Rapid 3D fMRI using an Echo-Volumar Imaging Trajectory

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Introduction

A new acquisition strategy for fMRI data is introduced where a small central region of 3D k-space is sampled repeatedly every 100*ms* using an echo-volumar imaging [1] trajectory. Using this method a low spatial resolution reconstruction with extremely high temporal resolution can be obtained. The technique shows great promise in estimating latency (e.g. onset, time-to-rise) differences in hemodynamic response functions across the brain. The feasibility and efficiency of the approach is confirmed using data from a visual-motor task.

Methods

Our trajectory travels through 3D k-space with the goal of hitting each coordinate on a 3D Cartesian grid. It starts at the point $(0,0,z_{min})$ and moves along the z-axis to the point $(0,0,z_{max})$. Upon reaching this point the trajectory makes a half circular loop over to the point $(1,0,z_{max})$ and then continues along the z-axis in the opposite direction until it reaches $(1,0,z_{min})$. The trajectory continues in a similar manner until it has completed a square spiral in the xy-plane (Figs. 1 A and B). Using this approach the central portion of 3D k-space (with dimensions 14×14×14) is sampled. To ensure that each straight line consists of the same number of points, each line begins at the same speed *u*, accelerates in the first half of the line and de-accelerates in the second half. The trajectory then travels in a half circle with constant speed *u* before starting the process again on the next line. As the data is sampled on a grid, reconstruction is straightforward. The data is zero-filled to a resolution of 64×64×64 prior to reconstruction, and a prolate spheroidal wave function filter [2] is applied to reduce truncation artifacts. The spatial resolution using our approach is equivalent to that obtained after applying a Gaussian filter with FWHM of 12mm to an image with a FOV of 20cm and matrix size 64×64×64.

Experiment

To demonstrate the method's utility for dynamic studies, a high temporal resolution fMRI experiment was designed to track the hemodynamic signals in the brain while the subject undergoes a visual-motor activation paradigm. The paradigm consisted of fifteen cycles of 20*s* intervals. At the beginning of each interval a 100*ms* light flash was presented. The subject was instructed to press a button with their right thumb immediately after sensing the flash, thereby leading to activation of the motor cortex. During the 20 second interval, 200 images were acquired (TR 100*ms*). The first cycle was thrown out and the resulting data consisted of 14 cycles with a total of 2800 brain volumes. The data was acquired with an effective TE 30*ms*, flip angle 20 degrees, field of view 200×200mm^2, slice thickness 185*mm* and bandwidth 125kHz. The experiment was performed on a 3.0T whole body scanner (GE magnet, General Electric Medical Systems, Milwaukee, WI, USA).

Results

Statistical analysis was performed using the General Linear Model and voxels with significant activation were identified ($p<0.01$). For each active voxel, the time of the peak positive BOLD response (time-to-rise) was estimated. Results for two slices, one centered in the visual and the other in the motor cortex, are shown in Fig. 2. Fig. 3 shows the average signal over the 14 repetitions for two time courses extracted from the center of the visual and motor cortices, respectively. Prior to averaging, the time courses were detrended and heart rate effects were estimated and removed. Note that the rise peaks first in the visual cortex followed by the motor cortex a few hundred milliseconds later. Interestingly, the same results hold for the negative dip, which is apparent in both time courses.

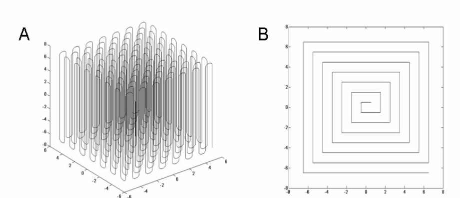

Fig. 1. (A) An implementation of the EVI trajectory. (B) The EVI trajectory shown in (A) projected onto the xy-plane.

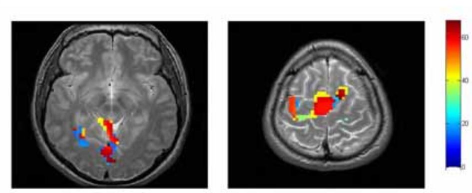

Fig. 2 Two slices showing the visual (left) and the motor (right) cortex. The time-to-rise for voxels with significant activation is color-coded, indicating that the rise appears earlier in the visual then the motor cortex.

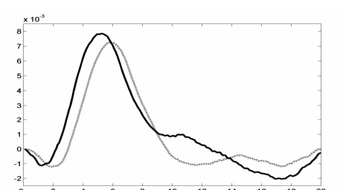

Fig. 3. Time courses from the visual (bold) and motor (dashed) cortices averaged over the 14 cycles of the visual-motor stimulus.

References

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(2) Yang,Q.X., Lindquist M., Shepp L., Zhang C.H., Wang J., and Smith M.B., Two Dimensional Prolate Spheroidal Wave Functions for MRI, J. Magn. Reson. 2002. **158**, 43-51.