Diagonal multi-slab inner volume 3D GRASE imaging for high resolution T2 weighted fMRI

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Introduction:

Single shot 3D GRASE [1,2] has recently enabled cortical layer-specific and columnar studies of human visual areas V1 and MT [3,4]. Despite providing T2 weighted images with high isotropic resolutions over a 3D volume and in a single shot, the technique has yet to see wide usage in fMRI in part due to its limitation of imaging only a small field of view. Multi-slab 3D approaches could extend the FOV, however when inner volume imaging is used to achieve high resolutions, the orthogonally oriented refocussing RF pulses saturate potential neighboring slabs. In many cases however, neighboring slabs are not always needed (see [5] for 2D DTI application). Here we present a method of multi-slab 3D GRASE inner volume imaging for fMRI which avoids the problem of saturated neighboring slabs and allows imaging of multiple regions of interest without extending TR and without any significant SNR penalties.

Methods:

Diagonal multi-slab (DMS) inner volume GRASE was implemented by enabling independent spatial positioning of each imaging volume's excitation and refocussing RF pulses (Fig 1). As long as the desired zoomed imaging volumes can be excited with non-overlapping RF pulses (as with diagonally aligned volumes), saturation of neighboring slabs is avoided (Fig 2-3 top). Multiple single shot slabs are acquired without extending the TR since the imaging time of a single slab is only a few hundred milliseconds while typical TRs are 2-3 seconds in T2 weighted fMRI acquisitions at high field, due to SAR and SNR constraints. However, SAR at 7T does limit DMS GRASE to 3-4 slabs.

DMS (2-3 slabs) and single-slab 3D GRASE were acquired on a Siemens 7T scanner using an 80 mT/m head gradient insert in both a Lego+water phantom and human subject. Scan parameters were TR = 3000ms, TE = 27ms (centric ordering), slices per slab = 18, voxel size = 0.8mm iso, FOV = 184 x 22.4 mm^2, bandwidth = 1810 Hz/px. BOLD responses in the subject were evoked using a 5 min, 8Hz flashing checkerboard paradigm (period = 30s). The paradigm was repeated 3 times per sequence (including gradient-echo EPI for localization of primary visual areas and positioning of slabs). BOLD contrast was calculated on linearly detrended timeseries as power of stimulus divided by mean power of non-stimulus frequencies.

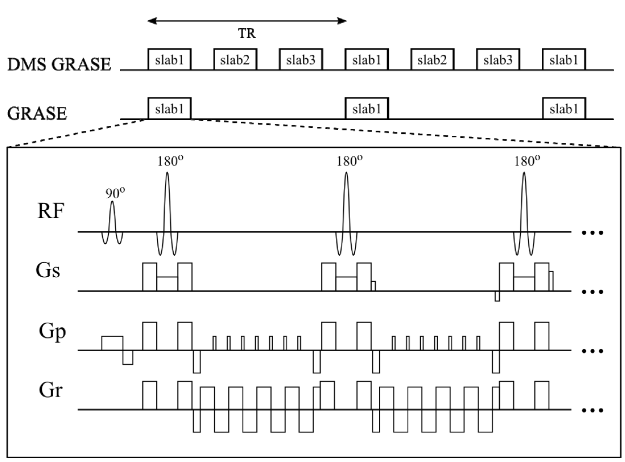

Figure 1. Diagonal multi-slab GRASE sequence diagram.

Results:

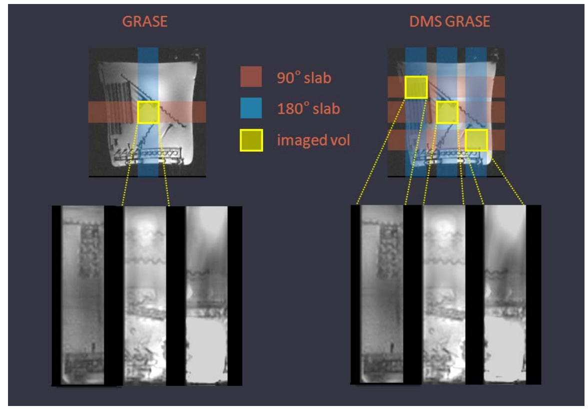

Figure 2. Phantom study: (left) GRASE example slices acquired from three separate diagonally aligned slabs requiring three separate runs. (right) DMS GRASE example slices acquired from a single run. As expected, image quality is virtually identical. Images shown are after steady state (10^{th} repetition).

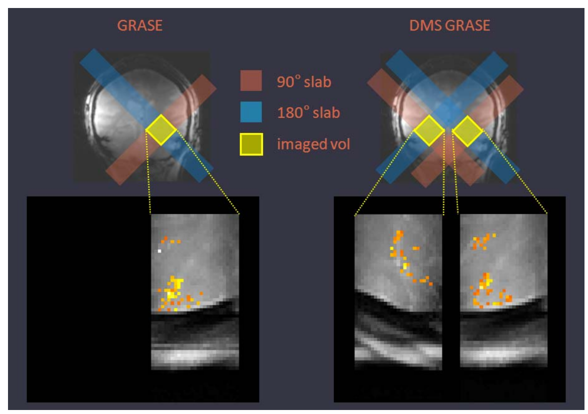

Figure 3. Human study: (left) GRASE example slice from left visual cortex overlaid with BOLD activation. (right) DMS GRASE example showing both left and right visual cortex with overlaid BOLD activation. Activations in the left visual cortex for both sequences are very similar. Activations shown are thresholded by $p<0.05$ (uncorrected) and cluster size 15 voxels.

Conclusion:

DMS GRASE allows for acquisition of multiple non-contiguous, non-overlapping slabs without increases in TR or losses in image quality. Future applications may include layer specific connectivity as well as simultaneous columnar level topographic mapping across multiple ROIs, or bilateral fMRI investigations at high resolution which will by default likely have non-overlapping excitation and refocussing planes.

References:

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