Improved detection of olfactory fMRI BOLD signal with through-plane phase precompensated spectral-spatial pulses

Christopher Thomas Sica[1], Prasanna Karunanayaka[1], Jeff Vesek[2], Jianli Wang[1], and Qing X Yang[1,3]

[1]*Radiology, Penn State College of Medicine, Hershey, PA, United States,* [2]*Molecular Biology, Penn State College of Medicine, Hershey, PA, United States,*

[3]*Neurosurgery, Penn State College of Medicine, Hershey, PA, United States*

Purpose: Artifacts in axial slices due to through-plane signal-losses are of primary concern in olfactory functional Magnetic Resonance Imaging (fMRI). This is because the primary olfactory cortex (POC), located in the inferior part of the brain, is in close proximity to air/tissue boundaries and suffers from considerable susceptibility-related MR signal losses. Many brain regions in the olfactory network, including the inferior orbital frontal cortex (OFC), also experience these susceptibility-related signal losses making it one of the hardest regions to detect fMRI activation. In this abstract, we investigated the use of Spectral-Spatial (SPSP) radiofrequency pulses for through-plane compensation in order to recover the diminished signal in these regions [1,2]. Our results show that the recovered MRI signal by this method readily translates into fMRI activation in olfactory areas located near the base of the brain.

Materials and Methods: Olfactory fMRI: Olfactory fMRI was performed using an MR compatible olfactometer with a flow rate of 8 L/min that synchronized odor delivery with a visual cue. Three rounds of different lavender odor intensities were presented to the subject's nostrils sequentially. Each odor stimulation was interleaved with a 30 sec rest period of odorless air presentation [3]. This fMRI paradigm was run twice with and without susceptibility compensation on a Siemens Trio 3T with the following parameters: TR/TE = 2000 ms / 30 ms, FOV = 240×240 mm^2, matrix = 80×80, 32 axial slices, slice thickness 4 mm, number of repetitions = 231. The standard fMRI analyses (preprocessing, GLM) were performed using SPM8. **SPSP Pulse Design:** The SPSP pulses were designed following the method described by Anderson et al [2]. The pulses utilized 5 frequency bands, with a frequency spacing (Δf) of 60 Hz. Six subpulses of 2.4 ms duration were utilized, for a total pulse duration of 14.4 ms. The design was monopolar with flyback lobes. Nine SPSP pulses with α values ranging from -0.76 to -1.72 uT/m/Hz were designed through incremental shifts of the subpulses relative to the slice select gradient center. **SPSP Experiment:** All SPSP pulses utilized a 65 degree flip angle. Prior to the fMRI experiment, the EPI sequence was run in a mode that swept through all nine α values and the uncompensated sinc pulse. After placement of ROI's in susceptibility plagued regions, the α value that recovered the most signal for each slice was determined. The EPI sequence was configured to apply a SPSP pulse with the specified α value per slice.

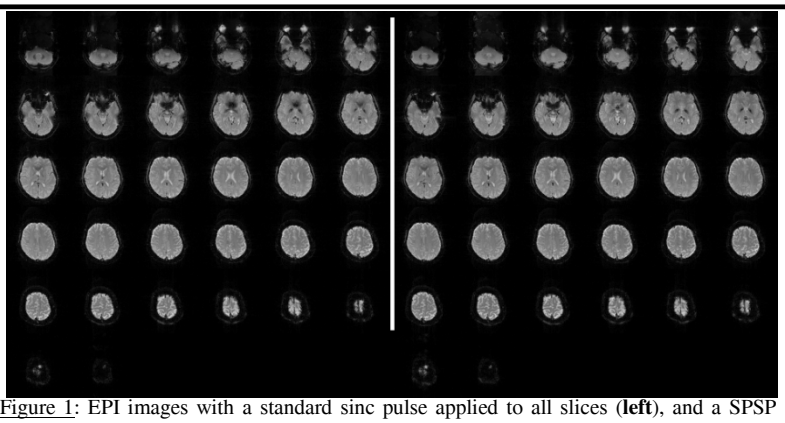

Figure 1: EPI images with a standard sinc pulse applied to all slices (**left**), and a SPSP pulse applied to all slices with α = -1.72 uT/m/Hz (**right**). Signal recovery is evident in the lower part of the brain.

