# Optimize the sampling of volumetric magnetic resonance inverse imaging

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**TARGET AUDIENCE** Researchers interested optimizing fast fMRI acquisitions.

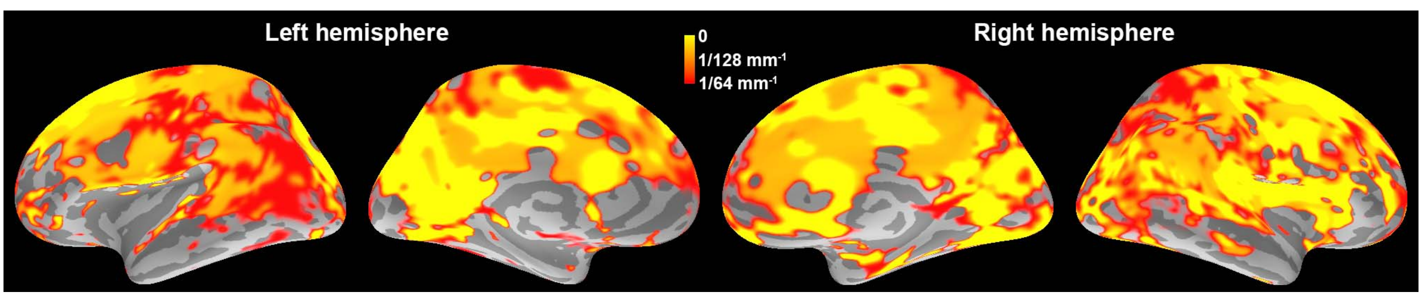
**PURPOSE** Magnetic resonance inverse imaging (InI) [1,2] is a method of achieving fast functional MRI (fMRI) using highly parallel RF detection to estimate spatial distributions of dynamic changes without relying completely on gradient coils for spatial encoding. Similar to MR-encephalogrpahy [3], such an acquisition strategy allows whole-brain fMRI with 100 ms sampling rate and approximately 5 mm spatial resolution at cortex using a 32-channel head coil array at 3T [2]. Previously, accelerated InI acquisitions always measure the central *k*-space partition in a 3D *k*-space repetitively [2,4]. Consequently, each accelerated InI image voxel represents the signal integrated along the partition encoding direction. Previously it has been suggested that the sensitivity of fMRI at high field is limited by physiological noise and that acquisitions with large image voxels can be suboptimal because the physiological noise is in proportional to the signal [5,6]. Collecting the $0^{th}$ order spatial harmonic, effectively the largest image voxel possible in the partition encoding direction, can significantly limit the sensitivity of InI fMRI at high field.

Here we hypothesize that, considering the physiological noise, accelerated InI may measure the *k*-space partition other than DC in order to improve its sensitivity in fMRI measurements. Specifically, we use the time domain signal-to-noise ratio (tSNR) to evaluate which *k*-space partition may give the best performance quantitatively. Results show that the optimal partition varies across cortical locations. While overall partitions with slow spatial variation is preferred, based on the histogram of the optimal partition across cortical locations, the optimal partition was found at the first slow spatial harmonic, not the DC one.

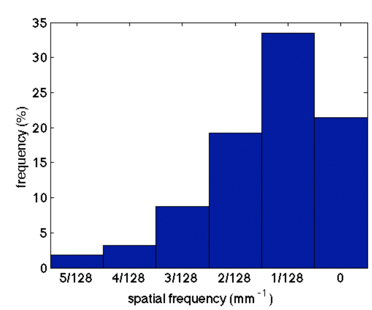
**METHODS** Six subjects, giving informed consent, were instructed to lie still in a 3T MRI scanner (Skyra, Siemens Medical Solutions, Erlangen, Germany, 32-channel head coil array) with their eyes open during InI measurements. A fully gradient encoded InI reference scan was repetively 60 times, where partition-encoding steps were along the anterior-posterior direction. The imaging parameters were: TR=6.4 s (64 partitions with 100 ms per partition); TE=30 ms; flip angle=$30^o$; FOV=256x256x256 $mm^3$; image matrix=64x64. The total imaging time was 384 s. High-resolution anatomical images were also acquired using a 3D T1-weighted (MPRAGE) pulse sequence.

Given 64 partitions in each reference scan, we simulated accelerated InI acquisitions by selecting a specific *k*-space partition encoding (from spatial frequency of 0 to 16/128 $mm^{-1}$ in steps of 1/128 $mm^{-1}$) from reference scan number 2 to 60. Volumetric InI images were reconstructed using the minimum-norm estimate, where the forward matrix was based on the first reference scan. The resting-state fMRI time series from each subject were morphed to a standard brain template based on the high-resolution anatomical images in a spherical coordinate system. Maps of tSNR was calculated for each subject and then averaged. The *k*-space partition giving to the highest tSNR was considered the optimal.

**RESULTS** Figure 1 shows the spatial distribution of the optimal *k*-space partition for the accelerated InI acquisition. More than 70% of cortical surface locations favors the *k*-space partition corresponding to DC (yellow) or slow varying spatial harmonics (orange/red). The optimal partition for deeper cortical areas, such as insula, inferior parts of the temporal lobe, and regions close to the center of the brain, corresponded to higher order spatial harmonics. Averaging across the whole cortex, the most favored k-space harmonic was the first spatial harmonic (1/128 $mm^{-1}$ in our imaging parameter; Figure 2): approximately 35% of the cortical locations had the highest tSNR if this partition is chosen for accelerated InI acquisition. The conventionally chosen partition (the DC partition) was only optimal for about 20% of cortical locations.




**DISCUSSION** In this study, we estimated the optimal *k*-space partition for the accelerated InI acquisition using simulations based on empirically measured data. We found that InI samples at the first spatial harmonic, corresponding to the spatial frequency of 1/128 $mm^{-1}$, can have the maximal tSNR in average. Note that the same method of choosing the regularization parameter was applied to all inverse solutions in the image reconstruction in order to avoid potential bias in tSNR calculation. Note that the optimal partition estimated here can be confounded by the relatively slow sampling rate of the reference data (6.4 s for one volume). This suggests that the tSNR estimated in this study may be different from the tSNR when InI is acquired at 10 Hz. Further experiments are needed to validate the optimal partition reported here and to demonstrate how much fMRI sensitivity can be improved by InI sampling the optimal partition.

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