T2 prepared RUFIS: A new imaging paradigm for 3D whole-brain, silent and distortion-free BOLD fMRI

Ana Beatriz Solana Sánchez[1], Anne Menini[1], Laura Sacolick[1], Nicolas Hehn[1], and Florian Wiesinger[1]
[1]*GE Global Research, Garching bei Muenchen, Bayern, Germany*

Target Audience: MR physicists, Neuroscientists, Radiologists, Neurologists

Purpose: In this work, we propose a novel acquisition method for BOLD fMRI, T_2 prepared RUFIS, which addressed two significant problems, the geometric distortions[1] and the amount of acoustic noise[2]. The use of a quiet sequence is of particular interest for imaging auditory or speech paradigms, as well as for resting-state studies. The reduced geometrical distortions and signal drop-out renders this technique attractive for imaging regions highly affected by susceptibility artifacts, such as orbitofrontal cortex.

Methods:

Pulse sequence and reconstruction: The T_2-prepared RUFIS pulse sequence (Figure 1) consists of three blocks: 1) a T_2 preparation module consisting of a 90°x-180°y-180°y--90°x pulse train to generate T2-weighted longitudinal magnetization including a trapezoidal z-gradient spoiler to eliminate residual transversal magnetization. 2) a segmented 3D center-out radial RUFIS[3] readout where the spoke end points follow a spiral path with minimal gradient ramping between spokes, which enables quiet scanning, and nominal TE_{RUFIS}=0, resulting in robustness against off-resonance effects. Finally, 3) a waiting time is added to allow T1 relaxation between acquisition volumes. Image reconstruction is based on a non-Cartesian SENSE iterative reconstruction[4] and a second order total generalized variation (TGV) regularization[5].

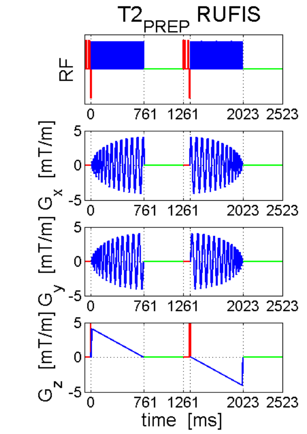

Figure 1: Schematic of the segmented T_2-prepared RUFIS pulse sequence profile. Each segment consists in a T2 preparation module (red), a RUFIS readout (blue) and a recovery period (green).

A single-shot improved version was also developed including three main modifications with respect to the schema defined in Figure 1: A) The gradient spoiler after the T_2 preparation module is one of the main sources of remaining acoustic noise. This gradient spoiler was substituted by increasing the length of the slow initial ramp along the z-axis prior to RUFIS readout. This increases the total acquisition time per volume by 17ms but decreases the Lpeak noise by 4dB. B) The whole undersampled k-space is acquired in a single-shot using a radial trajectory which rotates by the golden angle around the Z axis for every shot. C) Reconstruction includes an initialization volume reconstructed out of the whole dataset (high resolution image) and a Gaussian sliding-window where every acquisition volume (i) is reconstructed using a Gaussian weighted combination (0.2, 0.4, 1, 0.4, 0.2) of the k-space rawdata from five neighboring shots.

fMRI experiment: Two block-design fMRI tasks (finger-tapping motor and beeping auditory, 6 cycles, 120 volumes) were performed by 4 healthy volunteers on a GE 3T MR750w scanner using a GEM head array coil (GE Healthcare, Waukesha, WI, USA).

T_2-prepared RUFIS fMRI sequence parameter were: flip angle = 3°, BW = ±15.625 kHz, FOV = 18 cm, 1024 spokes per volume divided in 2 segments of 512 spokes, isotropic 3mm voxel size, recovery time between segments of 500ms, TE_{T2prep} = 80ms, TR =2.65ms. Standard multi-slice GE-EPI and SE-EPI were acquired as well (TR = 2.65 s, flip $angle_{GE}$ = 86º, TE_{GE}=30ms, TE_{SE}=70ms, FOV = 22 cm, isotropic 3 mm voxel size, 41 slices per image volume).

