High Resolution BOLD-fMRI of the Auditory System in Rats

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Introduction

Despite a large body of work mapping the human auditory pathway with functional MRI (fMRI), there has been very little work mapping the rodent auditory system with MRI. Recently, manganese-enhanced MRI (MEMRI) has been used to map the tonotopic reorganization in the auditory midbrain of juvenile mice [1]. This method indicated that auditory midbrain plasticity could have major contributions to the adapting auditory system during development [2]. Drawbacks of this approach were that it was not able to map the auditory cortex and required long-term sound stimulation, which could induce cortical habituation. In the present study, BOLD-fMRI was used to map the sound evoked activity in both the auditory midbrain and the auditory cortex in anesthetized rats. BOLD signal changes were detected at high resolution using an 11.7T MRI. Activation maps could be made from the inferior colliculus (IC) and auditory cortex (AC). This work demonstrates that it should be possible to use BOLD-fMRI to map changes in neural representation in both auditory midbrain and auditory cortex.

Methods

BOLD-fMRI was performed in 5 rats anesthetized with propofol. Detail procedures of imaging setup and animal preparation for fMRI were similar to those previously described [3]. Briefly, all images were acquired with an 11.7T/31cm horizontal bore magnet (Magnex, Abingdon, UK), interfaced to an AVANCE III console (Bruker, Billerica, MA) and equipped with a 9 cm gradient set. A 3D gradient-echo, EPI sequence was used for the fMRI studies. MRI was run with the following parameters: effective echo time (TE) 16ms, repetition time (TR) 1.5s, bandwidth 150 kHz. This sequence gave isotropic resolution of 300 microns with a 64 x 64 x 32 matrix at FOV 19.2 x 19.2 x 9.6 mm and 200 microns with a 96 x 96 x 32 matrix at FOV 19.2 x 19.2 x 6.4 mm. For acoustic stimulation, electrostatic speakers (STAX) were used to deliver acoustic signal in the magnet during MRI. A 200ms short pulse of broadband noise with 10ms ramp at the edges was repeated with 50ms inter-stimulus duration. To reduce habituation during acoustic stimulation, a randomized sound profile was designed by concatenating the 200ms short pulse of broadband noises with different bandwidths (1-5 kHz, 1-20 kHz, and 1-50 kHz). During imaging, rat ears were covered with customized sound attenuation barrier to reduce the effects of scanner noise. A sub-skin electrical stimulation with 2.5 mA, 300μs pulses repeated at 3Hz was delivered to the mystacial pads to stimulate whisker cortex. A Block design paradigm was applied for fMRI studies with 2 epochs of 36s on and 24s off for acoustic stimulation and 5 epochs of 30s on and 30s off for mystacial pad stimulation. AFNI software (NIH, Bethesda) and Matlab was used for Image analysis.

Results

The activity pattern in the auditory cortex and midbrain could be mapped with BOLD-fMRI. To characterize the location of the auditory cortex, the barrel cortex was also mapped It is located rostromedial to the auditory cortex (Fig 1, inset). In Fig 1A and B, a color-coded t-map was superimposed on three 2D coronal slices across the barrel cortex (BC), auditory cortex (AC), and inferior colliculus (IC). The barrel cortex was activated in both hemispheres following electrical stimulation on both sides of the face. Acoustic stimulation was delivered to the left ear, and the AC and IC in the right hemisphere were activated. The BOLD signal change was detected each area, showing a good correlation with the stimulation paradigm. The sound evoked percentage BOLD signal change was around 1% in IC and AC. Electrical stimulation of mystacial pads induced 3-4% BOLD signal enhancement. In addition, 200 micron isotropic 3D EPI images were acquired in the IC with acoustic stimulation of both ears. In fig 1D, we showed the t-map of three consecutive coronal IC slices. A 3D fMRI contour is shown in a segmented brain slab (anatomical IC, green, active IC, red).

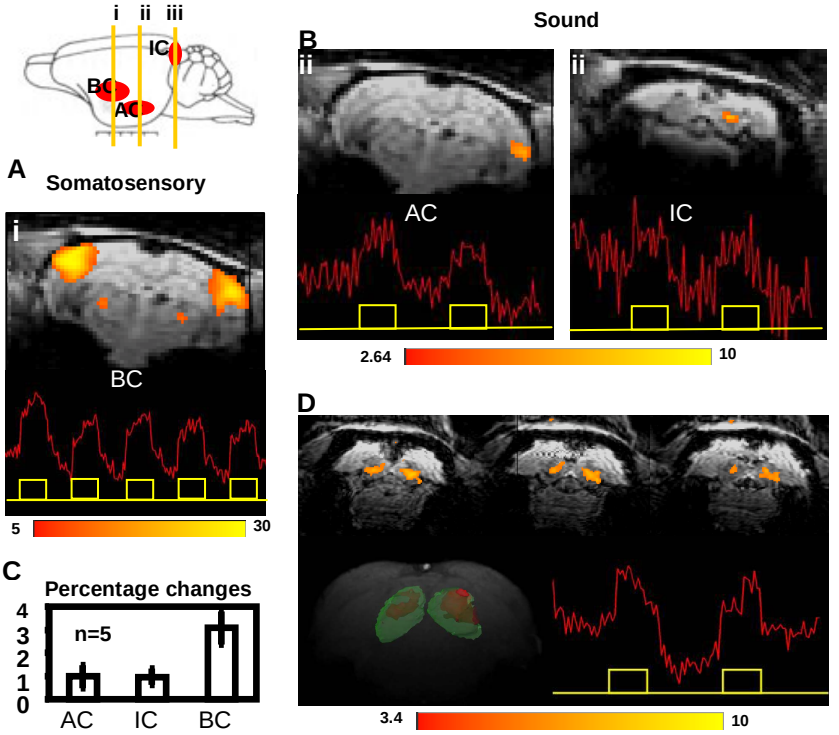

Fig. 1. A and B: 2D t-maps and BOLD signal changes of the BC, AC and IC. C: average BOLD signal percentage changes of BC, AC, and IC (n=5). D: high-resolution t-map and 3D contour of active IC with BOLD signal changes.

Conclusions

This work successfully detected fMRI activation in the auditory cortex and brainstem with 3D BOLD-fMRI. Future work will characterize auditory plasticity and analyze the interaction between the auditory midbrain and cortex under conditions where plasticity occurs.

Reference [1] Yu X et al., PNAS. **104**: 12193-8. (2007) [2] Knudsen EI and Brainard MS, Science **253**: 85-7 (1991) [3] Silva AC and Koretsky AP, PNAS, **99**: 15182-7 (2002)