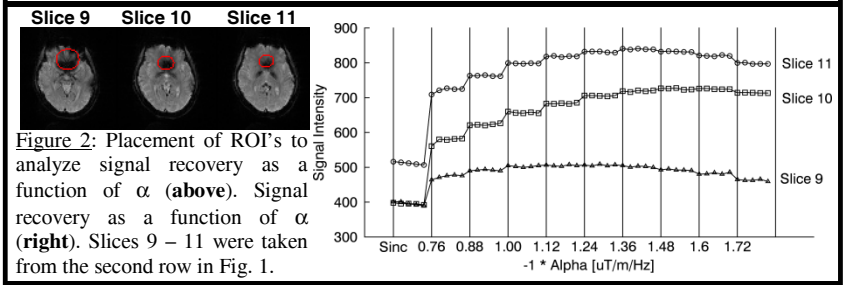

Figure 2: Placement of ROI's to analyze signal recovery as a function of α (**above**). Signal recovery as a function of α (**right**). Slices 9 – 11 were taken from the second row in Fig. 1.

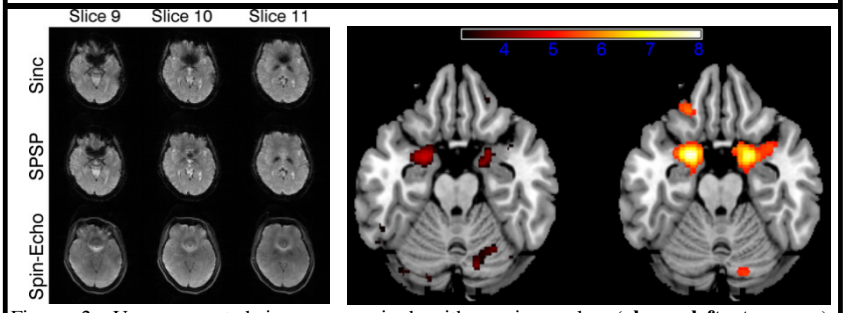

Figure 3: Uncompensated images acquired with a sinc pulse (**above left, top row**), compensated SPSP images with the optimally chosen α values (**above left, middle row**), and spin-echo EPI images (**above left, bottom row**) are displayed. The α values used were -1.24, -1.72, and -1.72 uT/m/Hz for slices 9, 10, and 11 respectively. The Z-score activation maps from the olfactory fMRI experiment (**above right**), with the uncompensated on the left and the compensated on the right. The detection of olfactory activation was significantly higher with the use of SPSP pulses.

Results and Discussion: Figure 1 shows a series of EPI images acquired with standard sinc and SPSP pulses with α = -1.72 uT/m/Hz. These RF pulses were applied to all slices, respectively. Compensation is evident near the POC region. Figure 2 shows an example of the ROI analyses for three slices near the POC, and the associated mean signal within respective ROIs as a function of α. ROI α selection was performed only for 12 slices at the base of the brain. The rest of the slices utilized standard sinc pulses during fMRI acquisition, as these slices did not show significant signal recovery with SPSP pulses. Figure 3 shows the same three slices from Fig. 2, acquired with the optimal α values chosen through the ROI analysis. Uncompensated images and spin-echo EPI images are also displayed. As shown in Fig. 3, the susceptibility compensated method detected strong as well as additional fMRI activation in the POC and OFC when compared to uncompensated method in identical general linear model (GLM) analyses. Olfactory fMRI represents a promising application for this class of SPSP pulses, which have not found widespread usage to date. An additional finding was the variability in optimal α value through the lower part of the brain. Specifically, for this volunteer, the optimal α values were close to -1.5 uT/m/Hz near the POC. The optimal α value at the base of the brain (the first row in Fig. 1) was found to vary between -1.0 to -1.12 uT/m/Hz. As such, this variability highlights the need for slice-specific values of α.

Conclusion: The approach presented in this abstract highlights the advantage of utilizing spectral-spatial pulses for susceptibility compensation when performing olfactory fMRI in the human brain. This work is relevant for neuroscience studies investigating olfactory function.

References: [1] Yip et al., "Spectral-spatial pulse design for through-plane phase precompensatory slice selection in T2*-weighted functional MRI", MRM 2009 [2] Anderson et al., "Simultaneous Multislice Spectral-Spatial Excitations for Reduced Signal Loss Susceptibility Artifact in BOLD Functional MRI", MRM 2014 [3] Karunanayaka et al., HBM 2013