LAMINAR FEATURES OF CORTICAL NATURAL SOUND PROCESSING IN HUMANS

Michelle Moerel[1], Federico De Martino[2], An T Vu[1], Valentin G Kemper[2], Kamil Ugurbil[1], Elia Formisano[2], and Essa Yacoub[1]
[1]*Department of Radiology, Center for Magnetic Resonance Research, University of Minnesota, Minneapolis, Minnesota, United States,* [2]*Faculty of Psychology and Neuroscience, Maastricht University, Maastricht, Netherlands*

Target audience: High-resolution fMRI community; auditory neuroscience

Purpose: To explore the laminar tuning to features of natural sounds in human primary auditory cortex.

Introduction: Previous research showed that throughout the human auditory cortex, neurons with similar feature preference cluster together creating large-scale maps (e.g. tonotopic maps)[1,2]. Invasive animal studies and recent results using ultra-high field fMRI in humans suggest that another spatial organization is implemented orthogonal to the cortical sheet. That is, neuronal preference to a subset of acoustic features is relatively stable throughout cortical columns, while tuning to other acoustic features displays variability[3,4]. Columnar tuning is generally investigated with simple artificial stimuli such as tones, yet the use of natural sounds would ensure ecological validity, elicit stronger responses in the cortex, and enable the exploration of cortical tuning to features beyond frequency (e.g. temporal and spectral modulations). Thus, here we explore the feasibility of examining laminar frequency preference based on responses to natural sounds.

Methods: Measurements were performed at 7T (Siemens) using a custom whole head 32 channel loop transceiver and a high performance head gradient insert. The experiment was divided into three sessions. In the first session, we acquired high-resolution anatomical data (T_1 and proton density [PD] weighted data; 0.6 mm isotropic) and gradient echo (GE) measurements of responses to amplitude modulated tones in four frequency ranges ('*GE Tones*'; 0.2-4 kHz; the GE measurements in this session were made using same sequence as described below for the '*GE natural sounds [NS]*' session). The anatomical data were used for segmentation[5] and cortical layer sampling[6]. The gray/white matter and GM/CSF boundary were defined on T_1/PD images, the voxels' distance to those two boundaries was computed and subsequently grid sampling as implemented in BrainVoyager QX was performed (resulting in n = 3 cortical depth dependent profiles; see Figure 1A for resulting grids). In the second and third sessions, high-resolution (0.8 mm isotropic) gradient echo ('*GE NS*'; TE = 22.8 ms; slices = 36; TR = 2400 ms; TA = 1200 ms; GRAPPA = 3; multiband = 2) and 3D GRASE ('*GRASE NS*'; TE = 27.9 ms; slices = 16; TR = 2000 ms; TA = 330 ms) images were acquired, respectively, while 144 natural sounds (e.g. speech, animal cries) were played. Slice placement was anatomically based, and included bilateral auditory cortex in the GE sessions, and left primary auditory cortex (medial part of Heschl's gyrus) in the GRASE session. In session two and three, a short T_1 weighted scan was acquired for the purpose of realignment across sessions. Tonotopic maps were computed three times: first based on responses to tones (session 1) by assigning the voxels' characteristic frequency as the frequency to which it responded best[2], and then a based on the natural sounds (on either GE or GRASE data) using an encoding approach[1].

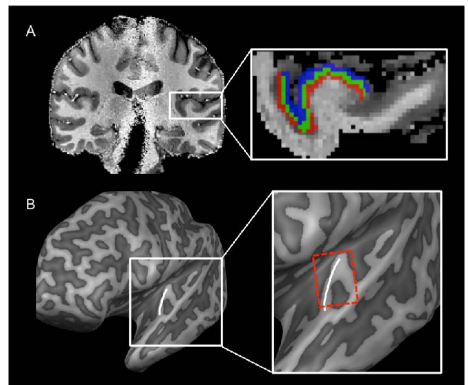

Figure 1. Location of primary auditory cortex in the volume (A) and on the surface (B). The three colors and red box show the laminar grid in A and B respectively, and the white line shows HG.

