Retinotopic Mapping of Human Visual Cortex using Arterial Spin Labeling

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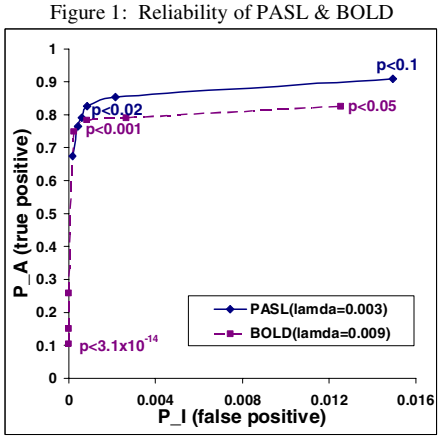
INTRODUCTION: Retinotopic organization of early visual cortex has been extensively studied using various techniques, including electrophysiological recording (1), ^{14}C-2-deoxy-d-glucose technique (2) and recent non-invasive BOLD (3-5) and VASO (6) fMRI techniques. BOLD offers high sensitivity which allows for advanced brain mapping, but is susceptible to large draining vessel contamination and therefore results in low spatial specificity. Compared to BOLD, ASL targets signal changes restricted to the arterial/capillary site and therefore might be more closely related to neuronal activity (7-8). Therefore ASL might provide complementary data and potentially may even result in more accurate retinotopic map. We acquired human retinotopic mapping using both pulsed ASL (PASL) fMRI (9) and BOLD fMRI and compared them.

METHODS: Stimuli: Horizontal and vertical wedges were presented in an interleaved fashion (switch every 36 second) to subject with his/her gaze on the fixation cross in the center of screen. Stimuli parameters were: black-white flashing checkerbroad, 8 Hz contrast polarity reversal rate, 30° degree polar angle width, 45° visual angel from fixation. MR protocol: Functional data of three subjects were acquired on a 3-T scanner (Siemens Trio) using 8-channel array head coil for reception and body coil as transmitter. PASL sequence was adopted from Dr. Wang, UPenn. Sixteen axial slices (4mm-thick, no gap) covering entire visual cortex, were acquired with parameters of TR = 3s (effective TR = 6s), labeling duration = 800ms, post-labeling delay = 1s, TE = 19ms, FOV = 20cm, matrix = 64X64, flip angle = 90° and acquisition = 120 volumes (6min). To test reliability of functional data, four PASL scans with identical setting were performed. For retinotopy study, each PASL run was repeated once to improve SNR. One BOLD run (TR = 3s and TE = 45ms) was also acquired with other parameters save as above. Anatomical (1mm isotropic 3D-MPRAGE) data were acquired on the 3T scanner using a standard head coil in order to avoid difficulty in segmentation caused by white matter signal inhomogeneity. Data analysis: Online motion correction and offline Talairach transformation were used for data preprocessing. Matlab SPM2 (Wellcome Department of Neurology, London, UK) was used to perform pairwise subtraction for perfusion data. BrainVoyager (Brain Innovation, the Netherlands) was used to segment, inflate and flatten anatomical cortex by applying cut on calcarine sulcus, and to generate functional activation map. General linear model (GLM) – derived activations were overlaid on flattened cortex as shown below, with yellow-red corresponding to horizontal wedge stimulation and green-blue corresponding to vertical wedge stimulation. Since early visual areas border each other with a mirrored representation of the visual field at the horizontal and vertical meridians, black lines were manually drawn in the center of activations to demarcate the boundaries.

RESULTS & DISUSSIONS: Figure 1 shows the ROC curves (10) for functional activation of single subject using PASL and BOLD contrasts. P_A and P_I denote for the probability that a truly active or inactive voxel is classified active, respectively. From the plot, we observe that the reliability of PASL data was comparable to BOLD data. In the region where P_I is smaller than 0.0004 and statistical threshold is very low, BOLD data seems to be slightly better due to its higher sensitivity, but when P_I gets larger, PASL data are superior in terms of detecting truly activated voxels, possibly because BOLD signal is generally more variable. The optimal thresholds of this dataset lie near the "knee" on curves: approximately p<0.02 for PASL and p<0.001 for BOLD. This suggests that it is appropriate to use lower threshold (higher p value) for PASL, relative to BOLD. Note we used BOLD data generated from PASL sequence (pairwise averaging) here. Figure2 shows the retinotopic maps obtained from both PASL and BOLD contrast. The activation locations and patterns of BOLD and PASL are quite similar, with threshold level of p<0.01 for BOLD and p<0.05 for PASL. Visual boundaries, including dorsal and ventral V1 and V2, V3 and VP, as well as V3A and V4V, were delineated successfully using both fMRI methods. Perhaps due to this particular subject, the activation corresponding to horizontal wedge in V3A of right hemisphere was not clearly detected under above thresholds for both fMRI methods, it somewhat demonstrates the detection consistency between BOLD and PASL. The average overlap between activated voxel coordinates in PASL and BOLD, with their total voxel counts matched, is about 65%. In V1, overlap is up to 96%. In order to accurately delineate boundaries, field sign map which requires both polar angle and eccentricity experiments might be needed. Adding one or two repeats for PASL run might improve the detection sensitivity. To our knowledge this is the first human retinotopic map generated with arterial spin labeling method, which may provide complementary information upon further investigation.

Figure 1: Reliability of PASL & BOLD



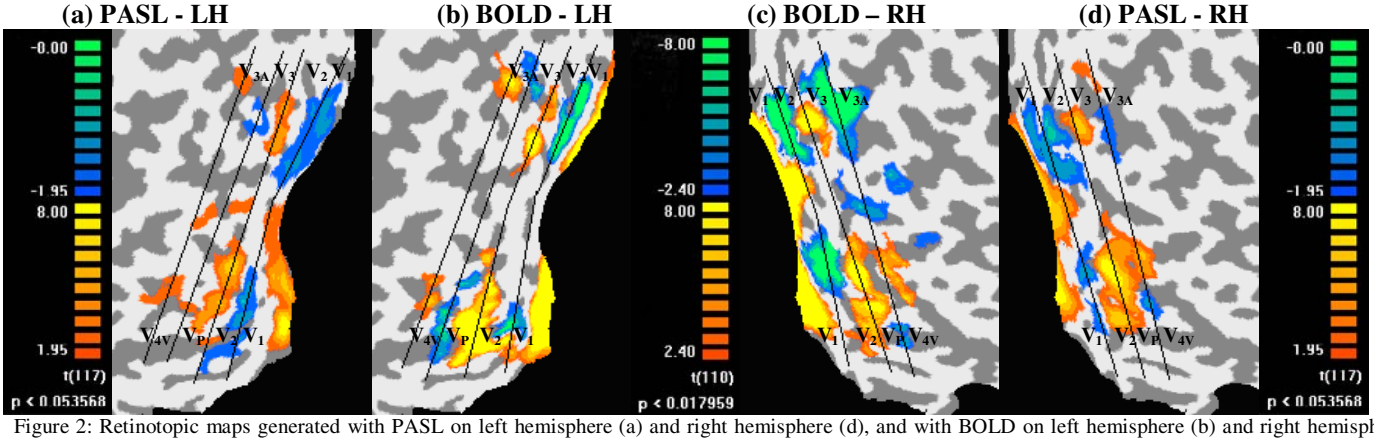


Figure 2: Retinotopic maps generated with PASL on left hemisphere (a) and right hemisphere (d), and with BOLD on left hemisphere (b) and right hemisphere (c). Borders between different early visual areas (V1 – V4V) were drawn manually with black lines.

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