High Resolution fMRI with Asymmetric SE EPI and Its Application in the Study of Tonotopic Organization in Human Auditory Cortex

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Purpose

An orderly relationship between the frequency of maximum neuronal sensitivity and position over the cortical surface has been observed in electrophysiological studies in lab animals and also in some preliminary studies in humans using PET and fMRI (Talavage TM, et al, Neuroimage 5:S8, *1997*). It is suggested that this tonotopic organization in the human brain is represented in the transverse temporal gyri within the primary auditory cortex, with high frequencies represented medially and lower frequencies represented laterally. High spatial resolution and sensitivity are required to reveal this organization. Single-shot Asymmetric-Spin-Echo EPI (ASE-EPI) with partial k-space scanning provides high spatial resolution without sacrificing temporal resolution (Hyde JS, et al, MRM 46:114-125, *2001*, Stables LA, et al, MRM 40:432-442, *1998*). Moreover, this sequence minimizes magnetic-susceptibility related signal dropouts in the temporal lobe and it is less sensitive to BOLD effect from macrovasculature and more sensitive to BOLD effects from the microvasculature. Therefore, this acquisition method has the potential to improve spatial specificity of fMRI studies (Stables LA, et al, MRM 40:432-442, *1998*).

Methods

One 26 years old healthy male volunteer was scanned using a 4T Magnex magnet interfaced with a Marconi EDGE console. Before the study, the subject signed a written consent that was approved by the IRB. For data acquisition, 2D ASE-EPI sequence was used with TR=2.5s, TE=31ms and an echo shift of 10 ms (GE center leading SE center). Our initial experience has shown that signal dropouts are stronger in acquisitions where SE leads GE compared to GE leading SE. 4mm thick, 15 axial slices were collected with 1mm gap, which covered a slab of the brain that encompasses the entire auditory cortex. 140 data points in the read out direction and 80 phase-encode lines with 55% partial k-space coverage were collected, resulting in a final image matrix of 140x146. Therefore, with 240mm FOV, we obtained 1.7mm x 1.6mm in-plane pixel resolution. Auditory stimuli were delivered by a Pentium PC that is connected to an audio amplifier, which drives a pneumatic earphone transducer (www.etymotic.com). The transducers feed the sound into earpieces through ~10m long acoustic waveguides. Earpieces were inserted partially into the ear canal and a headset (Newmatic Sound Systems) was placed over the earpieces. The combined acoustic attenuation of the headset and the earpieces was approximately 30-35 dB. Stimuli were presented by DMDX program (www.u.arizona.edu/~kforster/dmdx/dmdx.htm). During the experiment, the subject listened to two tones, one at 250Hz and another at 2KHz. Both of which were amplitude-modulated by a 20Hz sine wave. These tones were presented sequentially in 20s blocks. Each block alternated with 20s baseline of silence. Three blocks of each tone were played and the experiment was repeated four times. The application of stimuli was synchronized to the data acquisition by a TTL pulse generated by the scanner, which is fed into the game port of the PC.

Results

Prior to statistical analysis, the images were realigned for motion compensation. Then, they were analyzed by General Linear Model that is implemented by SPM2 software [*Friston, K.J. et al, Human Brain Mapping, (1994) 1, 153-171.*]. The four sessions were entered into a fixed effects analysis and contrasts were generated to assess activation in response to the two tones. Activation maps were generated for voxels that survived an uncorrected p threshold of 0.001. Sagittal and coronal slices that cut through the auditory cortex are displayed in Fig.1 showing maps of activation with 250Hz tone. Similarly, maps of activation with 2KHz were shown in Fig.2. In both pictures, the region of interest was enlarged for better view.

Discussion

GE-EPI based sequences, which are most commonly used in fMRI experiments, typically provide ~3mm in-plane pixel resolution, which is further degraded by low-pass effect of T2* decay. Moreover, GE based sequences are much more susceptible to the BOLD effect coming from draining veins. These will make it harder to map the closely spaced frequency selective areas of auditory cortex. It was reported that tones that are separated by two octaves are represented in areas 6mm apart in the cortex. Moreover, more than one focal region showing this organization was observed in previous studies (Talavage et al). Therefore, high spatial resolution fMRI experiments with better specificity are required to distinguish frequency selectivity both within a cluster and also between clusters. Our preliminary results show that the proposed acquisition technique is capable of providing high spatial resolution with good spatial specificity. These results are in accord with the current literature. High resolution could be achieved with multi-shot sequences if temporal resolution is sacrificed. However, in our future studies, we will investigate more frequency bands that are closely spaced in frequency and time, which requires event-related experiments with a temporal resolution of 1-2s. High temporal resolution can be achieved by limiting the acquisition to 1-2 slices. But, this might lead to missing of other possible ROI. The proposed method does not sacrifice volume coverage or temporal resolution while achieving high spatial resolution and specificity.

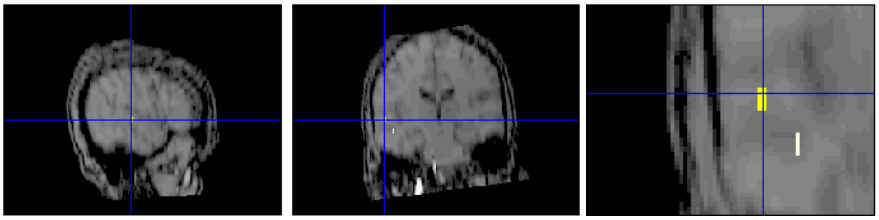

Fig.1. Maps of neuronal activity during 250Hz tone play. Left to right: Sagittal, coronal views and enlarged view of the ROI from the coronal slice.

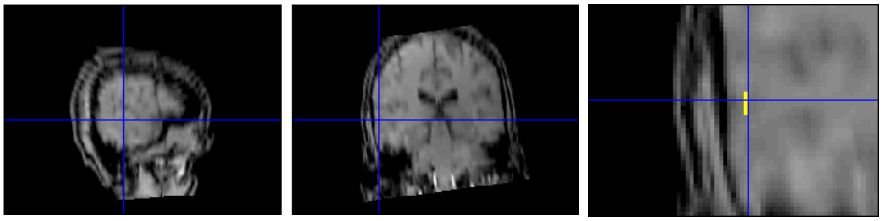

Fig.2. Maps of neuronal activity during 2KHz tone play. Left to right: Sagittal, coronal views and enlarged view of the ROI from the coronal slice.