# Spin Echo and Adiabatic Spin Echo Motion Compensated Spiral functional MRI

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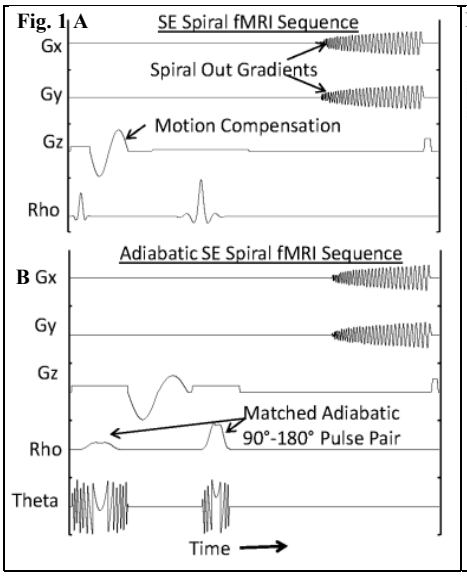
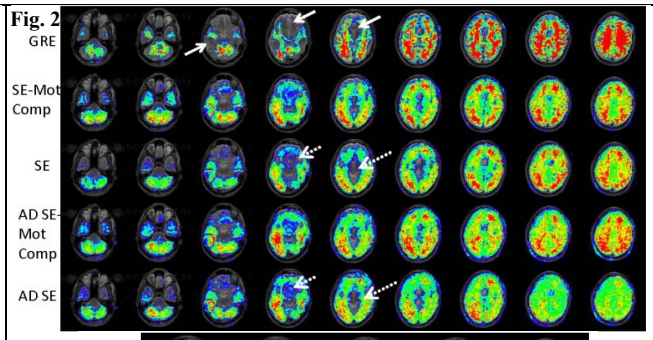
**Introduction**: Spin Echo (SE) functional MRI (fMRI) sequences have been found to be effective at isolating the microvascular contribution to the BOLD signal as compared to conventional gradient echo (GE) approaches [1-6]. The BOLD signal arising from microvasculature (i.e. small blood vessels or capillaries) is more spatially correlated to the underlying neuronal activity while the signal from larger veins may be significantly distant from the neuronal source [1]. The extravascular (EV) small blood vessel component increases quadratically with field strength, while the contribution from large veins increases linearly [1]. SE pulse sequences may be used to refocus the EV large blood vessel component and isolate the more neuronally coupled signal from the paryncheme [1-6]. In addition, SE sequences have the advantage of refocusing $T_2^*$ losses due to $B_0$-inhomogeneity. However, the 180° pulse used in the SE excitation is particularly susceptible to $B_1$ variations and preliminary experiments have demonstrated that SE sequences have increased sensitivity to brain pulsatility and/or other subject motion. In this work we have developed a novel SE Spiral fMRI sequence and Adiabatic SE (AD SE) Spiral fMRI sequence with integrated motion compensation (MC) gradients for robust $B_1$- and $B_0$-insensitive SE functional imaging of the brain.

**Method**: We replaced the single excitation RF pulse in a GE Spiral fMRI sequence [7] with a 90°-180° SLR pulse pair in which both pulses were designed to have matched profile shapes. A 3.84-ms 90° pulse with a bandwidth (BW) of 1.6 kHz and a 10-ms 180° pulse with a BW of 0.6 kHz were used to generate the SE. A second version of the sequence with a matched-phase adiabatic SE 90°-180° pulse pair, designed using the adiabatic SLR and phase-matching methods described in [8,9] was also developed to provide an option with greater immunity to the $B_1$-variations at high field strengths. Initial phantom experiments showed that the SE excitation was more susceptible to artifacts caused by motion. Therefore we added motion compensation gradients (in particular, a bipolar sinusoidal gradient pair) designed to null the first moment of the gradients at the time of the spin echo. An added benefit of adding the bipolar gradients was a mild diffusion encoding effect which reduces the intravascular signal from rapidly moving spins within the large blood vessels [2,3], an effect that should diminish with increasing field strength. The two sequences are shown in Figs. 1 A and B. After verifying pulse sequence performance in phantoms, functional *in vivo* scans were performed at 3.0 T (GE Signa 750) with an 8-channel head coil. Fifteen axial slices were obtained with 4-mm slice thickness and 4-mm gap. Functional acquisition using a GE Spiral fMRI, SE-MC Spiral fMRI, and AD SE-MC Spiral fMRI pulse sequence with TR=2000 ms, TE=30 ms for GE and 50 ms for SE/AD SE, flip angle=70° for GE and 90°-180° for SE/AD SE, matrix 64×64, FOV=22 cm and 128 time frames was performed. MC was turned on and off to investigate the difference in signal-to-fluctuation-noise ratio (SFNR). Reference $T_2$-weighted anatomical scans with the same slice prescription were also obtained. The activation task used simultaneous visual, auditory and sensorimotor (SM) stimuli during a 15-s "on" block, and a fixation cross during a 15-s "off" block. During the "on" blocks, the stimuli comprised simultaneous alternating high contrast checkerboard, variable pitch auditory tones presented in pseudo-random order, and a pneumatic glove-like manipulandum that flexed each of the 10 fingers in pseudo-random order.



