FMRI using a 3D radial-Cartesian trajectory: spatio-temporal tunability and artifact correction

Nadine N Graedel[1], Mark Chiew[1], Jennifer A McNab[2], and Karla L Miller[1]

[1]*FMRIB Centre, University of Oxford, Oxford, Oxfordshire, United Kingdom,* [2]*Department of Radiology, Stanford University, California, United States*

Introduction: 3D acquisitions are attractive for fMRI due to potential gains in SNR efficiency [1]. However, typical 3D multi-shot acquisitions require several seconds to form a volume, making them susceptible to temporal fluctuations such as motion and physiological noise. Retrospective corrections (e.g. motion and RETROICOR) can mitigate these effects, but do not correct for intra-volume fluctuations. We propose an alternative 3D EPI trajectory for fMRI using a hybrid radial-Cartesian readout in which k_{xy}-k_z EPI "blades" are rotated in an angle scheme based on the golden ratio [2] about the k_z-axis [3,4] (Fig. 1). Because each blade crosses the centre of k-space, this acquisition scheme enables blade-by-blade detection of motion, physiological noise and other temporal fluctuations. Furthermore the sequence is temporally tunable: the same data set can be reconstructed at flexible temporal resolution by selecting different numbers of blades per image.

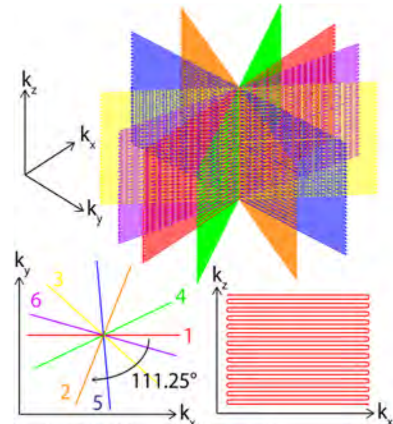

Fig. 1. **Hybrid radial-Cartesian readout:** schematic showing acquisition of 6 blades.

Methods: *Acquisition:* fMRI data was acquired at 3T on 3 healthy volunteers with a visual stimulus (30s ON/OFF 8Hz checkerboard). One 300s run was acquired with only visual stimulus. In a second 200s scan, subjects were asked (using auditory cues) to deliberately shift in the z-direction on a defined schedule (Fig. 3). The acquisition used TR/TE=50/25ms, blade matrix 100x76, 2mm isotropic, R=2 along blade PE.

Reconstruction: Image reconstruction was performed in MATLAB. GRAPPA reconstruction was applied along k_z prior to regridding. To demonstrate temporal flexibility, no-motion runs were reconstructed for three different temporal bin widths: 200/100/50 blades/volume (TR_{vol} = 10/5/2.5 s). The deliberate motion data sets were reconstructed using 100 blades/volume.

Image correction: Example corrections supported by this trajectory were implemented: linear phase ramp and 0-order phase offset, corresponding to a shift along z and a B_0 offset were fitted for every blade (using the high SNR center portion of k-space). These phase effects were removed in k-space prior to gridding.

Analysis: fMRI analysis was performed in FEAT (FSL) using no smoothing or pre-whitening. Rigid body motion correction (MCFLIRT) was performed across all datasets.

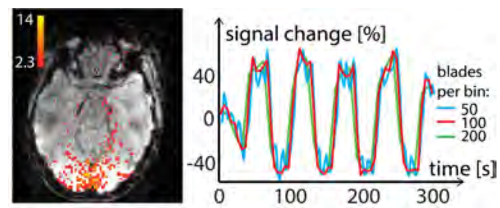

Fig. 2. **Visual experiment:** Activation map for 100 blades/bin and high z-stat example voxel time courses for all three temporal resolutions.

Results: The no motion data (Fig 2) show clear visual activation for all three temporal resolutions. Radial aliasing artefacts due to under-sampling were visible only in the 50 blade reconstruction, and for this reason 100 blades were used for the deliberate-motion reconstructions. Estimated phase correction parameters are shown for a representative subject in Fig 3. The linear phase parameters show good correspondence to motion correction z-shift estimates from uncorrected data, as well as the intended head motion. The 0-order phase offset, reflecting variations in B_0, tracks the measured respiration and slow B_0 drift. Under deliberate motion, the uncorrected data sets have volumes with severe artifacts (Fig. 4) and show no super-threshold visual activation. After correction, corrupted volumes and visual activation can be recovered, although there is some artificial activation at image edges due to stimulus-correlated motion. Voxel-wise mean temporal variance was reduced by 45/35/21% for subjects 1-3 respectively.

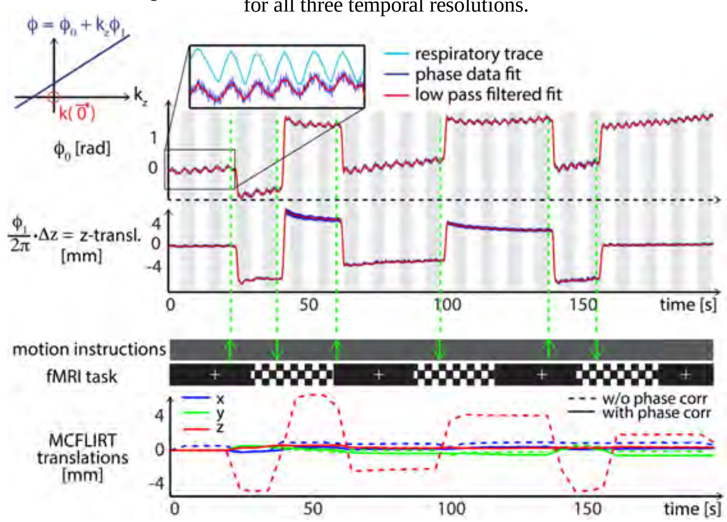

Fig. 3. **Phase correction:** Fitted phase coefficients (top plots) and motion estimates from FEAT before and after phase correction (bottom plots).

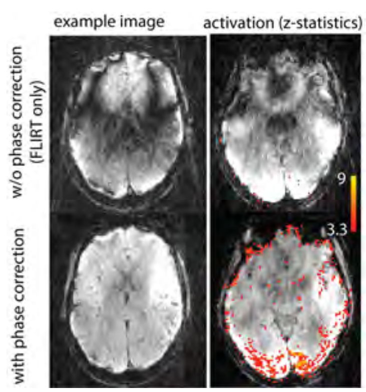

Fig. 4. **Result phase correction:** Example image at t = 46 s and z-statistics maps with and without phase correction. MCFLIRT applied for all data sets.

Discussion: The proposed 3D trajectory has several benefits, including flexible post-acquisition definition of spatio-temporal resolution and correction of many sources of temporal phase fluctuations. Future work will include expansion of this correction for full rigid body motions and other physiological noise. Furthermore, this trajectory is well suited to sophisticated k-t accelerations, as demonstrated in another abstract from our group [5].

References: [1] Poser at al., MRM 2010; [2] Winkelmann et al., IEEE Trans. Med. Imag. 2007; [3] McNab et al., MRM 2010; [4] Ehses et al., ISMRM 2014 [5] see Chiew et al., ISMRM 2015;