Spectral-spatial pulse design for through-plane phase precompensatory slice selection in T2*-weighted functional MRI

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Introduction

T2*-weighted functional MR images of the inferior human brain are plagued by signal loss artifacts, which arise from field inhomogeneity caused by the magnetic susceptibility difference between air cavities and tissues. One way to mitigate the loss is slice selection with through-plane phase precompensation, using multi-D excitation pulses in lieu of the standard sinc pulse (e.g. [1]). In this study, we investigated a novel approach to achieve phase precompensatory slice selection using 2D spectral-spatial (SPSP) pulses [2], which can be precomputed prior to functional studies. Experiments with human subjects showed that the SPSP pulses were very effective in signal loss mitigation at different brain regions.

Theory

Phase-precompensatory slice selection relies on the assumption that magnetic field offset is spatially correlated with through-plane field gradient that causes dephasing. This assumption can be exploited by 2D SPSP pulses that possess (1) spatial selectivity for exciting a slice profile, and (2) spectral selectivity for prescribing precompensatory through-plane phase variation, whose rate is a function of frequency offset. The pulse is designed with desired SPSP pattern as shown in Fig. 1. If this pattern is excited, spins in an on-resonance slice volume flip down with the same phase, as indicated by the red dash line. Meanwhile, through-plane spins within an off-resonance slice volume flips down with different phase, as indicated by the blue dash line. The rate of phase variation in the desired pattern is determined by a design parameter. If it is properly chosen such that the through-plane phase matches the negative of that caused by dephasing during TE, spins become focused at TE and therefore signal loss is mitigated. Ideally, such phase precompensation takes place at different image regions, resulting in an image with reduced signal loss everywhere.

With an oscillatory z gradient (Fig. 2a), the SPSP pulse can be designed iteratively using conjugate gradient (Fig. 2b). A collection of such SPSP pulses, designed with different rates of phase variation, can be precomputed prior to fMRI studies. Based on current field maps or prior studies, a suitable subset of those pulses can be deployed for different slice locations.

Experiment

We compared GRE images acquired with sinc and SPSP pulses incorporated in a spiral-in-out sequence. Flip angle = 60. TE = 30 ms. One common SPSP pulse (Fig, 2), chosen empirically a priori, was used for all the slice locations. To shift the SPSP slice volume away from iso-center, we modulated the pulse carrier frequency by the z-gradient waveform (Fig. 2a) with appropriate scaling [3]. To account for off-resonance effects during readout, all images were reconstructed iteratively as described in [4]. Five subjects were scanned at 13 axial slice locations. The extent of signal loss within the brain ROI, in either the sinc or SPSP case, was quantified relative to spin-echo images at the same locations.

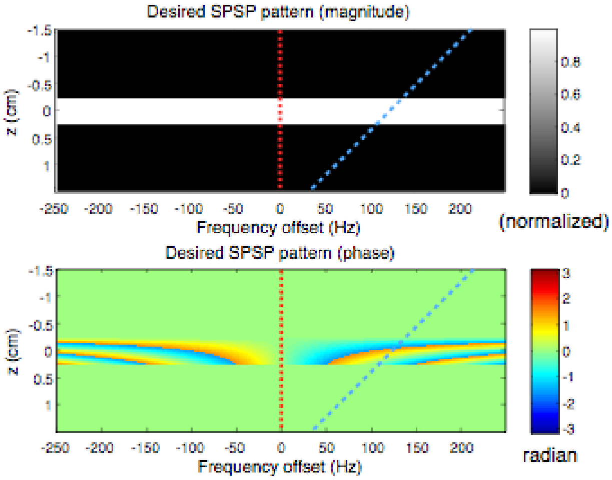

Fig. 1: SPSP desired pattern for slice selection and precompensation of through-plane dephasing. Slice profiles in on- and off-resonance brain regions are indicated by the red and blue dash lines, respectively.

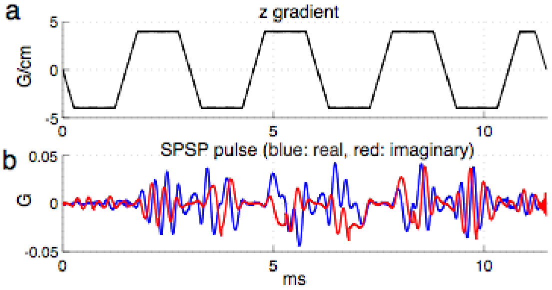

Fig. 2: The z-gradient waveform (a), with which the SPSP pulse (b) was iteratively designed for the desired pattern in Fig. 1.

Using SPSP instead of sinc pulse, signal loss was globally mitigated at different inferior brain regions in all five subjects. Image of four slices in a particular subject show significant signal recovery at the orbital frontal and inferior temporal lobes, without reduction in SNR at regions originally unaffected (Fig. 3). Within-brain-ROI voxel counts for different loss levels reflect that the SPSP pulse was robustly effective in signal loss mitigation in all five subjects (Fig. 4).

Discussion

We have shown in multiple subjects that one SPSP pulse, precomputed and properly modulated in real time, was effective in slice selection with signal loss mitigation in different brain regions, including the orbital-frontal and inferior-temporal lobes. Future works include developing a mechanism for choosing different SPSP pulses for individual slice locations based on field maps, and showing that the signal loss mitigation actually leads to boosted fMRI activation statistics.

References

1. Yip et al, MRM 56(5), 2006
2. Meyer et al, MRM 15(2), 1990
3. Zur, MRM 43(3), 2000
4. Sutton et al, TMI 22(2), 2003

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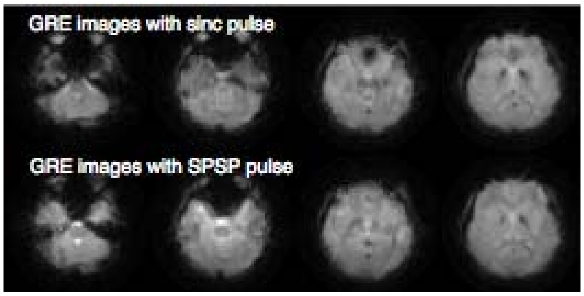

Fig. 3: Axial human brain images acquired with sinc and SPSP pulses. SPSP pulses led to signal loss mitigation in regions close to air cavities.

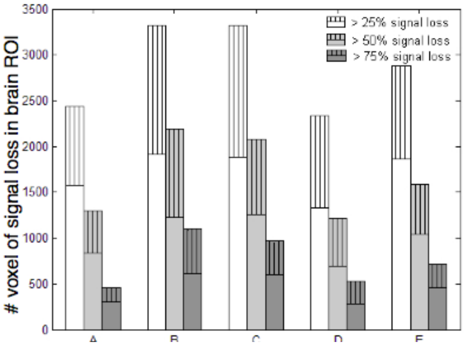

Fig. 4: Number of voxels at different loss levels in images acquired with SPSP and sinc pulses (solid: SPSP, striped: additional counts with sinc). Loss mitigation was robustly observed in all subjects.