Distinct Characteristics of Brain Activity in Cat V1 and LGN in Response to Flicking and Grating Visual Stimuli: A fMRI Study at 9.4T

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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 sub-cortical nuclei in human brain[1]. We have recently demonstrated the feasibility of high-resolution fMRI at 9.4 tesla for reliably mapping the thalamocortical activation in the cat visual sensory system, which provides a well-established animal model for vision science[2]. The detected functional structures include the lateral geniculate (LGN), pulvinar (PL) and colliculus superior (CS) nuclei along with the visual cortical (V1) during the visual stimulation, that constitute a thalamocortical network related to the visual sensory system in the cat. In this study, we have applied the same fMRI technique to investigate the dependence of neuronal activity in both LGN and V1 on the type of visual stimulus. Two visual stimuli (flicking and grating stimuli) were used for this study. Our results illustrate significantly distinct characteristics of brain activity between LGN and V1 in response to the flicking and grating visual stimuli indicating that the grating stimulus may be an optimal stimulus for achieving large brain activation in both LGN and V1.

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 home-built head-holder with mouth-bar and ear-bars. There were two binocular visual stimuli used in this study: (i) high-contrast square-wave drafting gratings (0.3 cyc/deg and 2 cyc/sec) and (ii) flicking red LED boards at 2-4 Hz 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 multi-slice T_1-weighted anatomical images were acquired first for identifying the cat LGN and V1 for appropriately choosing fMRI image slices. Then, the multi-slice gradient echo planar images (TE = 17.5 ms, FOV = 5×5 cm^2, 790μm×780μm or 390μm×390μm (4 segments) in-plane resolution, 1 mm slice thickness and 4-5 adjacent coronal images covering both LGN and V1) were applied for fMRI studies using a block paradigm design (3 control and 2 task periods in an interleaved way). Multiple fMRI runs were performed in each cat for signal averaging and the fMRI maps were generated by using the period-cross correlation method. In addition, the superparamagnetic particle (MION) was used for imaging and quantifying CBV using the similar visual stimuli.

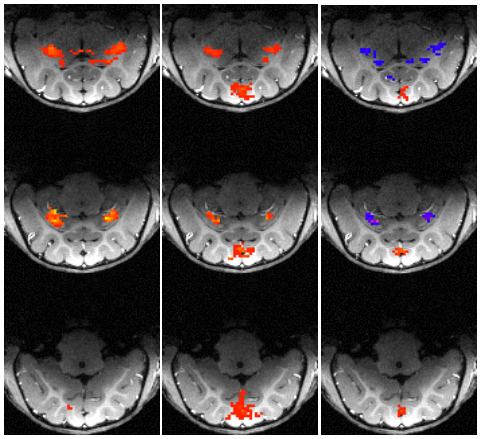

Fig. 1 Functional MRI Maps of activation in LGN and V1 using visual stimuli of flicking LED (a), moving grating bar (b) vs. dark control; and flicking screen vs. moving grating (c) in a representative cat.

Results Figure 1 illustrates the fMRI maps from three representative imaging slices acquired from one cat showing the activation areas in LGN and V1 during the flicking (a) and grating (b) visual stimulation versus the dark control. It clearly shows comparable BOLD changes in LGNs (and PL) in response to the two visual stimuli, although the LGN activation is significantly stronger for the flicking stimulus (averaged BOLD = 3.0% and 86 activated pixels, n=3) compared to the grating stimulus (averaged BOLD = 2.1% and 48 activated pixels, n=4) for the same cat as presented in Fig. 1. In contrast, the magnitude of the activation in V1 is much stronger for the grating stimulus (averaged BOLD = 2.1% and 157 activated pixels, n=4; *vs.* averaged BOLD = 1.9% and 6 activated pixels, n=3). Figure 1c shows the fMRI maps from the same cat by using the interleaved flicking and grating visual stimuli without dark control periods. In these maps, the blue-colored pixels indicate that the activation by the grating stimulus is weaker than the flicking stimulus, and the red-colored pixels present that the activation by the grating stimulus is stronger than the flicking stimulus. These results reveal an opposite trend of BOLD changes in LGN and V1 in response to two different visual stimuli, and the same trends were consistently observed in other cats as well. Figure 2 demonstrates the comparison between BOLD- and CBV-based fMRI maps from another cat during two visual stimulations. It clearly shows (i) comparable activation location and sizes between the BOLD and CBV maps, and (ii) the same relation as demonstrated in Fig. 1.

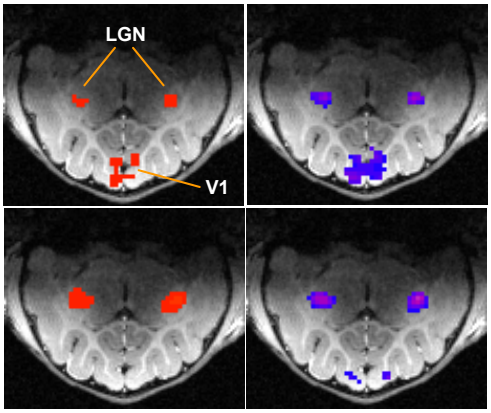

Fig. 2 BOLD (left column) and CBV (right column) based fMRI maps obtained using grating (top row) or flicking (bottom row) stimuli in another cat.

Discussion and Conclusions During a visual stimulation, LGN receives and processes the visual inputs from retina first and then projects the visual information to V1. Thus, any visual perception (or stimulation) must activate LGN in the thalamus and then the cortical V1 areas along the thalamocortical network in the visual sensory system. However, the characteristic for processing visual information can be significantly distinct between different visual processing stages, such as LGN and V1. The fMRI mapping results in this study show clearly the dissociated BOLD changes in LGN and V1 elevated by flicking and grating stimuli. The different BOLD behaviors in LGN and V1 are unlikely due to the differences in the mismatched the hemodynamic and metabolic changes in different brain regions. This notion was supported by the observation showing the same BOLD- and CBV-based fMRI maps (see Fig. 2) for the same visual stimulus. Therefore, the detected BOLD response should directly reflect the local brain activity. Our results reveal that the grating stimulus is more efficient for stimulating the neurons in the cat visual cortex than the flicking stimulus. This conclusion is consistent with the electrophysiological studies indicating that the cells in cat V1 gave the largest response to gratings[3,4]. In contrast, the flicking stimulus leads to a strong neuronal activity in LGN indicating that neurons in LGN can be more sensitive to the "on-off" type of visual stimulation. Finally, the combination of the cat animal model and high-resolution fMRI should be useful for noninvasively mapping brain activation covering both thalamocortical nuclei and surface cortical areas and for addressing neuroscience questions regarding to vision science.

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