High-resolution fMRI Mapping of Cat Thalamocortical Network involving Visual Sensory System

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Introduction The unique advantages of high sensitivity and specificity of fMRI at high fields enable one to image the brain activation in small subcortical nuclei in human brain [1]. This capability is essential for mapping and studying the large-scale neural networks covering both cortical and subcortical brain structures. In this study, we explored the feasibility of using high-resolution fMRI for mapping the brain activity in the lateral geniculate (LGN), pulvinar (PL) and colliculus superior (CS) nuclei along with the visual cortical area (V1) during the visual stimulation in the cat brain, which is a well-established animal model for vision study. The detected functional activations in these brain structures constitute a thalamocortical network related to the visual sensory system in the cat. Additionally, we studied the binocular inhibition in cat V1 and LGN by comparing the BOLD responses of binocular vs. monocular visual stimulations. Our results show the robustness of fMRI for mapping neural activity. We also found a much larger BOLD change in LGN than V1, and strong binocular inhibition in both LGN and V1.

Method Gaseous anesthesia (isoflurane (0.9-1.2 %) in a mixture of 70% nitrous oxide and 30% oxygen) was applied to anesthetize the cats for fMRI studies. The fovea area of the 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 head-holder with mouth-bar and ear-bars. The visual stimulus consisted of two red LED matrix boards with large view angles allowing either binocular or monocular visual stimulation at 8 Hz flicking frequency. 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 multiple-slice T_1-weighted anatomical images were acquired first for identifying the appropriate image slices and brain structures of the cat visual system. Then, the multiple-slice and multiple-segment gradient echo planar images (GE EPI) (TE = 17.5 ms, FOV = 5×5 cm^2, 390μm×390μm in-plane resolution and 1 mm slice thickness) were applied for fMRI studies using block paradigm design (4 control and 3 task periods with 8 images per period in an interleaved way). Each fMRI run consisted of three visual tasks (one binocular and two monocular stimulations) in a random arrangement. Multiple fMRI runs were performed in each cat for signal averaging.

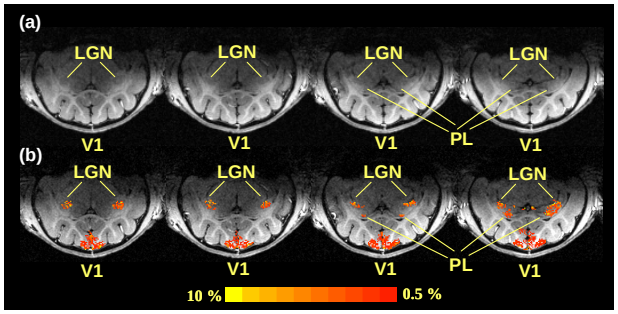

Fig. 1 Multiple-slice anatomic images (a) and fMRI maps (b) from a representative cat brain. The nuclei and visual cortex location and the corresponding activities detected by fMRI are identified. LGN: lateral geniculate nucleus, PL: pulvinar nucleus, V1: visual cortex.

Results Figure 1a shows four adjacent anatomic images (in the coronal orientation) from a representative cat. The imaging quality and contrast were superior for identifying the brain structures in both cortical (e.g., V1 areas) and subcortical nuclei (e.g., LGN and PL). Figure 1b illustrates the high-resolution fMRI maps from the same imaging slices and cat brain as illustrated in Fig. 1a, showing robust activation in the LGN and PL nuclei bilaterally and the V1 areas across multiple imaging slices (4 slices for LGN and V1, and 2 slices for PL) during the binocular visual stimulation. Additionally, the activation in CS on other imaging slices (not shown in the figure) was also reliably detected. The activated sites in the fMRI maps are in excellent agreement with the brain structures identified by the anatomical images and brain atlas. Figure 2 demonstrates the summarized results showing the averaged BOLD changes in the activated LGN and V1 areas, respectively, in the same cat. It reveals that (i) the BOLD change in LGN was approximately *two times* higher than that in V1 for both binocular and monocular visual stimulations; (ii) the sum of the averaged BOLD changes of left-eye and right-eye stimulations was significantly larger than the averaged BOLD change elevated by the binocular stimulation.

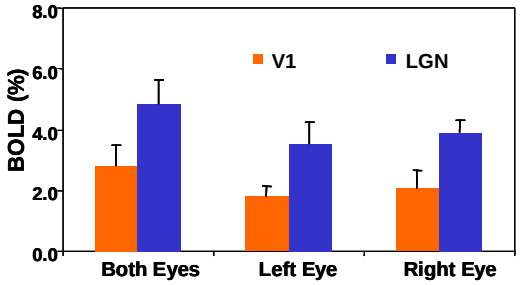

Fig. 2 Averaged BOLD amplitudes detected in LGN and V1 during binocular (both eyes) and monocular (left eye and right eye, respectively) visual stimulations.

Discussion and Conclusions Our results indicate that the high-resolution fMRI at high field is useful and robust for mapping and studying the thalamocortical network involving a large number of subcortical nuclei and visual cortical areas in the cat brain. It is interesting to note that the fMRI detection of LGN activation in cats is even more robust than that of V1 activation in contrast with the human brain in which the V1 activation was much easier to be detected [2]. One reason attributing to this observation is the much larger BOLD change in the cat LGN. This may indicate the differences in the hemodynamic and metabolic responses in these two brain regions during the visual stimulation. We had demonstrated a binocular competition between the left-eye and right-eye ocular dominance columns (ODCs) leading to an inhibition in one eye ODC in the human primary visual cortex by using the dynamic fMRI approach [3, 4]. The results from this new study reveal that the similar binocular competition not only exists in the cat ODCs in V1 but also extends to the early visual processing stage in the multiple layers of LGNs. This finding should have an important impact on the understanding of the neural mechanisms underlying vision and the large-scale neural networks linking cortex and thalamus. Finally, the combination of the cat model and high-resolution fMRI should provide a vital tool for noninvasively studying the vision science.

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