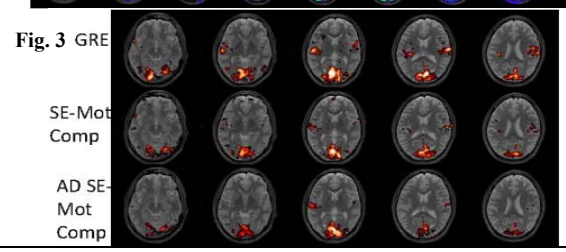




***Figure 1 (Leftmost)**: RF amplitude, phase and gradient waveforms for SE-MC Spiral fMRI and AD SE-MC Spiral fMRI sequences.*
***Figure 2 (Center top)**: SFNR maps overlaid on anatomical images for GE Spiral, SE-MC Spiral , SE Spiral, AD SE-MC Spiral and AD SE Spiral fMRI sequences. The conventional GE sequence suffers from loss of SFNR in areas of $B_0$-inhomogeneity. Both SE sequences benefit from the MC gradients in the areas indicated by the dotted arrows.*
***Figure 3 (Center bottom)**: Activation maps overlaid on anatomical images for GE Spiral, SE-MC Spiral, AD SE-MC Spiral fMRI sequences. The SE sequences are windowed similarly. Higher resolution activation maps are achieved by the SE sequences.*

**Results**: SFNR and activation maps overlaid on the anatomical images for a chosen set of axial slices through the brain are shown in Figs. 2 and 3. Much of the SFNR loss due to $B_0$ inhomogeneity, indicated by the white solid arrows, is recovered using the SE or AD SE techniques. The MC gradients recover SFNR in the central regions of the brain as indicated by the white dotted arrows and are particularly valuable for the AD SE excitation which was more sensitive to motion than the SLR SE excitation. At 3T, the AD SE-MC sequence provides a modest improvement for SFNR when compared to the SE-MC sequence, an effect that will likely become more pronounced at 7T. Activation maps are shown in Fig. 3 for the GE sequence and compared to the motion compensated SE and AD SE Spiral sequences. Greater activation was achieved by the GE sequence as expected, since the SE sequences isolate the tightly correlated, small-blood vessel fraction of the total BOLD effect. The SE activation maps in Fig. 3 are more narrowly windowed than the GE maps. Similar visual and auditory activation areas are observed for all three sequences. Noise autocorrelation in the x and y direction of the activation maps of the central slice in Fig. 3 was measured in order to obtain the resolution of the activated regions. The full width at half maximum of the autocorrelation function was 35% lower for the SE-MC and 26% lower for the AD SE-MC sequence than the GRE sequence indicating that the activation maps were higher resolution and more tightly coupled to the underlying neuronal source of activity.

**Discussion**: We have developed and tested two pulse sequences in phantoms and *in vivo* for robust SE Spiral fMRI at 3T. More uniform SFNR and higher resolution activation maps that more effectively isolate the fraction of the BOLD signal from paryncheme were obtained. The advantages of $B_0$ and $B_1$ robustness of the sequences at 3T will be further beneficial at 7T, and these experiments are underway. We are also planning to explore the use of this sequence with shorter variable density spiral interleaves for $T_2$-weighted structural MRI at 7T as a lower SAR alternative to fast spin echo sequences that use trains of RF pulses to generate $T_2$ contrast.

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