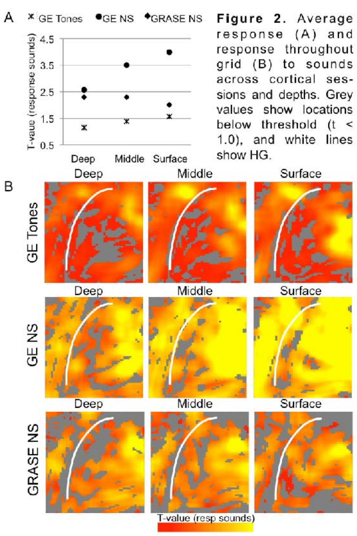

Figure 2. Average response (A) and response throughout grid (B) to sounds across cortical sessions and depths. Grey values show locations below threshold (t < 1.0), and white lines show HG.

Results: We observed significant responses to the sounds in all three sessions (q[FDR] < 0.05). Cortical responses to natural sounds were stronger than responses to tones (smaller t-value; see Figure 2A). While the overall response increased with decreasing cortical depth in the data from the *'GE Tones'* and *'GE NS'* session (strongest response near CSF), such pattern was not evident in the *'GRASE NS'* session (see Figure 2). In accordance with previous results, tonotopic maps from both the *'GE Tones'* and *'GE NS'* sessions showed a low frequency region on Heschl's gyrus (HG), bordered anteriorly and posteriorly by high frequency regions[1](see Figure 3). In spite of the small field of view of the *'GRASE NS'* session, a high-low-high gradient typical of primary auditory cortex could still be discerned (see first column of Figure 3). Preliminary results show both regions of consistent frequency preference in primary auditory cortex across cortical depths, and cortical regions in which frequency dependence varies across the laminar depths.

Discussion: Our preliminary results show the feasibility of exploring responses to a large set of natural sounds at submillimeter resolution in human auditory cortex using high field fMRI. The use of natural sounds will enable the exploration of laminar tuning to features beyond frequency, such as temporal and spectral modulations[7]. Additionally, as responses to both tones and natural sounds are collected, differences due to sound complexity can be explored. Furthermore, this dataset demonstrates the feasibility of investigating sound complexity using highly specific T_2 weighted (3D GRASE) fMRI signals which have been shown to be more optimal for columnar and layer specific applications[6]. However, compared to 3D GRASE, gradient echo measurements, while being more biased towards surface effects, have the advantage of covering the region of interest bilaterally with higher BOLD contrast.

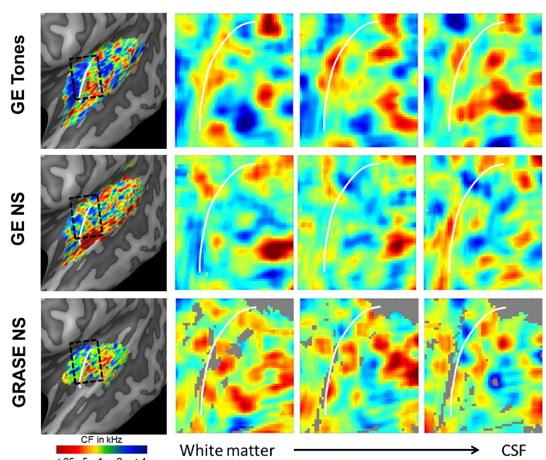

Figure 3. Large-scale tonotopic maps and frequency preference across cortical depths. The black boxes indicate the approximate location of the grid, and the white lines show the approximate location of Heschl's gyrus.

Acknowledgements: This work was supported by the Netherlands Organization for Scientific Research (NWO; Rubicon grant 446-12-010), the National Institutes of Health (NIH grants P41 EB015894, P30 NS076408, and S10 RR26783), and the WM KECK Foundation.

References: 1. Moerel M, et al. 2012: J Neurosci 32: 14205-14216. 2. Formisano E, et al. 2003: Neuron 40: 859-869. 3. Schreiner CE. Spectral processing in auditory cortex. In: The Auditory Cortex (Winer JA and Schreiner CE, eds), pp275-308. New York: Springer. 4. De Martino F, et al. 2013: ISMRM Salt Lake City. 5. van de Moortele PF, et al. NeuroImage: 2009. 6. De Martino F, et al. PLoS One. 2013: 8. Doi: 10.1371/journal.pone.0060514. 7. Atencio CA, Schreiner CE. J. Neurophysiol. 2010: 103: 192-205.