of TR=800ms, TE=30ms, flip angle=60°, 10 slices and 300 time points. For the initialization additional images were collected with TE = [32ms, 30ms, 38.3ms, 46.6ms, 55ms] where TE's 1 and 2 were used to find the initial field map, TE's 2 to 5 were used to estimate the initial R_2^* map and the first time point in the functional time series used to estimate $\mathbf{m}_0$. The time series for the R_2^* maps were correlated against the task waveform and the correlation maps thresholded at 0.3.

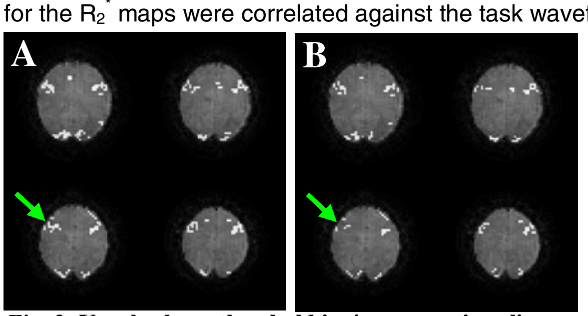

***Fig. 2*: Voxels above threshold in 4 representing slices using both spirals (A) or just spiral–in (B)**

Results and Discussion

Overall the correlation maps showed increased activation volumes for both motor and visual cortex, where the number of voxels above the threshold increased from 242 to 332 (38% increase) for the R_2^* maps reconstructed using spiral-in quick-spiral-out data versus only spiral-in data. Fig. 2 shows the voxels above the threshold for 4 of the 10 slices. The green arrows show a larger activation volume in the motor cortex using data from both spirals.

We have presented a new trajectory and reconstruction method to be used in fMRI, gaining temporal resolution relative to using full spiral-in spiral-out. The additional BOLD-weighting from adding the quick-spiral-out was large when used in conjunction with the reconstruction algorithm used here. Motion correction was not performed on the data, and the effects of motion on the estimates of R_2^* and field map requires further investigation.

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References

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