Simultaneous Multi-Slice Spectral-Spatial Excitation for Reduced Signal Loss Artifact in BOLD fMRI

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Target Audience: MR physicist and fMRI communities.

Purpose: Simultaneous Multi-Slice (SMS) imaging methods can increase BOLD fMRI acquisition speeds by factors of four and greater [1-4]. However, fMRI in the inferior brain still remains difficult due to susceptibility induced signal loss in gradient-echo EPI. Recently, spectral spatial (SPSP) pulses have been shown to correct signal loss in a single excitation [5]. Here we extend the SPSP method to SMS excitations and demonstrate Multi-Band (MB) and Power Independent Number of Slices (PINS) [6] SPSP pulses that are capable of exciting multiple signal-loss corrected slices simultaneously. Using breath-hold fMRI at 3T, we demonstrate that the pulses successfully recover lost signal and activation.

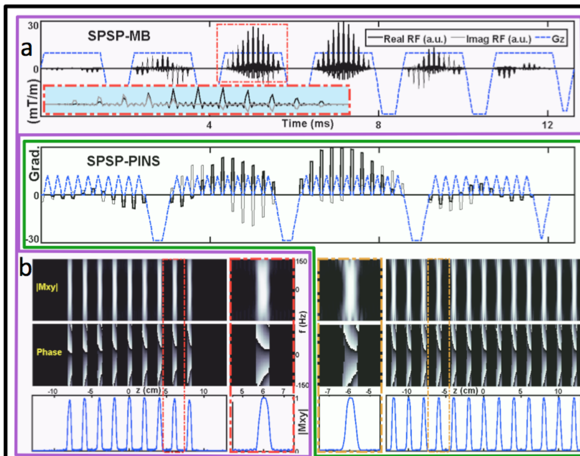

Figure 1. The B0-correcting SPSP-MB (**purple**) and SPSP-PINS (**green**) RF waveforms (**a**) and the corresponding Bloch simulations of their SPSP excitation patterns (**b**), showing the transverse magnetization, phase, and z-profiles.

Methods: SMS excitation is typically achieved using an MB pulse, a modulated single-slice waveform, that produces N slices with separation Δz. If RF power is a concern, the PINS technique, a series of non-selective pulses separated by z-blips, is a useful alternative. Both can be made spectrally selective by repeating the pulse waveforms in time, and subsequently used to correct signal loss using the relationship between through-plane susceptibility gradient and frequency: $G_s(f)= \alpha f$ [7]. Fig. 1 (a) shows example SPSP-MB and SPSP-PINS pulses that excite N=9 5mm thick slices Δz=2cm apart created in MATLAB (150mT/m slew rate, 30mT/m peak gradient). The RF was formed by linear superposition of five waveforms at 0, ±60, and ±120 Hz with a correcting factor α=-1.0mT/m/Hz. Frequency shifting was created by phase modulation. Pre-phasing across each slice for TE=35ms was achieved by time shifting. Fig. 1 (b) shows Bloch equation simulations of the transverse magnetization and pre-phasing patterns.

Breath-hold fMRI experiments (20s on/off) for 5 min were performed using a Siemens 3T MRI scanner and a 32-channel head coil with three different pulses: 1) a standard N=9 MB pulse, 2) the N=9 SPSP-MB pulse, and 3) the SPSP-PINS pulse. A standard sinc was used to acquire 36 reference slices for a 3x4 sliceGRAPPA reconstruction kernel. A blipped-CAIPI EPI sequence [4] was implemented with FOV/3 shift (350ms TR, 37° FA, 36ms TE, 2.5x2.5x5mm^3 voxels). FSL was used to analyze the fMRI data (5mm smoothing, 1.6-10 z-stat threshold).

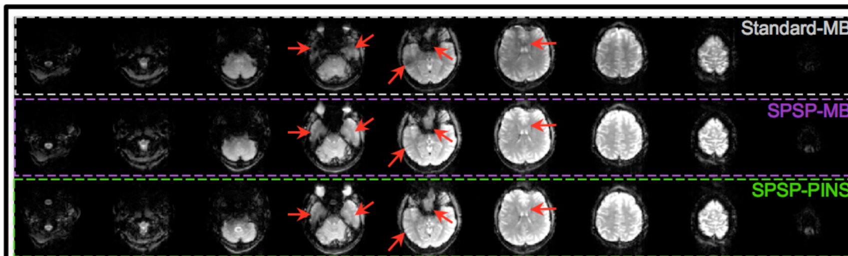

Figure 2. Nine simultaneously acquired slices, taken from the three fMRI experiments. Comparable signal recovery (arrows) is seen for the SPSP-MB and the SPSP-PINS slices.

Results: Fig. 2 shows nine simultaneously acquired slices for each of the fMRI runs. Signal recovery above the nasal cavity and the ear canals is observed for the SPSP pulses, as indicated by the arrows. Fig. 3 shows the breath holding activation data. Note the recovery of a significant volume of brain activation that goes undetected in the conventional MB-excitation without B0 correction.

Discussion and Conclusions: We have presented two SMS SPSP pulse methods for correcting susceptibility induced signal loss. It was shown that corrected fMRI data can be acquired at a rate of three volumes per second, enabling future studies of the frontal lobe and nearby regions with high temporal resolution. Both pulses were shown to be effective but have tradeoffs. SPSP-PINS requires roughly half the voltage as SPSP-MB. However, SPSP-PINS may excite unwanted slices and hence requires careful positioning.

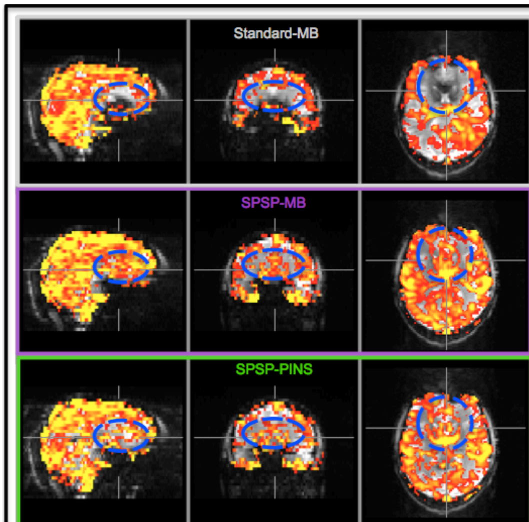

Figure 3. Orthogonal views of the breath-hold fMRI data for the three SMS pulses. Activation is clearly detected in the ROI when using an SPSP pulse, but is lost entirely in the uncorrected standard-MB case.

References: [1] Larkman, D., et al., JMRI, 2001. **14**: p. 329.; [2] Moeller, S., et al., MRM, 2010. **63**: p. 1144; [3] Feinberg, D., et al., PlosOne, 2010. **5**: p. e15710. [4] Setsompop, K., et al., MRM 2012. **67**: p. 1210. [5] Yip, C.Y., et al., MRM, 2009. **61**: p. 1137. [6] Norris, D.G., et al., MRM, 2011. **66**: p. 1234. [7] Yang, C., et al., MRM, 2012.

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