505-04-003 ISMRM ABSTRACT

Whole-brain, cerebral blood volume weighted imaging optimized for the study of cortical networks on NexGen 7T scanner

Primary: Brain Function and fMRI - Functional Connectivity 〉 **Secondary:** Physics & Engineering - High-Field MRI 〉 **Oral** · 11 min | Mesoscale Functional MRI · Wednesday, 13 May, 4:22 PM–4:33 PM · Session: 4:00–5:50 PM · Ballroom West 〉 **Keywords:** VASO HIGH PERFORMANCE GRADIENTS FUNCTIONAL MRI ULTRA HIGH FIELD FUNCTIONAL NETWORK CONNECTIVITY

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Impact

Recent advances in hardware and sequence optimization allow for whole-brain CBV weighted imaging with sufficient temporal resolution for functional connectivity studies.

Synopsis

Motivation: Previous implementations of whole-brain CBV weighted VASO were limited by spatially low-frequency ghosting ("fuzzy ripples") caused by eddy currents, which prevented the use of high-acceleration factors.

Goals: Recent advances in the mitigation of these fuzzy ripples should enable the collection of whole brain, layer resolution CBV VASO with higher acceleration.

Approach: Using this newly achievable, high acceleration coupled with the fast image readout achievable by the NexGen 7T, we were able to collect whole-brain layer-fMRI images with a TR of 5s.

Results: This data allowed cortical depth-dependent, brain networks to be resolved and investigated using functional connectivity analyses.

Introduction

Mapping functional brain circuits at the levels of cortical columns and layers requires mesoscale (submillimeter) resolution, with sufficient temporal resolution to measure relevant signals, and a functional imaging contrast specific to the area and depth of cortical activity. While recent advances have allowed for laminar imaging in limited field of view slabs, meeting these criteria with whole-brain coverage is technically challenging, with previous approaches being limited in their achievable temporal resolution1,2.

In this study, we leverage the Next Generation (NexGen) 7T scanner, specifically designed for high-resolution cortical neuroimaging3, to fully optimize our approach. The dedicated hardware of the scanner allows us to achieve cerebral blood volume (CBV) weighted functional imaging using VAscular Space Occupancy (VASO)4, with whole-brain coverage, submillimeter resolution and sufficient temporal resolution to reveal cortical networks in a movie watching paradigm5,6.

Methods

Data were collected from three subjects on the NexGen 7T MRI scanner3 using an 8-ch transmit, 64-ch receive array coil7. Images were acquired using a Skipped-CAIPI8 3D EPI VASO4 sequence, with a dual-polarity readout to correct for the "fuzzy ripple" artifacts seen when pushing to high resolutions, image acceleration factors and imaging bandwidths9,10. VASO scan parameters were: 0.85mm isotropic resolution, whole volume TR 5s, TE 16.2ms, TI 1128.5/3071.6ms, Partial Fourier 7/8, Skipped-CAIPI 4x4z2 (total acceleration 16), Bandwidth 1766 Hz, Echo Spacing 0.63ms. Participants undertook 3-4 runs (45-60 min) of a movie watching task (using a 15-min collection of movie clips from the 7T HCP study (a.k.a. MOVIE1))5. Data were denoised using NORDIC11,12, motion corrected using ANTS13, and the fuzzy-ripple artifact was removed using the dual-polarity read-out calibration approach10. Blood-nulled and not-nulled (BOLD) timeseries data were used to create a BOLD-corrected VASO timeseries after temporal upsampling to an effective volume TR of 2.5s. The temporal mean of the T1-weighted VASO images were used for tissue segmentation using Freesurfer, the gray-matter ribbon was exported to functional space using SUMA, and cortical depth (layers) and distance (column) ROIs were generated using LayNII14. After averaging across runs, MELODIC ICA was run on the BOLD and VASO time-series at the subject level.

Subsequently, whole-brain connectomes were defined to assess known patterns and novel layer-specific features of functional brain organization. Data were denoised using regression (aCompCor, 6 motion regressors), scrubbing and band-pass filtering (0.008–0.1 Hz), and concatenated across runs. Time-series were averaged for three layers (deep, middle, superficial) of 25k cortical columns (max distance between points 2.5 mm), and connectivity was measured by pairwise correlations. VASO and BOLD networks were then assessed based on the presence of sensory-associative connectivity gradient via diffusion map embedding15, connectivity density mapping16, connectivity with large-scale networks, and the similarity of network fingerprints across the three layers. Large-scale networks were estimated based on 7 network seeds of a probabilistic atlas (62% threshold, right hemisphere only)17.

Results

Images collected using the optimized sequence showed high levels of detail without artifacts following dual-polarity correction (Figure 1). The expected components from movie watching could be resolved in the BOLD time-series, and in the VASO time-series after a moderate amount (1mm FWHM) of within-layer smoothing (Figure 2), demonstrating that this approach can be used to study whole-brain networks and circuits.

Both VASO and BOLD data showed firmly established organization of the sensorimotor-association (SA) axis (Figure 3A) and high centrality in the association cortex (3B). In these associative areas, connectivity density was also predominantly stronger in the superficial than deep layers using both VASO and BOLD, consistent with previous layer-fMRI reports suggesting a superficial layer emphasis in network communication of frontal regions2,18,19. Putative layer-specific features emerged from network correlation analysis, where cortical depths sometimes mapped preferentially to different large-scale functional networks (3C) and in the similarity of network connectivity across depths (3D). With BOLD alone, it would be unclear how much of these patterns are driven by neural connectivity or large vein biases. Having vein-free VASO available here can augment the interpretation of these results.