The improved single-shot approach was tested for a finger-tapping motor task, 6 cycles, 240 volumes, TR=1.32s maintaining the rest of the sequence parameters.

fMRI analyses: A standard fMRI preprocessing pipeline was applied including motion correction, high-pass filtering, spatial smoothing (FWHM=8mm), pre-whitening and normalization to the 2mm brain MNI template. Individual activation statistical spatial maps were obtained using a voxel-based GLM analysis using an off-on boxcar function defining the paradigm model. Z score statistics were considered significant for z>3, FWE corrected. Peak z statistics, %BOLD contrast and number of activated voxels in expected area of activation were obtained as quantitative measurements.

	%BOLD (peak z)	*Number_voxels (cluster)*	*Peak z*
Motor RUFIS	*1,33 ± 0,09*	*108,25 ± 27,93*	*7,88 ± 0,71*
Motor GE	*2,18 ± 0,36*	*861,25 ± 348,33*	*11,47 ± 2,19*
Motor SE	*1,83 ± 0,22*	*263,00 ± 336,06*	*8,53 ± 2,38*
Audio RUFIS	*1,21 ± 0,13*	*220,00 ± 257,69*	*4,95 ± 0,46*
Audio GE	*2,61 ± 0,66*	*510,25 ± 123,98*	*8,46 ± 1,24*
Audio SE	*1,68 ± 0,11*	*314,75 ± 251,50*	*5,84 ± 0,62*

Table 1: Quantitative MRI results of the two fMRI task for the four volunteers (mean and standard deviation values)

Results: In-bore acoustic noise measurements provided LAeq dB(A)-Lpeak dB values of 72,4dB(A)-95.5dB, 74,6dB(A)-100,0dB, 114,0 dB(A)-121,7dB for ambient in-bore, T_2-prepared RUFIS and EPI-based methods, respectively. This means that T_2-prepared RUFIS provides a decrease of up to 40 dB(A)-22dB with respect to EPI. Table 1 shows the quantitative comparison between the T_2-prepared RUFIS, GE-EPI and SE-EPI for the 4 volunteers. In general, T_2-prepared RUFIS is less sensitive but spatially more specific to the area of expected BOLD activation than both EPI-based methods due to the lack of T_2* contamination[5].

Figure 2 shows first results for the improved single-shot version. Figure 2A illustrates an axial slice obtained using the default approach (left) and the improved single-shot one (right). Figure 2B also shows the average temporal profile of the %BOLD change (1.2%) over 1 cycle over all activated voxels in the motor-related areas of interest in one volunteer.

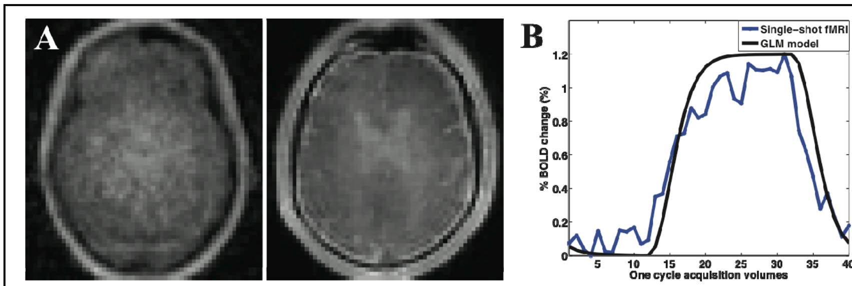

Figure 2: A) One slice from the 2-segments approach (left) versus the improved single-shot approach (right). B) Average % BOLD change temporal profile during one cycle over all activated voxels in motor-related areas for one volunteer using the single-shot approach.

Discussion and conclusion: A novel BOLD fMRI acquisition method which permits quiet and distortion-free whole-brain has been described. We demonstrated the feasibility of further improving this pulse sequence including further acoustic noise mitigation, increase image quality and temporal resolution. We expect this method to be particularly useful for applications requiring reduced noise, such as auditory, language fMRI, resting-state or sleep studies, or studying areas affected by susceptibility artifacts like in memory or emotions studies.

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