Noise Analysis of Accelerated 3D-EPI fMRI

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Introduction:
Three-dimensional acquisition with parallel imaging acceleration is a promising technique to achieve high spatial resolution without loosing information in gaps between slices combined with rapid acquisition [1]. The contribution of temporal noise is the limiting factor in fMRI experiments. 3D acquisition has shown different signal stability levels than 2D [2]. Acceleration and unwrapping will also inevitably affect noise and signal properties. The aim of this work is therefore to quantitatively study certain aspects of signal fluctuation and correlation changes with the above methods.

Methods:
Acquisition: For methodological evaluation same studies were repeated on a healthy volunteer on different occasions. Data was collected on a 3T Siemens scanner using an 8-channel head coil. Four schemes based on a segmented EPI sequence were applied: 1) conventional 2D multi-slice, 2) 3D-EPI full volume scan, 3) 3D-EPI with two-fold 1-dimensional acceleration (R=2) and 4) 3D-EPI with four-fold 1-dimensional reduction (R=4). RF-spoiling was employed in 3D methods. For comparison, same setup and acquisition parameters were used: TE=30 ms, TR=65 ms (1200 ms for 2D), isotropic spatial resolution of 1.7 mm for 3D-EPI (1.7 x 1.7 x 2 mm^3 for 2D). Total acquisition times for 20 slice volumes were ~ 7s (2D), ~ 6s (3D full), ~ 4s (3D, R=2) and ~ 2s (3D, R=4). For accelerated scans GRAPPA reconstruction was performed offline. The functional MRI consisted of a simple motor task with self-paced, unilateral sequential finger tapping of ~30s off / 30s on blocks.
Analysis: For all methods t-score activation maps based on 90 time points were calculated. Signal fluctuations were analyzed based on the standard deviation of temporal signal magnitude variations normalized by the mean voxel signal intensity, *NSD*, and spatio-temporal signal correlations based on the average time series autocorrelation, *AC*, and voxel cross-correlations, *XC*:

$$NSD_i = \frac{\sigma_i}{\langle S_i \rangle}$$

$$AC = R_{xx}[k] = E\{x_{n+k} x_n^*\} = \sum_n x_{n+k} x_n^*$$

$$XC = R_{xy}[k] = E\{x_{n+k} y_n^*\} = \sum_n x_{n+k} y_n^*$$

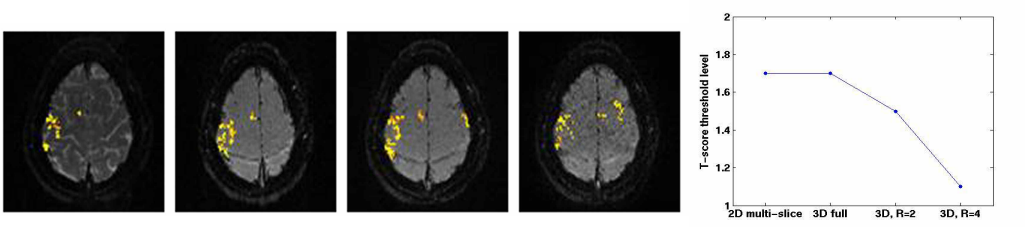

Fig. 1: ***Activation maps for corresponding slices from: 2D-multislice, 3D full volume, accelerated 3D (R = 2) and accelerated 3D (R = 4) scans showing expected activation structure with reduction in threshold level accounting for differences in intrinsic CNR and SNR (right).***

Results:
Functional results gave overall consistent activation patterns in expected contralateral motor cortex areas (fig. 1). Seen is a smaller decrease in t-score level (up to ~30 %) than theoretically expected, in disproportion to a larger SNR loss with acceleration.

The signal instability equivalently increased significantly (~80 %) for high acceleration (R=4), but slightly improved for 3D full acquisition (fig.2, top). Both spatio-temporal signal correlations, indicated by *XC* and *AC* respectively, were more than double as high (~140 %) in 3D than in 2D with no apparent stronger effect on signal correlation due to acceleration (fig.2, bottom).

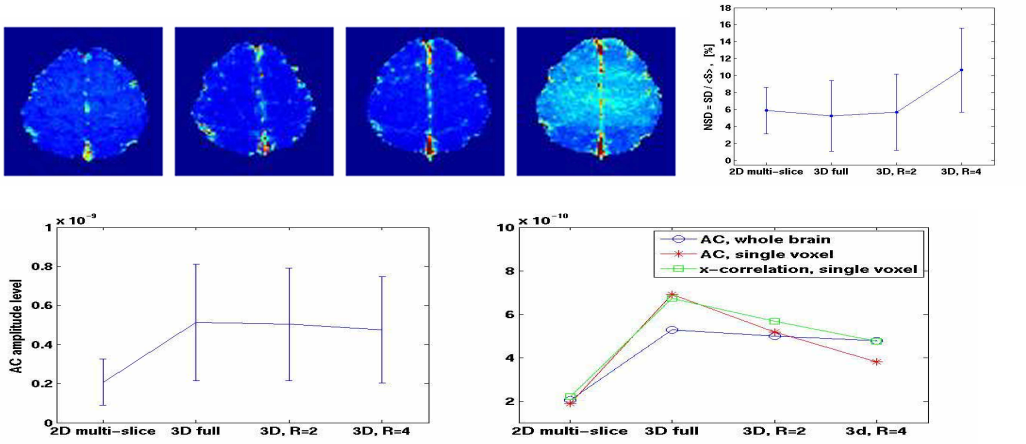

Fig. 2: ***Top row: Mean signal normalized standard deviation (NSD) maps and plot for the four schemes at corresponding slices. Bottom row: Mean correlation amplitudes with standard deviations for brain-averaged AC (left) and for all calculated correlation sequences (right).***

Conclusion:
We showed that accelerated 3D-EPI for improved fMRI is feasible. The current analysis of the signal variations based on signal fluctuation and correlation measures showed considerable changes with high acceleration. The signal stability of the 3D method with moderate acceleration slightly outperformed or was comparable to 2D experiments. The spatial and temporal increased signal correlations in 3D account for the observed increase in the number of false positives. Further exploration into the direct effects of these signal property differences on activation detection is needed for a reliable application of accelerated 3D fMRI.

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References: [1] Sodickson, DK. *et al.*, (2005), *Acad Radiol.* 12, 626-635. [2] Goerke, U. *et al.*, (2005), *NMR Biomed.* 18, 534-542.