Discussion & Conclusion

Previous implementations of whole-brain, high-resolution functional imaging using CBV contrasts to maintain functional specificity have been limited by the complexity of balancing the requirements of coverage, resolution and functional contrast. Combining the hardware of the NexGen 7T with novel sequence readout approaches, we were able to collect whole brain, high-resolution VASO data at temporal resolutions sufficient to resolve common functional networks, and to investigate layer-connectivity within these networks. Future work will focus on how to best investigate layer-connectivity profiles across the brain, and fully evaluate the relative advantages of VASO for these methods.

Acknowledgements

Research supported by the BRAIN Initiative (National Institutes of Health (NIH) grant nos. U01-EB025162, R01-MH111444 and U24-NS129949), NIH grant R44-MH129278, Weill NeuroHub and the Chancellor's Office of UC Berkeley.

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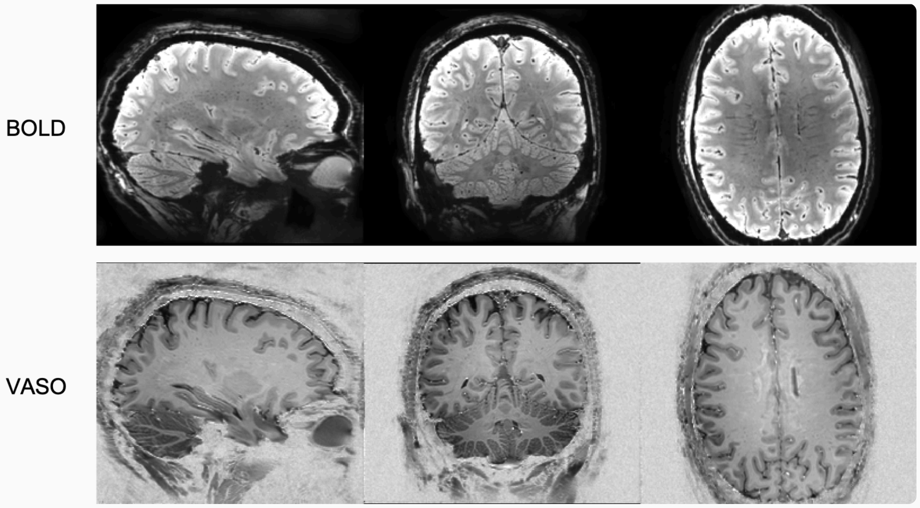
Figures and Tables



Scan for high-resolution version

Figure 1: *Temporal mean (1hr of scanning) of BOLD and VASO timeseries after dual-polarity correction for fuzzy ripples.*

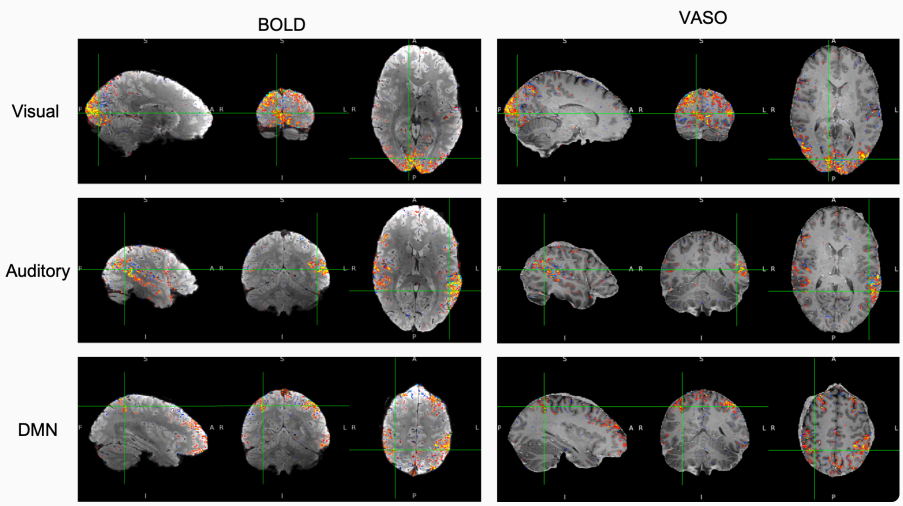


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Figure 2: *Example components from ICA analysis of BOLD data (left), and VASO data after moderate within layer smoothing (right). Corresponding components can be found in both datasets.*

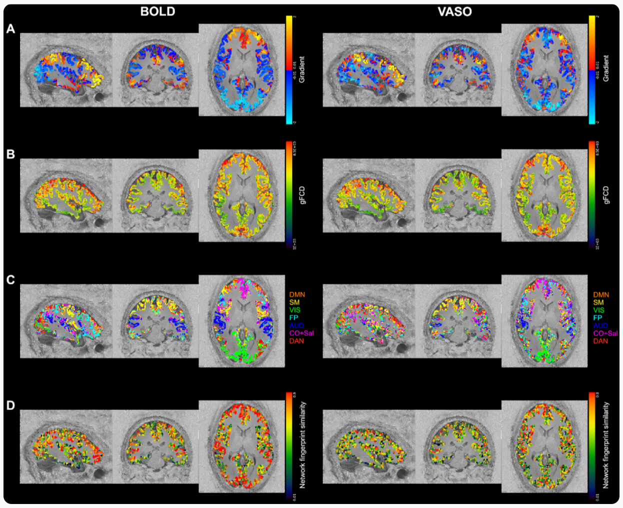

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Figure 3: *Characterization of the whole-brain layer-connectome using VASO and BOLD in an example participant. (A) SA axis from gradient analysis across columns. (B) Global functional connectivity density, showing expected high centrality in the association cortex. (C) Winner-take-all network mapping showing strongest network correlation per column-layer-ROI. (D) Functional network fingerprint similarity across the three depths per column.*