# OPTIMIZED FMRI PULSE SEQUENCE FOR SIMULTANEOUS EEG-FMRI: SPIRAL PSEUDO REAL TIME (SPRETI)

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**Target audience**: Physicists, psychologists and clinicians interested in the combination of MRI and electrophysiological signals.

**Purpose:** Simultaneous EEG-fMRI is challenging mainly due to the artifacts induced in the EEG by the MR gradients. EEG gradient-induced artifact (GA) is the most disturbing artifact in this multimodal technique[1]. GA depends on the characteristics of the fMRI pulse sequence; EPI and spiral are the most common fMRI readout techniques. GA is higher in spiral scanning[2,3] and explained due to the chirping spectrum of the spiral trajectory[2] and by the use of larger crusher gradients at the end of the readout[3]. One of the key applications of EEG-fMRI is study of epilepsy[4]. In these studies it is generally required whole brain coverage and taking into account that the scan could be manually stopped due to seizures in the patient. In this work, we present a new spiral fMRI pulse sequence, "Spiral pseudo REal TIme (SpRETI)" with key features that make it suitable for simultaneous EEG-fMRI including: 1) the generation of reduced EEG GA using reduced slew rate and amplitude gradients; 2) real time data storage directly in the MR console; and, 3) B0map calculation including two initial volumes with different TE (independent on the fMRI parameters). The performance of SpRETI was validated using EEG gradient-induced artifact characteristics, and its removal, and the BOLD contrast in motor and visual tasks. Results were compared with EPI and other two spiral fMRI pulse sequences

**Methods:** *Phantom:* EEG cap was placed on a spherical water phantom previously covered with electrolytic paste. *Subjects:* Two healthy subjects (mean age 26±1years) participated in this study.

*Data acquisition:* **EEG data** were recorded using a Brain Products MR compatible system using a synchronization setup[3]. **MRI data** were collected using a General Electric Signa 3.0 T MR Scanner. Four different 2D gradient-echo fMRI psds were used: GE-EPI, GE–SPRLIO[5] (spiral in-out) GE–SPEP[6] (spiral out) and GE-SpRETI (spiral out). BOLD fMRI parameters for all the sequences were: TR/TE/voxel dimensions/slices = 2.88s/25ms/3.3x3.4x3.4mm, 36.

*Stimuli and experiment:* The volunteers performed two tasks: First, a block-design motor task of 40 seconds cycle with 20 seconds of right hand grabbing movement and 20 seconds of rest (5 cycles). This task was repeated for GE-EPI, GE-SPRLIO, GE-SPEP and GE-SpRETI. Second, a mixed event-related block-design visual task with 62 seconds cycles: 12 neutral images were presented with randomized interval fitting in 42 seconds and 20 seconds rest (5 cycles). This task was repeated only for the spiral fMRI pulse sequences because only 3 different versions of the task (3 different sets of neutral images) were available.

*Gradient-induced EEG analysis:* Voltage spectral density (VSD) was calculated in the worst case EEG electrode (F3) for: 1) each EEG epoch during each kind of pulse sequences and in the absence of sequence (background noise) using the Welch estimation (window 1024) before and after the removal of GA using Average Artifact Subtraction (AAS)[1]. Two quantitative measurements were calculated: 1) Euclidean distance between the GA corrected EEG VSDs and the background VSD; and, 2) the gain between the voltage value in the slice frequency (fs=12,5Hz) and harmonics between each GA corrected EEG VSDs and the background VSD.

