

# A method to increase temporal resolution in 3D-EPI fMRI using UNFOLD

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## Introduction:

An fMRI study is ideally acquired at a high temporal resolution and with full brain coverage at each scan time point. This prerequisite is especially true in view of the rapid dynamic BOLD signal changes expected when cognitive tasks are studied. A cascade like brain recruitment is typically observed in complex mental exercises where neural recruitment occurs in both parallel and serial fashion. Currently multi-slice, single-shot 2D EPI is used for most applications. We propose a hybrid 3D EPI sequence instead, which is a standard 2D EPI sequence modified such that the third dimension of the excited slab is spatially encoded using 40 phase-encoding steps. So at each TR, the whole volume is excited. With this method, signal changes related to neuronal activity may be detected more reliably and may less likely be lost in gaps between slices as typically seen with multi-slice 2D imaging. Another advantage of Hybrid 3D-EPI is an improvement in SNR due to excitation of the whole volume at each repetition time, although the output image is more T1-weighted compared to the 2D-EPI [2]. Since both whole brain coverage and relatively high spatial resolution is of importance in cognitive fMRI, the temporal resolution in Hybrid 3D-EPI is slowed to an extent that analysis of time-resolved brain recruitment becomes a futile exercise. We applied therefore in this work, in order to increase temporal resolution, UNFOLD [1](in slice encoding direction) and Partial Fourier (in phase enc. direction) techniques to the 3D hybrid EPI sequence. Unlike in previous studies, UNFOLD was applied here along the slice encoding direction. This directly reduced the volume TR by fifty percent. The sequence was tested on healthy volunteers who were exposed to complex cognitive stimuli that lasted up to a time period of eight TRs. The resulting activation patterns were compared between data acquired with full k-space coverage and the UNFOLD-PF hybrid data.

## Methods

Experiments were performed with an 8-channel head coil on a 3T GE SIGNA machine with gradients constraints  $G_{max}=40\text{mT/m}$ , slew rate  $S=140\text{T/ms}$ .

**Imaging parameters:** FOV =  $192 \times 192 \times 120\text{mm}^3$ , matrix= $64 \times 64 \times 40$ , resolution = 3mm isotropic, flip angle =  $15^\circ$ , spatial-spectral 2D RF pulse, 100KHz readout bandwidth, 3D encoding direction: left-right, EPI-readout direction: anterior-posterior, fast phase encoding (EPI-blip) direction: head-foot. An oblique trajectory was applied to reduce the number of slices necessary to cover the whole brain.

• Full k-space coverage: TE=30ms, TR=60ms, EPI readout of 64 lines, TAQ/3D volume=2.4s.

• 2x UNFOLD was applied along the 3D encoding direction and Partial Fourier was applied along phase encoding direction. TE=30ms, TR=50ms, EPI readout of 52 lines, TAQ/3D volume=1s.

Two healthy volunteers underwent fMRI while they were exposed to audio-visual stimuli with arithmetic problems to solve. They were shown simple multiplication problems followed by an incorrect result. They indicated by button press if the offered but consistently incorrect product was (a) close to the correct mental solution, (b) too big or (c) too small. The task was self-paced. Stimulus events lasted between 4 to 8 seconds while the inter-stimulus interval was kept at 2 seconds. 250 volumes are acquired for full k-space coverage and 600 volumes are acquired for UNFOLD-PF coverage giving a total imaging time of 10 minutes. The first 4 time points are discarded due to the significant intensity fluctuation before a steady state is reached.

**Image Processing:** All images were reconstructed off-line using the standard reconstruction schemes for UNFOLD and the Cuppen method[3][4] for full k-space restoration. Data preprocessing and activation maps were computed with the SPM5 software. T-score thresholds were kept at  $p < 0.01$  uncorrected. Stimulus onset vector was convoluted with the canonical HRF.

