ENCODING OF SOUND FREQUENCY AND LOCATION IN HUMAN SUBCORTICAL STRUCTURES

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Target audience: High-resolution fMRI community; auditory neuroscience

Purpose: This study investigates sound processing in the human inferior colliculus (IC) and medial geniculate body (MGB) of the thalamus, which due to the small size of these structures and limitations in the spatial resolution of non-invasive imaging methods so far remained largely unexplored.

Introduction: The inferior colliculus (IC) and medial geniculate body of the thalamus (MGB) are pivotal relays in the auditory pathway. Recent fMRI studies at high spatial resolution revealed an orderly encoding of sound frequency in the human IC[1-2], and invasive animal studies indicate that one or multiple tonotopic gradients should also be present in the MGB[3]. Furthermore, previous studies suggest that IC and structures higher in the auditory hierarchy such as MGB play a crucial role in the integration of acoustic cues regarding sound location[4]. Here, we investigate how neuronal populations in the human IC and MGB represent the frequency content and spatial location of natural sounds. Specifically, we measure subcortical responses to natural sounds with ultra-high field fMRI (7T), and compare the performance of four different computational models in representing these responses.

Methods: Using a 7T MRI scanner (Siemens, Erlangen, Germany) we acquired high-resolution functional MRI time series (Nova Medical 1Tx/32Rx head coil; voxel dimension = 1.1 mm isotropic; TE = 19 ms; slices = 28;TR = 2800 ms; GRAPPA = 2; see Figure 1), while subjects (n = 6) listened to individual binaural recordings of 84 natural sounds (e.g. speech, music; 56 sounds for training and 28 sound for testing the models), presented at one of seven frontal azimuthal locations (-90 to +90 degrees). The response in the IC and MGB was analyzed using an encoding approach[5]. Specifically, each voxels' response was modeled as a linear combination of the sounds' features, representing the frequency content only, sound location only, or both frequency and location. For the combined representation of frequency and location, we compared an independent coding of the sound features (concatenation of 35 frequency bins and 7 locations) to a dependent or joint coding (6 frequency bins x 7 locations). The models were evaluated by their prediction accuracy of responses to 28 testing sounds. Maps were obtained by color-coding each voxel according to the frequency and location to which it responded best.

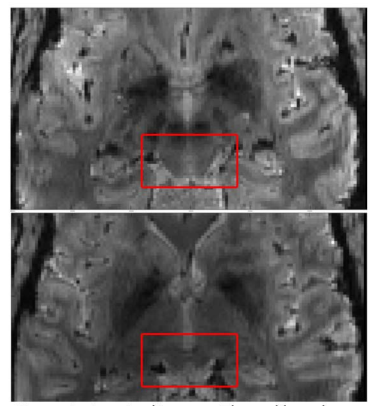

Figure 1. Acquired images. The red box shows our region of interest, including IC and MGB.

Results: We observed significant responses to the sounds in IC and MGB in all subjects (q[FDR] < 0.05). Only the dependent frequency x location model could significantly predict responses to novel testing sounds at group level (prediction accuracy [SE] = 0.56 [0.02]; chance = 0.50; $p < 0.05$; t-test) and in 3 out of 6 individual subjects ($p < 0.05$; permutation testing). A single tonotopic gradient was observed in the IC, with dorsolateral locations preferring low frequencies and ventromedial locations preferring high frequencies. Also in the MGB tuning to sound frequency was observed, and preliminary results show a high-low-high gradient in anterolateral to posterior medial direction (see Figure 2). Both IC and MGB were tuned to contralateral sound locations, yet show a wide spread of spatial preference within this general pattern of tuning to contralateral space (see Figure 2).

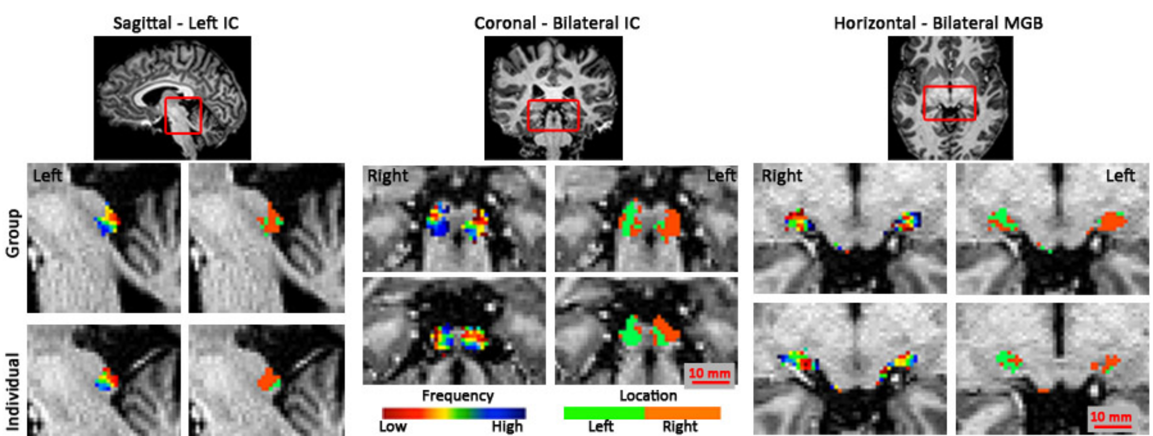

Figure 2. Frequency (in red-yellow-blue) and location (green-orange) tuning in IC and MGB

Discussion: Subcortical responses to binaural natural sounds are best represented as the combined preference for frequency and location of neuronal populations. In accordance with previous results[1], one tonotopic gradient was observed in the IC. The frequency tuning that we observed in MGB is in accordance with electrophysiological studies in various animal species[3], yet so far its presence in the human was not known. Both IC and MGB show a bias for contralateral sounds, but exceptions to this pattern are evident. Future work will explore spatial patterns in the contra- vs. ipsilateral tuning patterns, which may reveal subdivisions of IC and MGB. Furthermore, we intend to expand the computational models to include spectral and temporal modulations, and two to compare competing models of sound location coding[4].

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References: 1. De Martino F, Moerel M, van de Moortele PF, et al. Spatial organization of frequency preference and selectivity in the human inferior colliculus. Nat. Comm 2013. Doi: 10.1038/ncomms2379. 2. Ress D, Chandrasekaran B. Tonotopic organization in the depth of human inferior colliculus. Front. Hum. Neurosci. 2013. Doi: 10.3389/fnhum.2013.00586. 3. Imig TJ, Morel A. Tonotopic organization in ventral nucleus of medial geniculate body in the cat. J Neurophysiol. 1985; 53: 309-340. 4. Groh J, et al. (2003). J. Cogn. Neurosci, 15, 1217-1231.5. Kay K, Naselaris T, Prenger RJ, Gallant JL. Identifying natural images from human brain activity. Nature 2008; 452: 352-355.