Functional MRI Mapping of Laminar Structures in Cat Lateral Geniculate Nucleus

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Introduction Lateral geniculate nucleus (LGN) is the most important component in the thalamus in relaying visual information flow from the retina to primary visual cortex (V1). LGNs in primate, human and cat all have laminar structures, in which cells receive monocular inputs from one eye and send them to V1 with well-organized retinotopic relationship. Hence, the ability of mapping laminar structures in LGN *in vivo* is of critical importance in providing detailed information of visual streams and revealing the mechanism underlying many neuroscience phenomena such as binocular interaction and binocular integration. In this study, we explored the feasibility of mapping laminar structures in cat using high-resolution functional magnetic resonance imaging (fMRI).

Method Cats were anesthetized with 0.9-1.2% isoflurane in a 70%N_2O/30%O_2 gas mixture. The fovea area of the cat retina was located with the aid of a fundus camera (Zeiss, Germany) ensuring that the cat eyes were focused on the visual stimulus. The head position of cat was fixed by a homebuilt head-holder with mouth-bar and ear-bars. Visual stimulation presented as diffusive light flashing at 4Hz was generated by a pair of red LED goggles (Grass Instruments, Quincy, MA). All the fMRI studies were performed on a 9.4T horizontal magnet (Magnex Scientific, UK) interfaced with a Varian INOVA console (Varian Inc., Palo Alto, CA). The multi-slice T_1-weighted anatomical images were acquired first to ensure appropriate choice of slices located at LGN. Then, single-slice gradient echo planar images (TE/TR = 14/2468 ms, FOV = 5×5 cm^2, 391μm×391μm in-plane resolution, 4segments, 1 mm slice thickness) were acquired in fMRI studies using a block design. CBV-weighted fMRI images were obtained after an intravenous injection of monocrystalline iron oxide nanoparticles (MION). Every run is composed of a left-eye stimulus block and a right-eye stimulus block (15 images per block) interleaved by three control blocks (15 images per block) when cat was in uniform darkness during control blocks. 20-24 runs were acquired for each experiment. The BOLD/CBV amplitude maps for left-eye stimulus and right-eye stimulus conditions were separately generated for all the activated pixels. The final LGN laminar map was created using the subtraction method[1] based on the amplitude maps.

Results Figure 1a shows the mapping of LGN laminae using BOLD-based and CBV-based fMRI, respectively. Both maps successfully differentiate individual LGN layers (A, A1, C_M), that receive inputs from contralateral eye (for the layers A and C_M) or from ipsilateral eye (for the layer A1 with a much smaller laminar size). The majority of LGN volume comes from contralateral-eye laminae[2]. The morphology of the mapped laminae is conformed to the histology of the LGN laminae in cat[3]. Figures 1b and 1c demonstrate the maps generated using a half of BOLD and MION data, respectively. Maps from each half of data resemble each other, indicating that the fMRI map is highly reproducible. Averaged reproducibility rates were 77% and 88% for BOLD and MION maps, respectively. Figure 2 shows the BOLD and MION time courses from the activated right-eye and left-eye laminae at the right-eye stimulation and left-eye stimulation conditions, respectively. Significant residue BOLD signal can be clearly observed at right-eye laminae during left-eye stimulation. Similar situation can be observed at left-eye laminae during right-eye stimulation. These residues yet do not show up in the MION time courses. The residual signals observed in BOLD data result from the 'bleeding' signal from the neighboring laminae. These data collectively suggest that the point spread function of BOLD signal is significantly wider than CBV signal.

Conclusion The present work demonstrates the feasibility of mapping LGN laminae using high-resolution fMRI. Both BOLD and CBV data successfully differentiate individual laminae in LGNs. The maps generated using BOLD and MION signals are highly reproducible. In addition, the results suggest CBV signal has significant narrower point spread function or better spatial specificity for mapping activation in small laminar structures compared to BOLD signal measured by GE EPI.