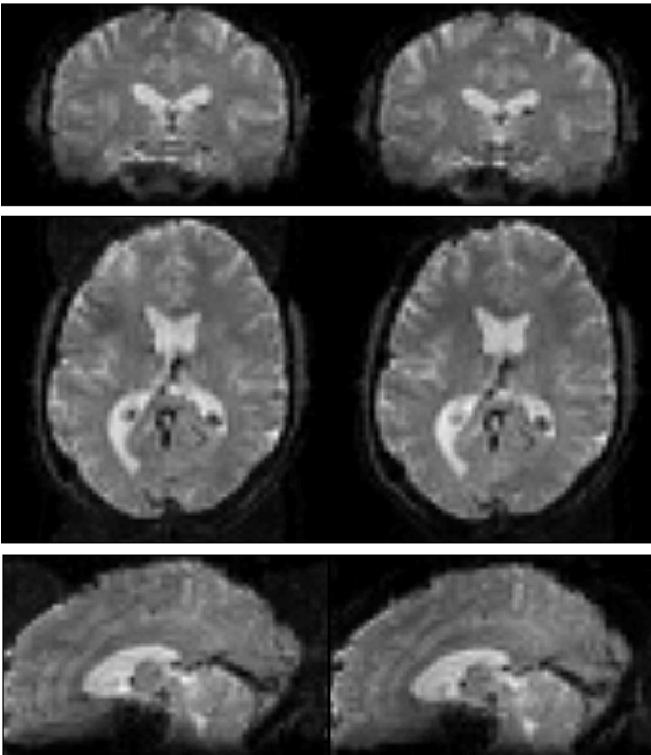


Figure 1- a)Coronal b)Axial c)Sagittal images. Left column shows UNFOLD images acquired in 1 sec. Right column shows the comparable full data set acquired in 2.4sec.

## Results:

Figure 1 (Left column) shows sample a) coronal, b) axial and c) sagittal images from the 3D data acquired by UNFOLD-PF approach in 1sec. and (Right column) full k-space coverage in 2.4sec. In the UNFOLD-PF images, weak aliasing artifacts can be seen in the axial images due to Nyquist ghosts and in the sagittal images due to UNFOLD reconstruction. Figure 2 shows the expected activation pattern in bilateral auditory cortex in a healthy volunteer following auditory stimuli for the UNFOLD data. Activation patterns were highly similar for full k-space data and UNFOLD data using HRF convolution. But they were much richer for the UNFOLD data when F.I.R. time bin related activations were extracted and compared. This improvement in the resolution of brain activation in the temporal domain is directly related to the short TR of 1s which is achieved by using the UNFOLD technique.

**Discussion:** Although this data was acquired using an 8-channel coil, this method can be used with a single channel coil without any modifications since no parallel MRI imaging techniques were applied. Increasing temporal resolution through parallel MRI may be undesirable, as the decreasing TE will destroy the BOLD response. Parallel imaging can be applied along the phase encoding direction to increase the spatial resolution, however, and is a focus for future work. When the number of reference lines is reduced for partial Fourier reconstruction, visible artifacts are seen. Nyquist ghosts appear stronger in the UNFOLD images as compared to the full k-space coverage, although they are still below 5%.

**Conclusions:** fMRI experiments with full brain coverage using an audio-visual numerical calculation paradigm were acquired using a hybrid 3D EPI with UNFOLD and Partial Fourier reconstruction at a volume TR of 1sec. Temporal decoding of neural activity improved in spite of a loss in SNR and stronger Nyquist ghosts.

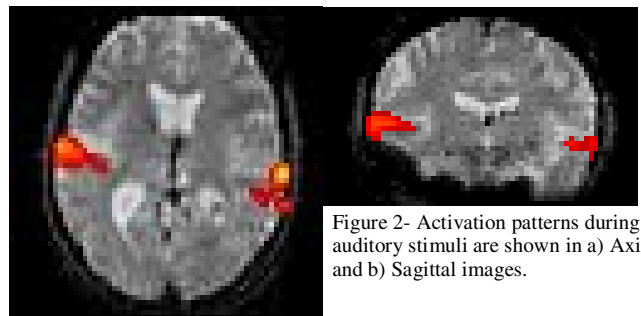


Figure 2- Activation patterns during auditory stimuli are shown in a) Axial and b) Sagittal images.

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