BOLD signal differences in the somatosensory and visual pathways

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Introduction. Modern functional neuroimaging methods such as functional magnetic resonance imaging (fMRI), have relied on the coupling between neuronal electrical activity and regional cerebral metabolic and hemodynamic changes to map neuronal activation. Despite the rapid evolution in application of neuroimaging methods as research and clinical tools to study the organization of the brain, there exists a wide gap in knowledge of how modulations in cellular metabolic and local hemodynamic properties that are detected by functional imaging methods are related to the underlying neuronal electrical activity.
In order to examine the local differences in BOLD signal, fMRI data were obtained from awake rabbits using either whisker or visual stimulation, and the BOLD responses in cortical and subcortical structures of the pathways were compared within and between each sensory system. Simultaneous fMRI and in vivo electrophysiology were used in the awake rabbit to investigate the relationship between the local hemodynamic functional signal and the corresponding neuronal activity.
Methods. Each Dutch-Belted rabbit in this experiment was chronically implanted with a restraining headbolt [1] and manipulator containing one bundle of 4 microwire gold-silver electrodes aimed at the whisker barrel cortex. MR imaging experiments were performed on a 9.4T Bruker BioSpec imaging spectrometer. fMRI data were acquired from four consecutive slices using a single-shot gradient-echo EPI pulse sequence (TR=2s and TE=13ms) with a 1 mm slice thickness and a 375x375 μm^2 in-plane resolution. The slices included the whisker barrel cortex and whisker thalamus for whisker stimulation and visual cortex, superior colliculus and lateral geniculate nucleus for visual stimulation. Neuronal activity in the whisker barrel cortex was recorded using the Neuralynx system. Data were analyzed after removal of blocks of gradient interference.
The visual stimulation consisted of four LEDs flashing at 8 Hz for a duration of 20 s. The whisker vibration was generated by a 15mm-diameter, six-turn, circular coil attached to a fiber band and driven by an alternating current produced by a function generator at 75Hz. Whiskers were attached to the fiber band using mildly adhesive tape. 2-3 adjacent whiskers were stimulated in each experiment. The vibration stimulus amplitude and frequency were kept constant at ±0.75 mm and 75 Hz, respectively, and monitored in real time by an optical reflectance sensor [2]. The stimulus paradigm for each trial consisted of a stimulus-free baseline period (10 images), followed by a stimulation period (10 images) during which the stimulus (i.e., whisker vibration or optical stimulation) was delivered, and a post-stimulus period to allow recovery of the BOLD signal (20 images). Each experiment consisted of 10 trials. Trials were averaged for each experiment and the averaged fMRI data were analyzed with a support vector machine-based algorithm [3] to detect activated voxels.

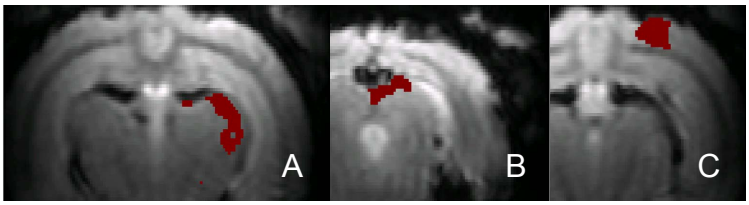

Fig. 1. Functional activation maps of the visual stimulation recorded from the lateral geniculate nucleus (A), superior colliculus (B), and visual cortex (C) of a representative animal.

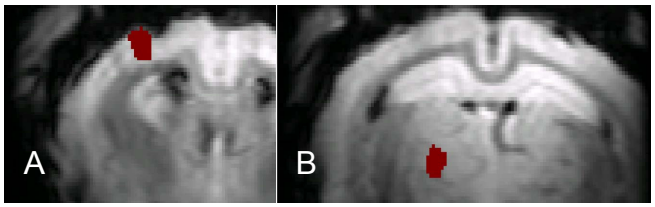

Fig. 2. Functional activation maps of the stimulation of three whiskers (C1, C2, and C3) recorded from whisker barrel cortex (A) and thalamus (B) of a representative animal.

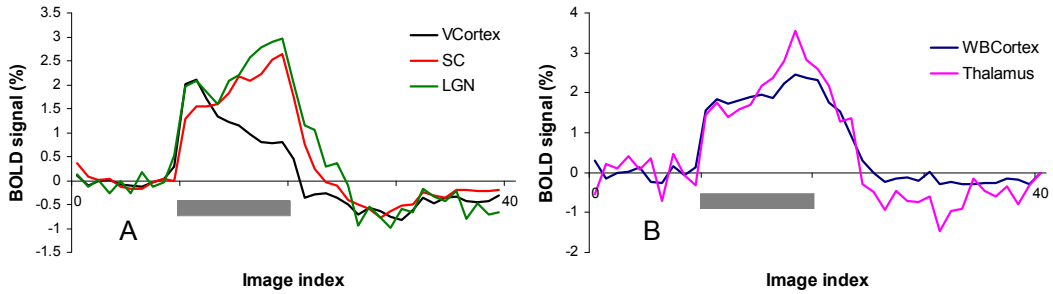

Fig. 3. Averaged temporal responses from the whisker and visual systems during stimulation. Temporal profiles of (A) visual cortex (VCortex), superior colliculus (SC), and lateral geniculate nucleus (N=6) and (B) whisker barrel cortex (WBCortex) and thalamus (N=3) were averaged across subjects. Note the difference in adaptation (i.e., decrease to a plateau following an initial peak) between the visual and whisker systems. The gray bars indicate the timing of stimulus presentation.

Results. Visual stimulation reveals the initial peak in the BOLD temporal response in the cortex at the onset of stimulus presentation (fig 1, 3). In contrast, temporal responses of the superior colliculus and LGN reveal a peak at the end of stimulus presentation (fig 2, 3). In contrast to the visual system, temporal responses obtained from the whisker system exhibit no peaks at the beginning or end of stimulation. The simultaneous single unit and local field potentials recording from whisker barrel cortex always revealed the initial peak at the onset of stimulus presentation and ended within 100 ms after the end of the stimulation unlike the BOLD temporal profile from the same location.
Discussion. Early results showed striking differences in the shape of BOLD time courses, in terms of adaptation (i.e., decrease to a plateau following an initial peak), between in the visual and whisker pathways. Within the visual pathway, responses in the superior colliculus and lateral geniculate nuclei showed no adaptation, in contrast to the cortex. Neither the thalamic nuclei nor the barrel cortex in the whisker pathway showed adaptation. These results suggest that visual cerebral cortical versus subcortical and whisker cortical regions are characterized by different hemodynamic properties.

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