Comparison of active voxel composition using BOLD vs. VASO and VAST/GMN fMRI

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Introduction:

Functional brain studies typically measure the blood-oxygenation-level-dependent (BOLD) increase in MRI signal intensity (SI) associated with neural activity. Two inversion-recovery alternatives to BOLD-based functional imaging have been proposed, both with the goal of measuring activity-associated changes in blood volume rather than oxygenation: 1) vascular space occupancy (VASO, 1,2), in which the blood signal is inversion-nulled and SI decreases with increased relative blood volume, and 2) VASO with tissue suppression (VAST, 3), or Gray Matter Nulling (GMN, 4), in which gray matter is inversion-nulled and SI increases with increased blood volume. Both methods appeared to offer better gray matter localization of activity compared to conventional BOLD-based functional imaging. The purpose of this study was to compare the gray vs. white matter localization of VASO, VAST, and conventional BOLD-based imaging at the low spatial resolution commonly used for functional brain studies.

Methods:

Eight young adult subjects (age 23 ± 11 [SD] years, 5 female) participated in the study after giving informed, written consent. Images were acquired on a GE 3T Signa® HDx MR scanner using a standard 8-channel clinical head coil. Block-design visual stimulation was provided by a flashing checkerboard display (8Hz, 4 cycles of 24 s duration, flanked by 36 s duration black screen). Axial one-shot gradient-echo echo-planar images (TR=4000 ms, 90^o pulse, 22 cm FOV, 64x64 matrix, 4 mm slice) were acquired from a single slice during this task by each of the following sequences: 1) conventional BOLD, TE=35, no inversion pulse, 2) VASO, TE=17 ms, TI= 994 ms, and 3)VAST/GMN, TE=17ms, TI = 746 ms. In order to estimate the relative contribution of CSF, gray, and white matter to each voxel, the same slice was imaged at the same spatial resolution (8-shot echo-planar, TR/TE=4000/9) at eight different TI's ranging from 521 to 3500 ms. Assuming perfect inversion and ignoring T_2 relaxation, the total signal, M_T, from any voxel with i components at inversion time TI and repetition time TR is $M_T = \sum_i M_i (1 - 2\exp(-TI/T_{1i}) + \exp(-TR/T_{1i}))$, where M_i is the magnitude and T_{1i} is the T_1 of the i'th component. This system of equations for the 8 TI's and 3 components [CSF (T_1= 3817 ms), white matter (758 ms), and gray matter (1127 ms)] was solved by the NNLS algorithm on a voxel-by-voxel basis. Voxels activated by visual stimulation were identified by cross-correlation vs. an idealized on-off waveform using AFNI (5) software (threshold $r>0.42$, $p<0.02$). The average composition of the voxels judged active was then computed for the three methods.

Results and Discussion:

Figure 1 shows the Talairach averaged location of active voxels overlaid on an averaged high resolution anatomical image (Fast GRE, TR/TE/TI = 4.4/1.1/500, 256x192 matrix, 1.5 mm slices) using the 3 methods. As expected from previous studies (1,3,4), the number of active voxels achieving statistically-significant activity was greater for BOLD compared to either VASO or VAST/GMN (Table). However, only a subset of voxels was judged active by both VAST and VAST methods (Figure 1, Table, VASO&VAST). Figure 2 shows the voxel composition map obtained by the multiple inversion method for a representative subject. Surprisingly, the contribution of white matter to active voxels not significantly different for BOLD vs. VASO at the spatial resolution of this study. VAST/GMN appears to be better localized to predominantly gray matter voxels (Table). However, this advantage is illusory, because it depends on only counting voxels active in which there was a positive correlation between SI vs. the task waveform. At the TI which nulls gray matter, white matter has recovered, but blood is still inverted. Therefore, increased blood volume in voxels containing substantial white matter results in decreased voxel SI using the VAST method. We conclude that at the low spatial resolution typical of functional brain studies, the gray matter localization of VASO and VAST/GMN are not significantly better than that of conventional BOLD.

References:

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Table (mean ± SE, n=8)

Method	# Active Voxels	% white matter
BOLD	115 ± 13	20.8 ± 2.0
VASO	30 ± 6	17.2 ± 3.3
VAST	42 ± 5	7.6 ± 1.6
VASO&VAST	14 ± 2	8.2 ± 2.0

Figure 1. Location of active voxels during visual stimulation.

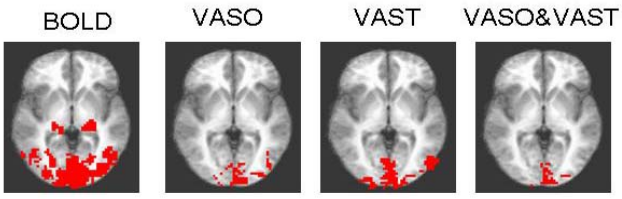

Figure 2: Representative Voxel Composition Maps