Point spread function for gradient echo and spin echo BOLD fMRI at 7 Tesla

C. A. Olman[1], P-F. Van de Moortele[1], K. Ugurbil[1]

[1]Center for Magnetic Resonance Research, University of Minnesota, Minneapolis, MN, United States

Synopsis. A perennial concern about the interpretation of BOLD fMRI data is the spatial specificity of the signal, which is expected to be impacted by the magnetic field magnitude. We have measured the point-spread function (PSF) at 7T using an established technique[1], which has previously estimated the gradient echo (GE) BOLD PSF to be 3.5 mm at 1.5T. For GE BOLD at 7T, we find two components, one with a PSF similar to that at 1.5T, and one with a PSF of 2 mm. Preliminary data for spin echo BOLD at 7T estimate the PSF at slightly less than 2 mm.

Introduction. Because the positive BOLD response is a hemodynamic response, which is detected in capillaries, venules and veins removing blood from sites of neural activity, the ability to localize neural activity using the BOLD signal may be limited by spatial averaging due to pooling of signal from a region larger than the locus of neural activity. Theoretical analyses suggest that the GE BOLD contrast at low fields (1.5T) should be dominated by signals originating in and near venuoles greater than 20 microns in diameter, resulting in spatial pooling with a point-spread function (PSF) of several millimeters. The same analysis applied to the GE BOLD signal at 7T predicts that the contrast originating from extravascular signals near very small venuoles and capillaries, absent at low fields, contributes a significant amount of the BOLD contrast at 7T. Therefore, GE BOLD should be a mixture of the capillary bed signal and the extravascular signal around larger veins; spin echo (SE) BOLD will be dominated by this capillary bed signal (pooling signal over roughly a millimeter of cortex).

Methods. Imaging was performed with a Varian console on a Magnex 7T magnet, using an actively decoupled half-volume transmit, quadrature receive coil placed behind the occipital cortex. T_2- and T_2^*-weighted images were acquired with a multi-slab, single shot spin echo sequence[2], modified to simultaneously acquire gradient and spin echo data. Stimuli were generated in Matlab and delivered via an Avotec vision system. Imaging resolution was 1mm x 1mm x 2mm. Stimuli were identical to those used in Engel et al.[1]: either one, two, three, or four rings of flashing checkerboard expanded out to a maximum 12° of eccentricity at a rate that was inversely proportional to the number of rings. The ring width (constant for each stimulus) was also inversely proportional to the number of rings, so that the temporal dynamics of the stimuli were consistent. Due to cortical magnification, visual representations of rings at greater eccentricity were closer together on the cortex, so each stimulus modulated neural activity with a cortical spatial frequency (measured in cycles per millimeter of cortex) that increased with increasing eccentricity. For each voxel within an anatomically and functionally delineated ROI, the amplitude of modulation of the BOLD response was calculated for each stimulus and cortical spatial frequency. Data were pooled across all scans and averaged, and the decrease in amplitude with increasing frequency (spatial frequency response function) was fit to a Gaussian shape. The inverse Fourier transform of this Gaussian provides an estimate of the full width at half-maximum (FWHM) of the spatial PSF.

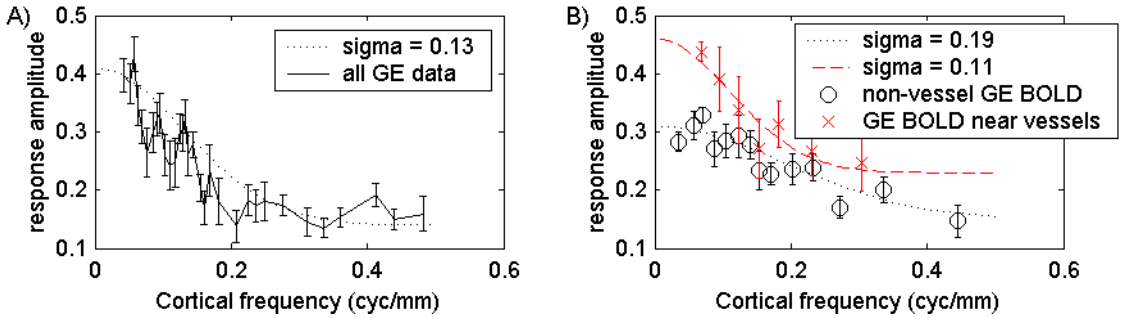

Figure 1. A) Averaging over all active voxels, the GE BOLD PSF at 7T is estimated at 3.0 mm. B) Separating out data from strongly modulated voxels (likely near veins), the PSF is estimated at 3.5 mm for the large venule/vein contribution, and 2.0 mm elsewhere. Data are shown for a second subject, but are representative of all data sets.

Results. Fig. 1A shows the estimated spatial frequency response function for the total GE BOLD at 7T. The Gaussian fit in the spatial frequency domain had a sigma of 0.13 cyc/mm; this corresponds to a spatial point-spread function with a FWHM of 3.0 mm. However, the data is composed of two components: voxels near vessels with a high response amplitude, and voxels farther from large veins. Fitting the spatial frequency response function independently for these two groups (Fig. 1B) produces an estimated PSF of 3.5 mm for the "near vein" group; the voxel group with smaller amplitude, farther away from visible veins, reveals a PSF of 2.0 mm.

Discussion. These results support the prediction that high field GE BOLD is a mixture of two components. In this study, the larger venules/vein signal comprised a smaller proportion of voxels in the GE BOLD signal, but the larger amplitude of the venule/vein-driven response dominated spatial averages of the GE BOLD response. Preliminary measurements of the point spread function for the SE signal show no evidence of this contamination, providing a uniform PSF comparable to the low-PSF component of the GE signal.

References. [1]Engel *et al.*, Cereb Cortex 7:181 (1997). [2]Van de Moortele *et al.*, *ISMRM 2003,* Abstract #988.

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