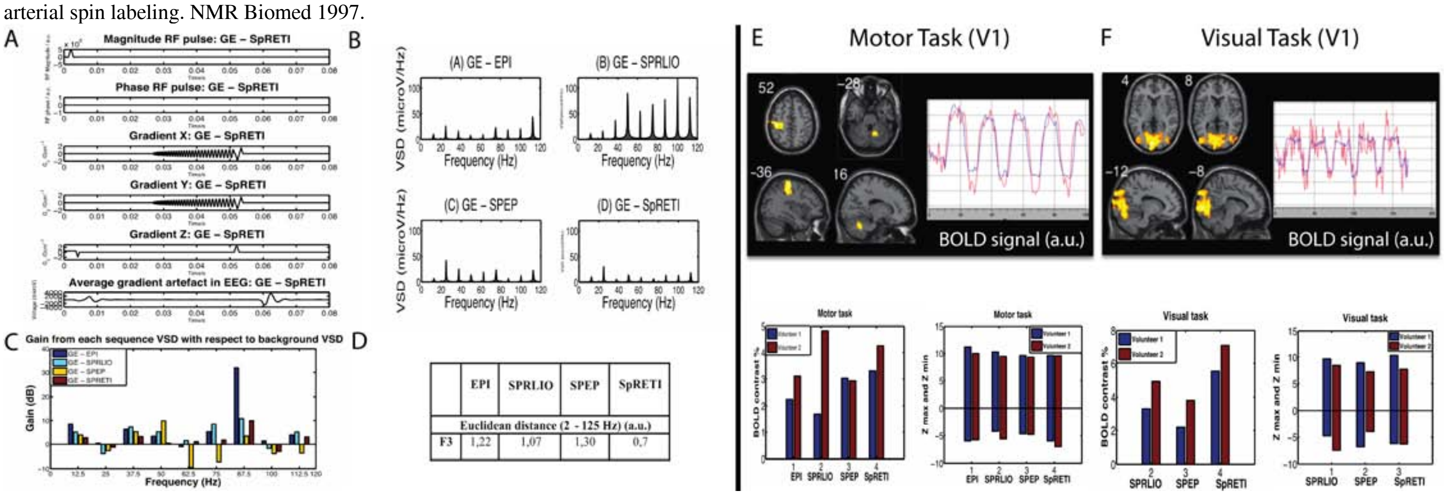
*fMRI Image analysis:* Standard fMRI preprocessing pipeline and GLM statistical analyses of the two task were analyzed for each pulse sequence and subject independently using FSL. The maximum and minimum Z value, and the percentage of BOLD change (mean of BOLD change per cycle) in the statistical peak voxel were used as quantitative measurements for comparison among the fMRI pulse sequences.

**Results:** An example of one slice acquisition of the GE-SpRETI profile in physical units with its associated gradient artifact (in the phantom for the worst case EEG channel) is shown in Fig. 1A. EEG VSDs before AAS correction for all sequences are shown in Fig. 1B. SpRETI generated the lowest VSD peaks in the slice frequency and harmonics. Fig.1C shows the gain values from the corrected EEG epochs of all the pulse sequences with respect to the background noise for the slice frequency and harmonics for the phantom data. Last, Fig. 1D shows the Euclidean distance from the corrected EEG VSDs to the background noise VSD.

On the other hand, Fig. 1E and Fig. 1F shows the results of the motor task and the visual task fMRI analyses, respectively. The spatial statistical map (FWE, $p<0.05$) and the BOLD timecourse response in the most significant voxel for volunteer 1 using GE-SpRETI are shown an example for each task. Additionally, the comparison quantitative measurements are summarized using bar plots. Results with GE-SpRETI were equivalent or superior to the rest of fMRI for both volunteers and tasks

**Discussion:** GE-SpRETI has shown optimal characteristics for simultaneous EEG-fMRI. A good performance in the motor and visual fMRI tasks and the lowest distortions associated to the gradient-induced artifact compared to GE-EPI and other spiral pulse sequences. This new fMRI sequences also stores the data in real time and calculates B0map within the same acquisition. All these features made this sequence optimal for simultaneous EEG-fMRI including epilepsy studies.

**References**: [1] Allen PJ et al. A method for removing imaging artifact from continuous EEG recorded during functional MRI. Neuroimage, 2000. [2] Ryali S et al. Development, validation, and comparison of ICA-based gradient artifact reduction algorithms for simultaneous EEG-spiral in/out and echo-planar fMRI recordings. Neuroimage 2009. [3] Solana AB et al. Simultaneous EEG-fMRI synchronization using EPI and Spiral sequences, OHBM 2011,, Canada. [4] Ritter, P. et al. Simultaneous EEG-fMRI. Neuroscience & Biobehavioral Reviews,2006 [5] Glover HG et al. Improved Combination of Spiral-In/Out Images for BOLD fMRI. Magnetic Resonance in Medicine, 2004. [6] Wong EC et al. Implementation of quantitative perfusion imaging techniques for functional brain mapping using pulsed arterial spin labeling. NMR Biomed 1997.




| | EPI | SPRLIO | SPEP | SpRETI |
|---|---|---|---|---|
| Euclidean distance (2 - 125 Hz) (a.u.) | | | | |
| F3 | 1,22 | 1,07 | 1,30 | 0,7 |

Figure 1: A-D: Results from the EEG gradient-induced artifact comparisons. E-F: Results from the fMRI comparisons for motor and visual task, respectively.