Functional MRI of Auditory-Visual Convergence in the Superior Colliculus

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INTRODUCTION: Extensive research has been conducted to understand how the central nervous system receives information from individual sensory channels and converts it into perceptions of sight, sound, touch, smell, and taste. Noninvasive and large field of view fMRI studies have shown cortical regions such as the primary auditory cortex respond to inputs from multiple sensory channels [1]. However, fMRI studies have only observed visual responses in the superior colliculus (SC) [2,3] even though its neurons respond to auditory, visual, and somatosensory inputs [4]. In this study, we apply fMRI on rats to measure hemodynamic responses in the SC and inferior colliculus (IC) during auditory and visual stimulation.

MATERIALS AND METHODS: Animal Preparation: SD rats (N=6) were anesthetized with 3% isofluorane for induction and 1% for maintenance. Respiration rate, heart rate, body temperature and blood oxygenation level were monitored (SA Instruments). **Stimulation Protocol:** Auditory and visual stimuli were presented together in a 300s paradigm. The auditory stimulus was a 22kHz continuous pure tone delivered to the right ear from 40 to 260s. The binocular visual stimulus was two light spots turned on and off during the periods: 80 to 100s, 140 to 160s and 200 to 220s (Fig. 1). Refer to our previous publications for more detail [5,6]. **MRI Protocol:** All MRI measurements were acquired using a 7T Bruker scanner and a surface receiver coil. Eight 1mm slices (spaced 0.2mm apart) were positioned such that the fourth slice was centered on the SC. Throughout a fMRI experiment, 300 gradient-echo EPI scans (3.2x3.2cm^2, 64x64 voxels, TR = 1s, TE = 20ms) were acquired. The experiment was repeated ten times per animal with five minutes rest in between. **Data Analysis:** The images from each experiment were registered and all experiments from an animal were averaged to form one data set. The time series were cross correlated with the auditory and visual stimulation paradigms (refer to Fig. 2) using Simulate6.0 and voxels with correlation coefficient (cc) greater than 0.2 were considered activated. ROIs were drawn around activated voxels in the left and right SC and IC. The SC and IC ROIs were separated by one slice to avoid partial volume artifacts. The average time series from each ROI was averaged and transformed into baseline change (%) and BOLD signal change (%). Baseline change is the percentage change between the signal before any stimulation (average from 1 to 40s) and the signal with only auditory stimulation (average from 40 to 80s, 120 to 140s, 180 to 200s and 240 to 260s). BOLD signal change is the change between baseline and the signal during the three visual stimulation periods (average from 80 to 100s, 140 to 160s and 200 to 220s).

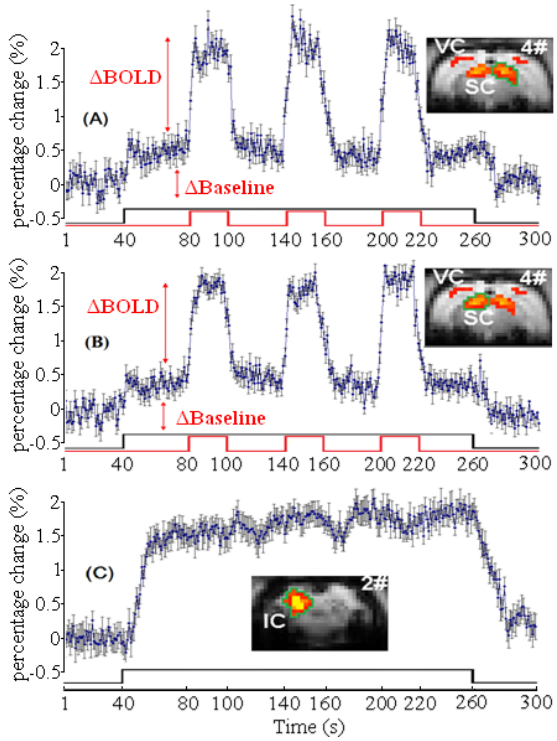

Fig. 3: Population-averaged BOLD time series of left SC **(A)**, right SC **(B)**, and left IC **(C)** during bilateral visual stimulation and unilateral auditory stimulation (right ear). ROIs shown are from a representative rat.

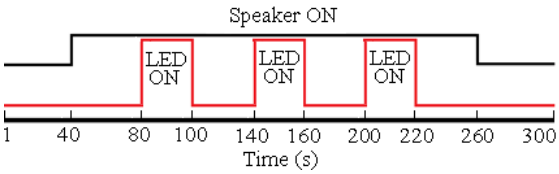

Fig.1: The timing diagram showing the on-off status during the auditory and visual stimuli.

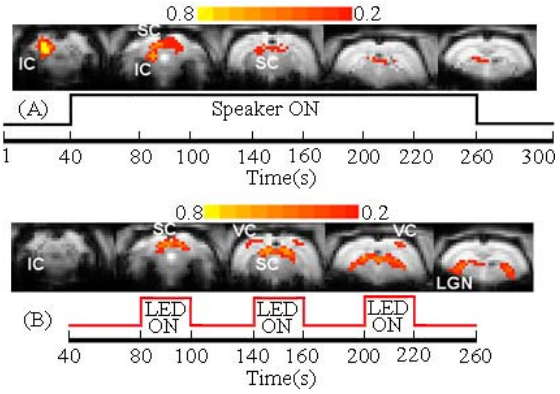

Fig.2: Response maps from a representative rat computed by correlating the fMRI time series with the auditory stimulation paradigm **(A)** and with the visual stimulation paradigm **(B)** using Stimulate 6.0. Only voxels with correlation coefficient (cc) > 0.2 are color coded.

Table 1

	Baseline change (%)		BOLD signal change(%)	
	Left SC	Right SC	Left SC	Right SC
rat 1	0.43	0.45	1.78	1.81
rat 2	0.51	0.52	1.67	1.68
rat 3	0.47	0.42	1.92	1.88
rat 4	0.54	0.56	1.38	1.41
rat 5	0.45	0.41	1.47	1.52
rat 6	0.44	0.45	1.85	1.78

Table 1: The baseline and BOLD signal changes in left and right SCs of six rats.

RESULTS: Fig. 2 shows both SCs and the contralateral IC respond to auditory stimulation while both SCs, lateral geniculate nuclei (LGNs), and visual cortices (VCs) respond to visual stimulation. In Fig. 3, the time series in left and right SC increase during the ON periods of auditory and visual stimulation. In the IC, the time series only increases during auditory stimulation. The baseline and BOLD signal changes, which measure auditory and visual responses, respectively, in the left and right SCs of all animals are positive (Table 1). The amplitude of the SC BOLD signal changes are consistent with those in our previous study [6].

DISCUSSIONS AND CONCLUSION: The left and right SCs respond to monaural and binocular stimuli. The SC baseline and BOLD signal changes in both hemispheres are positive. This is the first fMRI evidence for auditory-visual convergence in the SC. The auditory hemodynamic responses likely reflect the activity of auditory only and multisensory neurons, which reside alongside visual only neurons in the SC [4]. fMRI provides a noninvasive view of auditory-visual convergence centers in the cortex and subcortex and is an important tool to complement invasive studies.

REFERENCES: [1] Kayser *et al.*, Hearing Res., 2009. [2] Schneider *et al.*, J. Neurophysiol., 2005. [3] Lau *et al.*, NeuroImage, 2011. [4] Stein, Behav. Brain Res., 1981. [5] Cheung *et al.* (abstract 3676), ISMRM, 2011. [6] Chan *et al.*, NeuroImage, 2010.