Volumetric Dynamic Magnetic Resonance Inverse Imaging in the Human Brain

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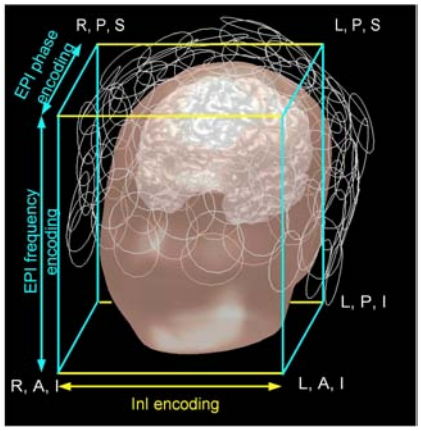
INTRODUCTION

Magnetic resonance Inverse Imaging (InI) uses a highly parallel radio-frequency coil array to solve an inverse problem in image reconstruction [1]. Due to minimal gradient encoding, InI can achieve high temporal resolution in milliseconds. Previously we demonstrated a single slice 2D InI acquisition and reconstruction for functional brain imaging without using phase encoding gradient for spatial encoding. Combining with fast spatial frequency and phase encoding by the 2D echo-planar imaging (EPI) method [2], InI can complete a 3D fMRI acquisition in a fraction of a second, which can be used for detecting differential activation time courses at distributed cortical areas across the whole brain and/or physiological noise monitoring. We present this volumetric MR InI method using a visual fMRI experiment with a 32-channel head array coil at 3T with 200 ms temporal resolution per 3D volume.

METHODS

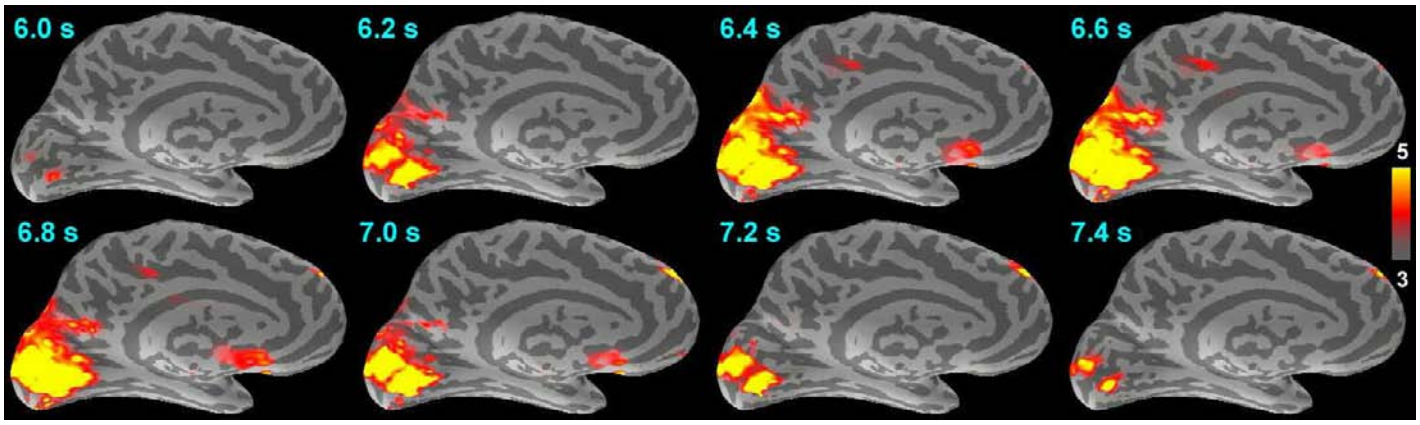
In 3D InI, each volume of data acquisition was obtained by EPI frequency encoding along the inferior-superior direction and EPI phase encoding along the anterior-posterior direction. The spatial resolution in the left-right direction was calculated from InI reconstruction. The schematic figure at right illustrated the 3D spatial encoding using EPI and InI. Specifically, we collected gradient echo reference images on transverse planes (TR=200 ms, TE =30 ms, 4mm thick, 64 slices) to construct the forward model **A**. Accelerated InI acquisition was done by collecting one thick slab sagittal slice using EPI (TR=200 ms, TE=30 ms, 256 mm thick, 64x64 image matrix, FOV = 256mm). After 2D Fourier transform, image voxels with identical EPI spatial encoding index ρ were concatenated from all channels of the coil array to generate an observation vector $\mathbf{y}(\rho)$. Minimum-norm estimate (MNE) provided the reconstructed image vectors $\mathbf{x}_{InI}(\rho)$ along the left-right dimension: $\mathbf{x}_{InI}(\rho)=\mathbf{A}(\rho)^H(\mathbf{A}(\rho)\mathbf{A}(\rho)^H+\lambda\mathbf{C})^{-1}\mathbf{y}(\rho)$, where **C** is the noise covariance matrix of the array, λ is the regularization parameter, and $\mathbf{A}(\rho)$ indicates the extracted image voxels from gradient echo reference images with the spatial index ρ.



We demonstrated InI in an event-related visual fMRI experiment with 8-Hz checkerboard stimulus. The experimental paradigm consisted of 6 seconds pre-stimulus baseline, followed by 2 seconds checkerboard flashing, and then 20 seconds fixation. Total 16 repetitions were measured on a 3T scanner (Trio, SIEMENS Medical Solutions, Erlangen, Germany) using a 32-channel head RF coil array [3]. After InI reconstruction, fMRI time courses from all channels were first detrended and subsequently averaged across experiments to improve the SNR. Reconstructed data were also spatially smoothed by 6-mm Gaussian kernel. Using the 6 second pre-stimulus interval as the baseline, we calculated the dynamic *t*-statistics maps in 200 ms temporal resolution.

RESULTS

3D volumetric functional activation *t*-statistics maps at different time instants after the onset of the checkerboard flashing were rendered on an inflated cortical surface shown below. We showed the medial aspect of the results, where light gray indicates gyri and dark gray indicates sulci. Strong occipital activation around the calcarine sulcus was observed with 6.0 s latency and 1.4 s duration. The spatial resolution in EPI encoding dimensions is homogenous and isotropic; in contrast to the inhomogeneous spatial resolution in the InI encoding dimension, which is approximately 10 mm in average in our previous calculation [1].



DISCUSSIONS

In this research, we present a fast 3D fMRI data acquisition method using the combination of EPI and InI to achieve volumetric studies with a temporal resolution of 200 ms. This temporal resolution was currently limited by the data through-put. With technical advancement, we expect to further accelerate such volumetric data acquisition in less than 100 ms. Using a coil array with more elements may further improve the spatial resolution of 3D InI. Advances in different InI reconstruction kernels, such as minimum-norm estimates and linear constrained minimal variance beamformer, can be incorporated in this 3D imaging approach.

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