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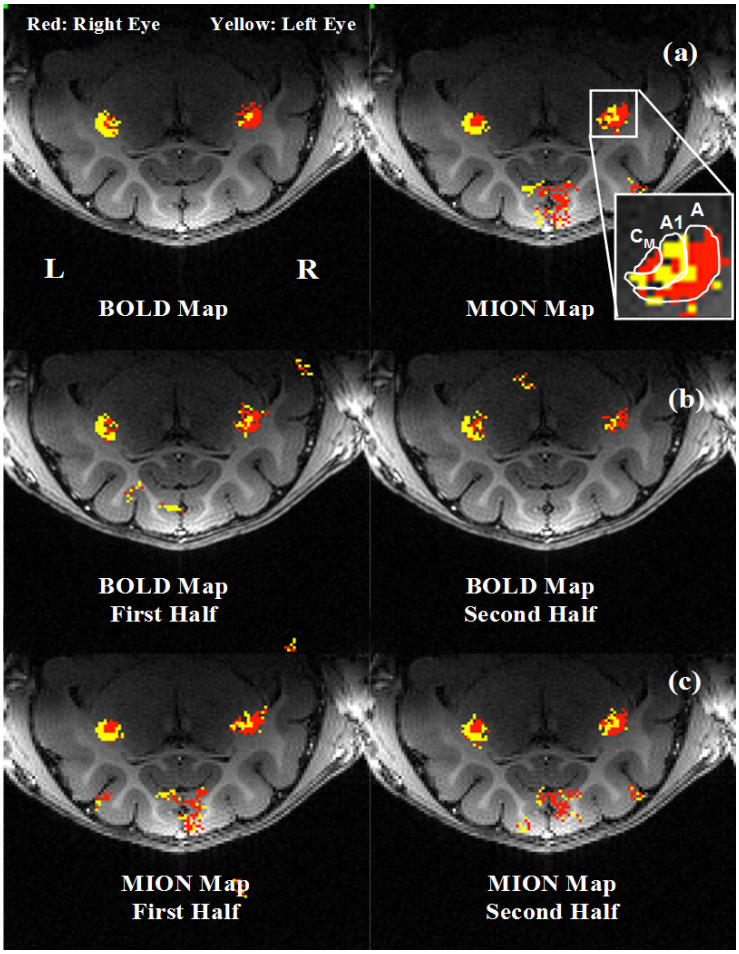

Figure 1. Mapping LGN laminae. (a) LGN laminae maps generated using BOLD and MION data. (b) Examination of reproducibility of LGN mapping using BOLD signal. (c) Examination of reproducibility of LGN mapping using MION signal.

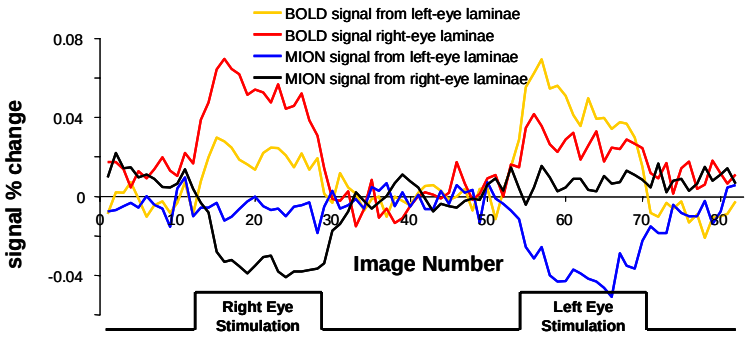

Figure 2. The BOLD and MION time courses from right-eye and left-eye laminae at the right-eye stimulation and left-eye stimulation conditions, respectively.

References: 1. Cheng, K. et al Neuron 2001. 2. Lee I. et al Anat Rec 1999. 3. Synider, RS and Niemer, WT, A stereotaxic atlas of the cat brain.