3D kSPA for High Spatial and High Temporal Resolution fMRI

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INTRODUCTION: Parallel imaging techniques have been applied in functional MRI (fMRI) to improve spatial and temporal resolution (1, 2, 3, 4). However, its application has so far been hampered by reduced signal-to-noise ratio (SNR) and extensively prolonged image reconstruction time, especially for non-Cartesian sampling trajectories. In this abstract, we introduce a novel 3D kSPA (k-space SPArse matrix) parallel imaging technique (5) with volumetric acquisition to alleviate these two problems. kSPA is a fast reconstruction algorithm that is particularly suited for repetitive image reconstruction where thousands of images are acquired in a single scan. The kSPA algorithm computes a sparse approximate inverse that can be applied repetitively to reconstruct all subsequent images. By combining kSPA with 3D fMRI, we can trade the SNR gain from 3D acquisition for higher spatial or temporal resolution, and less geometric distortion and signal drop-off. *In vivo* 3D kSPA fMRI is demonstrated with a stack-of-spiral 3D gradient echo sequence using a typical contrast-reversing checkerboard visual stimulus. The kSPA reconstruction results in an improved temporal resolution without compromising the activation volume.

METHOD: A 3D stack-of-spiral sequence was implemented on a 3.0T whole-body system (GE Signa, GE Healthcare, Waukesha, WI) equipped with a maximum gradient of 50mT/m and a slew rate of 150 mT/m/s. An 8-channel head coil (MRI Devices Corporation, Pewaukee, WI) was used for image acquisition. The acquisition matrix was 128x128x32. For each slice encoding line (of the total 32 lines), data were acquired on a two-interleaf spiral trajectory. The sequence parameters were: flip angle = 21°, TE = 30ms, TR = 90ms, FOV = 22cm and slice thickness = 1mm. A contrast-reversing (3 Hz) checkerboard visual stimulus was used in the block-trial paradigm which included 8 cycles of 20 seconds of stimulus-on and 20 seconds of stimulus-off. With 100 time frames, the scan time was 9 minutes and 36 seconds.

Images were reconstructed with both gridding reconstruction and kSPA reconstruction. For gridding reconstruction, both interleaves of data were used. Gridding were performed for each slice. Following the gridding procedure, images were obtained using 3D inverse Fast Fourier Transform (FFT). Correlation coefficient maps were calculated by correlating the measured 100-frame time series magnitude signal in each voxel with a sinusoidal regressor with a period equal to 40 seconds. Z-score maps were obtained from correlation-coefficient maps and the degrees of freedom by using a Fisher transform.

For kSPA reconstruction, only one interleaf of the data was used to reconstruct a unaliased image resulting in a sampling reduction factor R = 2. Coil sensitivity maps were estimated using the first 10 frames of images. Unlike the iterative SENSE algorithm which estimates a real-space image directly from sampled **k**-space data, kSPA estimates **k**-space data on a Cartesian grid based on arbitrarily sampled **k**-space data. To accomplish that, kSPA computes a sparse reconstruction matrix such that the Fourier transform of an image can be computed directly through a matrix-vector product. Such reconstruction matrix depends solely on the coil-sensitivity and the sampling pattern. This matrix only needs to be constructed once and can be reused to reconstruct all images in the series. With R = 2, the temporal resolution is doubled, resulting in a 200-frame times series. Correlation coefficient and Z-score maps were computed accordingly. For comparison, Analysis was also performed by using only half of the frames.

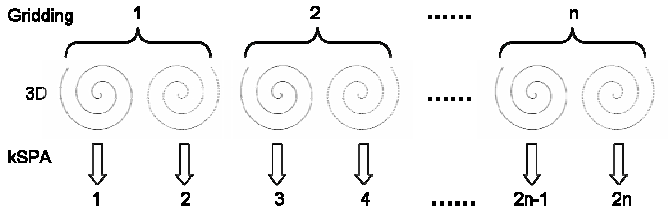

Fig.1 – kSPA parallel imaging reconstruction for 3D fMRI

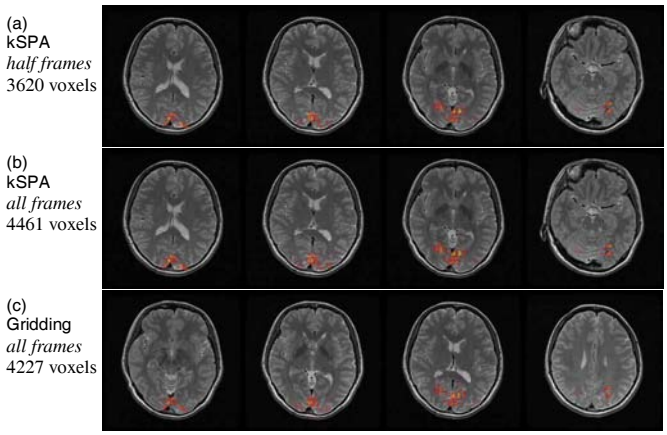

Fig.2 – Comparison of activation maps for 4 typical slices out of a total 32 slices. (a) kSPA reconstruction with R = 2, half of the frames were used for correlation; (b) kSPA reconstruction with R =2, all frames were used for correlation; (c) normal gridding reconstruction. kSPA results in comparable activation maps but increases the temporal resolution. $p < 0.001$ in all cases.

RESULTS: Figure 2 compares the activation maps of 4 typical slices. With R = 2, kSPA results in very similar activation maps as the conventional gridding reconstruction. After the background of false positives was removed by Kleinschmidt's method, the t-score distribution further verified this similarity (Figure 3). When only half of the frames were used, the activated voxel counts decreased as expected.

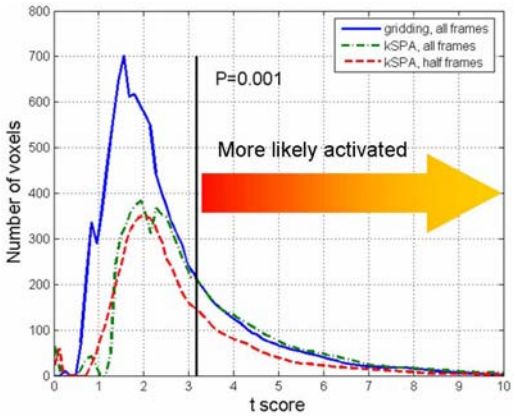

Fig.3 – When all frames were used (same scan time), kSPA results in similar number of activated voxels, but twice the temporal resolution of normal gridding reconstruction.

DISCUSSION: We have demonstrated a 3D kSPA fMRI technique for improving the temporal and spatial resolution of fMRI. Compared to 2D acquisition, a 23% increase in SNR has been previous observed by using 3D acquisition (6). Such SNR gain is ideally suited for parallel imaging (PI). With PI, this SNR can be converted into higher spatial and temporal resolution, which otherwise would have been difficult to obtain.

3D PI for non-Cartesian trajectory has been challenging because of the large computational load especially for time series data. The kSPA algorithm offers some favorable properties for 3D fMRI. Because the reconstruction matrix only needs to be calculated once, kSPA is ideally suited for functional studies where thousands of images are acquired in a single scan. The resulting average reconstruction time per image is approximately the same as gridding. By reconstructing images from undersampled 3D data set using kSPA, we were able to increase the temporal resolution of 3D fMRI without sacrificing the quality of activation maps.

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