Dynamic magnetic resonance multi-projection inverse imaging (mInI) with isotropic spatial resolution

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INTRODUCTION

Functional MRI usually uses echo-planar imaging (EPI) (1) to achieve a volumetric temporal resolution of approximately 2 s. Previously, we proposed the MR inverse imaging (InI) (2) to achieve the unprecedented 100 ms temporal resolution with whole-brain coverage using highly parallel detection (3). However, InI achieves a high temporal resolution by trading off the spatial resolution as a consequence of solving ill-posed inverse problems in image reconstruction. Volumetric InI uses one projection image from each RF coil array channel to reconstruct a 3D object at each time point. In this study, we propose that InI can achieve high temporal resolution without compromised spatial resolution by combining multiple acquisitions with different projections. Specifically, this multi-projection InI (mInI) acquires projection data in three orthogonal directions (x-, y-, and z-axes) from all channels of an RF coil array separately. All data are used simultaneously to estimate the unknown volumetric magnetization. Thus mInI solves an over-determined linear system rather than an under-determined system. Here we present the results of using mInI to study the hemodynamic responses in human visuomotor system from 12 participants using a 32-channel head coil array at 3T with 100 ms temporal resolution and 4 mm^3 isotropic spatial resolution

METHODS

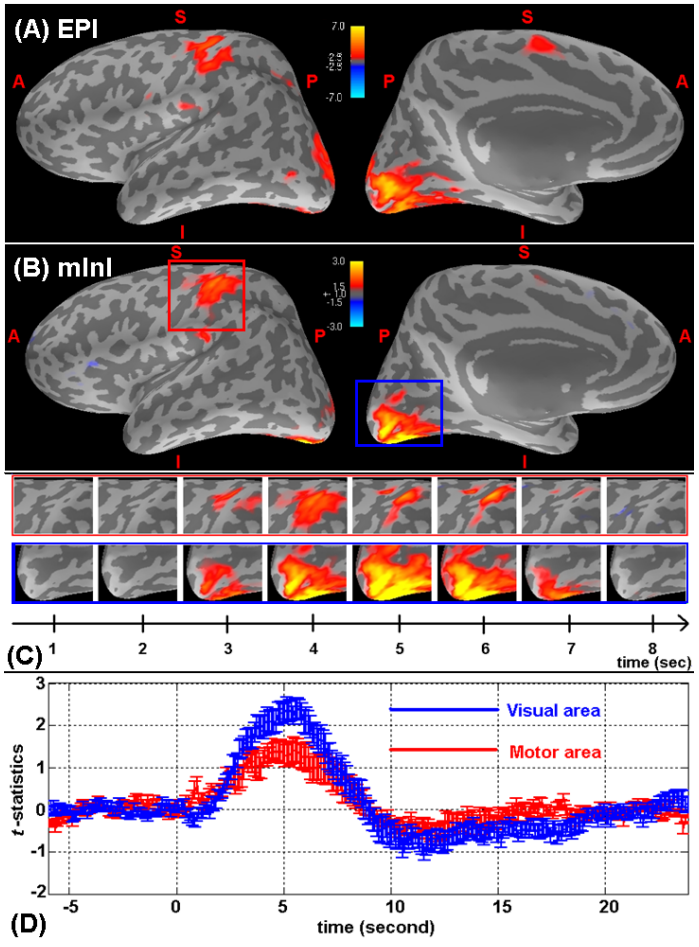
InI was based on the blipped EPI read-out with a large-*n* RF coil array. Specifically, the coronal, sagittal, and transverse projection data were collected separately after RF excitation from a 3T MRI scanner (Tim Trio, SIEMENS Medical Solutions, Erlangen, Germany) with a 32-channel head RF coil array (4). Before InI, multi-shot fully partition-encoded data were first acquired as the reference scan for each projection. Each InI acquisition started with navigators to correct the N/2 Nyquist ghost, followed by EPI read-out to generate one projection image by acquiring only the central k-space slice in the 3D k-space. The imaging parameters were: TR=100 ms, TE=30 ms, flip angle=30°, image matrix=64x64, 64 partitions, FOV=256 x 256 x 256 mm^3, bandwidth=2520 Hz/pixel.

The reconstruction of mInI data requires a forward matrix $\mathbf{A}_{acc}$ generated from three different reference scan, each of which has partition encoding in x-, y-, or z-direction. $\mathbf{A}_{acc}$ consists of data from all channels of the coil array and all three reference scans. Mathematically, the 3D image to be reconstructed **x** and mInI acquisitions **y** are related by a linear equation: $\mathbf{y}_{acc} = \mathbf{A}_{acc}\mathbf{x}$, which was solved by iterative CGS (5) algorithm implanted in Matlab (Mathworks, Natick, MA, USA). mInI reconstruction changes the under-determined inverse problem of InI reconstruction into an over-determined inverse problem. Thus we can achieve an isotropic spatial resolution.

Twelve participants providing informed consent were recruited to the fMRI study on visuomotor system. The task was to press ipsilateral response button when lateralized hemifield checkerboard flash was shown. We used general linear model (6) with finite impulse response bases to estimate hemodynamic responses with an effective TR of 100 ms. Four runs of InI data were collected for each of the projection. Coefficients of the FIR bases were then reconstructed to yield volumetric distribution of hemodynamic responses. Subsequently, *t*-statistics were calculated to reveal activated functional areas

RESULTS

Figure panel **A** shows the EPI results. Panel **B** shows the averaged activation map overlaid on an inflated left hemisphere cortex at 4 second after visual stimulation onset. The localization of functional area matched between EPI and mInI by revealing similar visual and sensorimotor cortices. Panel **C** shows the snap shots of mInI dynamic statistical maps at sensorimotor (red) and visual (blue) area between 1 and 8 second after the onset of the visual stimulation at 1 second step. The panel **D** shows the average HRF of the visual (blue) and motor (red) cortices between 6 second before and 23 second after the onset of the visual stimulation with 100 ms interval.



DISCUSSION

Here we demonstrated the feasibility of mInI to achieve isotropic spatial resolution (4 mm) and high temporal resolution (10 Hz/volume) with whole-brain coverage by combining 3 InI projections. Such a temporal resolution is already about twenty times speedup compared to conventional multi-slice EPI. Localization of functional areas by mInI is similar to that by EPI (panel **A**). mInI is sensitive to motion and image distortion since a good match between the accelerated projection scan and the reference scan is critical to ensure high image quality. This method can be also applied to motion correction in dynamic MRI scans.

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