Dynamic functional volumetric magnetic resonance k-space inverse imaging of human visual system

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INTRODUCTION

Magnetic resonance Inverse Imaging (InI) uses a highly parallel radio-frequency coil array to obtain spatial information by solving an inverse problem in image reconstruction in order to reduce the reliance on spatial encoding using gradient switching [1]. Here we propose a k-space inverse imaging (K-InI) approach, which differs from the previously proposed image domain InI reconstructions. Similar to the difference between GRAPPA [2] and SENSE [3], K-InI can be distinguished from InI by the use of an auto-calibration technique to estimate the reconstruction coefficients and the capability of coil-by-coil reconstruction to allow for flexible combination of different channels in the array. We demonstrate 3D K-InI using a 32-channel head coil array at 3T in an event-related whole head visual fMRI experiment with 100 ms temporal resolution.

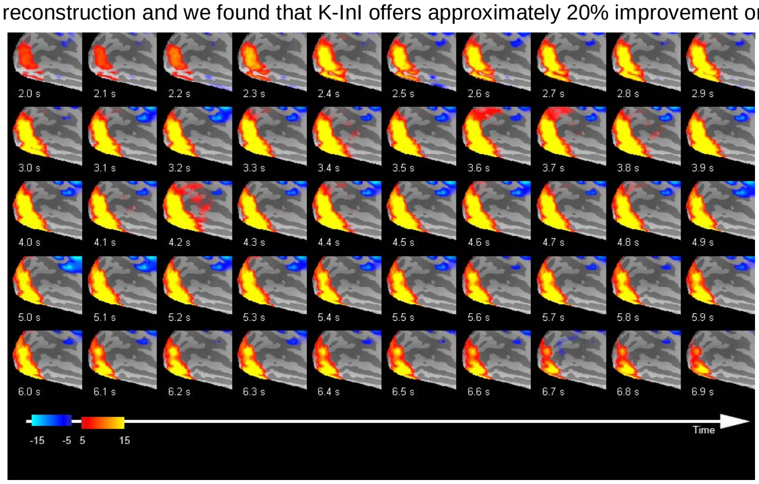
METHODS

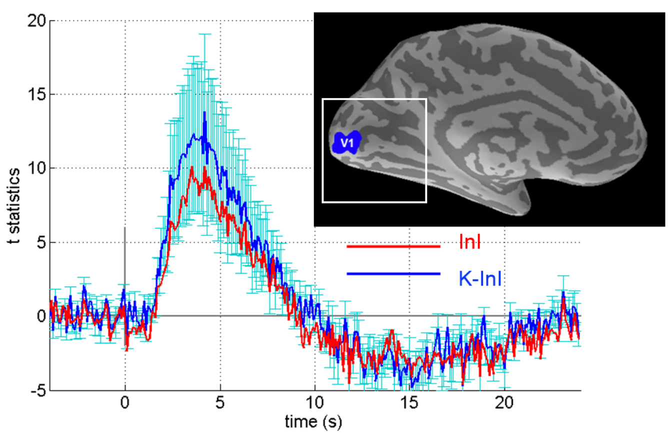
Without loss of generality, we present the formulation of K-InI reconstructions for each gradient-encoded spatial location. K-InI reconstruction of the stimulus evoked change from the data starts from the estimation of reconstruction coefficients β using auto-calibration k-space data $\mathbf{y}_{acs}$ with full partition and frequency encoding (reference scan) and accelerated k-space data $\mathbf{Y}_{acc}$ with the center of the partition encoding and full frequency encoding: $\mathbf{y}_{acs}=\mathbf{Y}_{acc}\,\beta$. Since it is an under-determined linear system, we used minimum-norm estimates (MNE) to obtain estimates of β: $\beta = \mathbf{Y}_{acc}^{T}(\mathbf{Y}_{acc}\,x\mathbf{Y}_{acc}^{T}+\lambda^2\mathbf{C})^{-1}\,\mathbf{y}_{acs}$. λ^2 is the regularization parameter and $\mathbf{C}$ is the noise covariance matrix $\mathbf{C}=<\mathrm{VAR}(\,\mathbf{y}_{acs}\,\mathbf{y}_{acs}^{\ T})>$, where <.> denotes the expectation value and VAR denotes the variance. Note that each RF coil has its individual β for image reconstruction. Given β and the actual accelerated inverse imaging acquisition ($\mathbf{Y}_{acc}$), the reconstruction was estimated: $\mathbf{y}_{kini}=\mathbf{Y}_{acc}\beta$.

We demonstrated K-InI using an event-related visual fMRI experiment with an 8-Hz checkerboard stimulus. The paradigm consisted of 6 s pre-stimulus baseline, followed by 0.5 s checkerboard flashing, and then 23.5 s visual fixation. Total 32 repetitions per run and 4 runs were measured on a 3T scanner (Tim Trio, SIEMENS Medical Solutions, Erlangen, Germany) using a 32-channel head RF coil array [4]. Data were acquired using 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 K-InI reconstruction. Specifically, we collected gradient echo reference images on sagittal planes (TR=100 ms, TE =30 ms, 4mm thickness, 64 slices) for the estimation of K-InI reconstruction coefficients. Accelerated acquisitions were collected from a single slab sagittal slice (TR=100 ms, TE=30 ms, 256 mm thickness, 64x64 image matrix, FOV = 256mm). K-InI reconstructions were calculated for each channel and each time point separately. To combine different channels, we calculated the pixel-by-pixel complex number projection with respect the phase of the reference scan in each channel. Projections were then averaged across channels.

RESULTS

The figure at left shows successive K-InI frames of visual activation from a single subject. Snapshots were the medial aspect views of dynamic statistical parametric mapping (dSPM) of *t* statistics overlaid on the left cerebral hemisphere using an inflated brain surface model. The critical threshold used is t = 5.0 (uncorrected p-value $<10^{-4}$). The time course (right) shows the average (dark blue) and the standard deviation (light blue vertical error bars) of the K-InI dSPM *t*-values within the primary visual cortex (V1) ROI. Without imposing any canonical model, K-InI offers highly time-resolved statistical estimates of the brain activity in response to the visual stimulus at 100 ms temporal resolution. For comparison, we also calculated the MNE InI (red) reconstruction and we found that K-InI offers approximately 20% improvement on the detection of the BOLD peak response.





DISCUSSION

Extending from the image-domain MNE inverse imaging reconstruction, we here proposed the k-space inverse imaging reconstruction and applied it to functional MRI with minimal gradient encoding to achieve high temporal resolution (whole brain coverage with TR=100ms. Similar to MNE InI reconstruction, regularization is used in K-InI reconstructions and it affects the reconstructed spatial resolution and noise amplification. Like InI, K-InI has the high temporal resolution and it may be used to monitor and reduce the fMRI physiological noise. K-InI can also be combined with other dynamic imaging contrasts and/or applied to spectroscopic imaging studies.

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