Bilateral Auditory Cortex Ablation Alters the Tonotopic Organizaiton of the Inferior Colliculus

Jevin W. Zhang[1,2], Shu-juan Fan[1,2], Patrick P. Gao[1,2], Joe S. Cheng[1,2], Dan H. Sanes[3], and Ed X. Wu[1,2]

[1]*Laboratory of Biomedical Imaging and Signal Processing, the University of Hong Kong, Hong Kong, Hong Kong, China,* [2]*Department of Electrical and Electronic Engineering, the University of Hong Kong, Hong Kong SAR, China,* [3]*Center for Neural Science, New York University, New York, New York, United States*

INTRODUCTION Corticofugal projections from cerebral cortex to subcortical nuclei are among the largest pathways in the brain, suggesting that they are important for subcortical processing [1]. However, the exact role of cortical input in modulating the response properties of subcortical nuclei is still not adequately understood. For example, previous studies have suggested that input from auditory cortex (AC) can modulate the frequency tuning curves of single neurons in the inferior colliculus (IC) [2]. But how the topographical encoding of sound frequency (i.e. tonotopy), a fundamental response property throughout the auditory system, are affected can be hardly delineated without examining the neuronal responses in this structure in a sufficient spatial scale. Functional MRI which can examine a large field of view is well suited to studying such essential questions. In this study, bSSFP fMRI with swept source imaging paradigm, which has been demonstrated to be an efficient tool for mapping tonotopy [3], was applied to examine the effect of bilateral AC ablation on the tonotopic organization in IC.

METHODS *Experimental animal:* Bilateral AC ablation surgery was performed on 6 Sprague-Dawley rats (~200g), and fMRI experiments were performed after one month (~350g). fMRI experiments were also performed on 5 age-matched control rats. Rats were anesthetized with 3% isofluorane for induction and maintained at 1% during the fMRI sessions. *Auditory stimulation:* Monaural broadband noise stimuli were produced by a free-field magnetic loudspeaker (TDT MF1) and driven by an amplifier (TDT SA1). Sound was generated by the computer with a high-power soundcard and was delivered to the left ear canal via a 165-cm long custom built tube. The swept source imaging paradigm was adopted from Cheung's study [3]. It contained 21 cycles and for each cycle the sound frequency swept linearly from 1 to 40 kHz or from 40 to 1 kHz in 40s (Fig. 1) *MRI protocol:* Rats were scanned in a 7T Bruker scanner with a surface receiver coil. 2D bSSFP scans were acquired with TR = 3.8ms, TE = 1.9ms, FA=19°, phase advance = 180°, FOV = 32x32mm^2, data matrix = 64x64 (zero-filled to 128x128) and NEX=4 (temporal resolution=1s). *Data analysis:* The first 10 images of each fMRI session were discarded. The remaining images were realigned to the mean image of the first session of each animal and then coregistered together using SPM8. To generate the tonotopic map, the amplitude and phase at the cycling frequency (1/40s = 0.025 Hz) were first computed on the pixel basis, and then the coherence (based on the amplitude information and normalized by the square root of the sum of squared amplitude at all frequencies) and tonotopic map (based on the frequency encoding time estimated from the phase information) were generated. Sweeping up and sweeping down scans were performed to cancel the hemodynamic delay effect. The difference between the control and AC ablation group were compared.

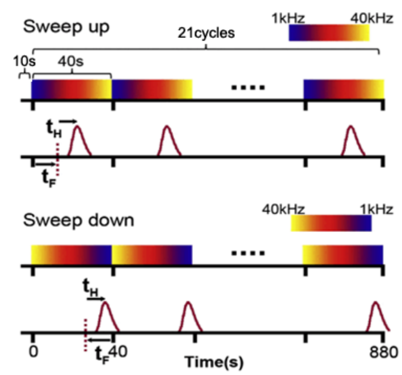

Fig. 1. Schematic of hemodynamic responses measured from a voxel by swept source imaging during the sweep up and down scans. t_H: hemodynamic delay time, t_F: frequency encoding time.

RESULTS Fig 2.shows the group averaged coherence and tonotopic maps for the control and AC ablation groups. The coherence value for the AC ablation group is larger than the control group in the middle and ventral side of the IC, but in the dorsal side it is slightly smaller (Fig. 2 C). The encoded frequency in dorsal IC was generally increased while that in ventral IC was generally decreased (Fig. 2 D). The encoded frequency change was small for voxels in the middle of the IC.

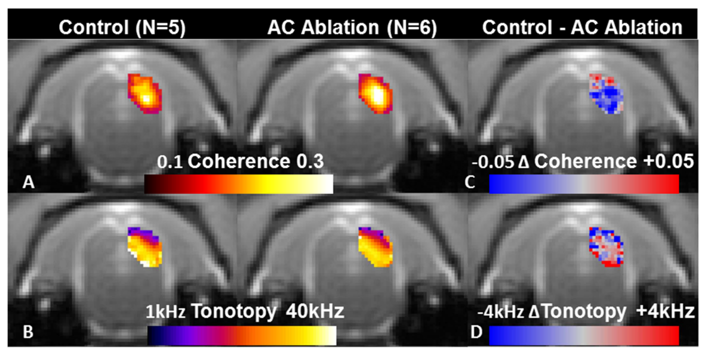

Fig. 2. (A&B) Group averaged coherence and tonotopic maps for the control and AC ablation groups. (C&D) The delta coherence and tonotopic maps by subtracting these of the AC ablation group from the control group.

DISCUSSION AND CONCLUSION bSSFP fMRI clearly demonstrated that cortical input can modulate the tonotopic organization in IC. The encoding frequency measured by the swept source imaging method is affected by the center of the tuning curve bandwidth (the frequency width of tuning curve at sound pressure levels above minimum threshold). The change of tonotopic organization may largely result from the broadened tuning curves of IC neurons with deprived cortical activities [2]. More interestingly, the differences between the changes of encoded frequency along the tonotopic axis suggested the tuning curve bandwidth center was shifted toward different directions for neurons at different portions of the IC. For the neurons with low characteristic frequencies (CFs), located in dorsolateral IC, the tuning curves were often asymmetric [4] so their bandwidth center would shift to higher frequency. In contrast, neurons with high CFs, located in the ventromedial IC, the tuning curve bandwidth center shifted oppositely. The small change of encoded frequency in middle IC suggested that the tuning curves were broadened more symmetrically. Such subtle details of the tonotopic change after bilateral AC ablation beautifully demonstrated that fMRI can be a highly efficient approach for investigating the functional roles of corticofugal connections. Future work will look into the modulation of other fundamental encoding mechanisms in the subcortical structures.

REFERENCES [1] A. Longstaff, Neuroscience, 2013. [2] N. Suga, J. Comp. Physiol. A., 2008. [3] M. M. Cheung, Neuroimage, 2012. [4] J.J.Yu, Front. Neural Circuits, 2013