High-resolution fMRI experiments on visual cortex using consecutive interleaved EPI at 7T

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Introduction. Single-shot echo planar imaging (EPI) has been a very common tool for functional MRI (fMRI), since it is a fast imaging with blood oxygenation level-dependent (BOLD) effects. In ultra high field (UHF), an improved signal-to-noise ratio (SNR) and an amplified BOLD effect can be provided, which is the advantages for fMRI studies. On the contrary, the challenges of UHF-fMRI are known well for distortion and signal loss due to field inhomogeneity, local magnetic susceptibility and the short T_2^* of tissues. Using consecutive interleaved multi-shot EPI scheme (ciEPI) with minimal intersegment delay and parallel imaging [1] is one of methods to obtain less-distorted images. Recently, multiple stimulus-driven retinotopic maps were introduced using conventional EPI schemes in the previous study [2,3]. In a present paper, a retinotopic response is observed by visual stimuli through ciEPI schemes with high-resolution at 7T.

Methods. (Pulse sequence) For gradient echo (GE) BOLD fMRI with high resolution, consecutive interleaved multi-shot echo planar imaging (ciEPI) sequence was used with parallel imaging technique, which was a kind of interleaved multi-shot EPI with minimal intersegment delay [1]. The imaging technique provided less-distorted images due to a short echo time and a short echo train length. In the imaging technique, a variable flip angle (VFA) was employed for inducing pseudo steady-state transverse magnetization, in which a slice profile of RF slice-selection pulse was considered to improve SNR of images [4].

(Data acquisition) To measure BOLD activity, data were acquired using ciEPI with 16 segments and R=4 in 7T magnetic field (MAGNETOM, SIEMENS, Erlangen). It means that a *k*-space was divided into interleaved 16 segments and the acquired data organized a *k*-space with effective reduction factor 4. The followings are imaging parameters: FOV 200mm^2, matrix 286^2, partial Fourier factor 6/8, EPI factor 14, In-plane resolution 0.7x0.7mm^2, Sl.thick.=1mm, TE=22ms, TR=3000ms, # of Slc.=13, and coverage 200x200x13mm^3. The number of segments was chosen for setting the echo train length of a segment to be below 25ms, which is smaller than T_2^* of gray and white matters [5]. The used flip angles were 38.2˚, 45.2˚, 57.6˚ & 90.0˚ in order. Fat-saturation pulses were used in all acquisitions. The acquisition region was chosen at the calcarine sulcus of the occipital lobe of the healthy volunteer, where the primary visual cortex (V1) is concentrated.

(Visual stimulus and analysis) For observing a retinotopic neural response, we used two kinds of stimuli: clockwise rotating wedge and expanding ring. The wedges had a polar angle of 45° in stimulus of clockwise rotating wedge. And the rings with 2.5˚ of eccentricity were given for stimulus of the expanding rings. Stimuli covered the visual field at a rate of 1 cycle every 24sec. Functional scans for each stimulus type lasted 258 seconds during 10 cycles with including initial dummy scans of 18sec. The data were processed by cross-correlation analysis with the given stimuli.

Results. The images were obtained with a voxel size of 0.7x0.7x1.0mm^3 during the stimuli. In sequent three slices of Fig.2, the response for the stimulus of the clockwise rotating wedge was shown with r > 0.36. The directions of wedge are almost consistent with the response on the V1. The response for the expanding ring was also confirmed with r > 0.38 as illustrate in Fig.3. The stimulus on the center of view reached on the V1 of outside of occipital lobe, while the stimulus on the periphery of view reached on the V1 of inside of occipital lobe.

Discussions and conclusions. The present work demonstrates the efficacy of the ultra-high-field high-resolution fMRI using ciEPI sequence with parallel imaging. ciEPI sequence yields a less-distorted images due to interleaved multi-shot EPI and also a fast imaging by minimal intersegment delay and parallel imaging. In contrast to a conventional BOLD EPI with geometric distortion, brain activities were able to be directly mapped on the images obtained by ciEPI, as shown in Fig. 2 & 3. To further study an ultra-high-resolution fMRI using ciEPI schemes, a low SNR by a small voxel and an imaging coverage will be very challenging. In our experiments, retinotopic responses were obtained by stimuli of various polar angles and eccentricity. As a result, the response seems to be consistent with the retinotopic map being known well. We hope that technique we have developed would be useful in high-resolution fMRI imaging, especially for the high field fMRI study using 7.0T MRI.

References. [1] D-H. Kang et al., Proc. ISMRM, 2012;20:3244 (submitted) [2] M.B. Hoffmann et al., Clin. Neurophysiol. 120:108-116 (2009) [3] C.A. Olman et al., Magn. Reson. Imaging 28:1258-1269 (2010) [4] D-H. Kang et al., Proc. ISMRM, 2012;20:4856 (submitted) [5] A.M. Peters et al., Magn. Reson. Imaging. 25:748-753 (2007)

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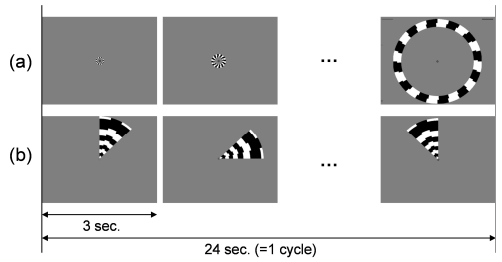

Fig. 1 Visual stimuli of (a) clockwise rotating wedge and (b) expanding ring. Each stimulus type lasted 258sec. during 10 cycles including initial dummy scans of 18sec.

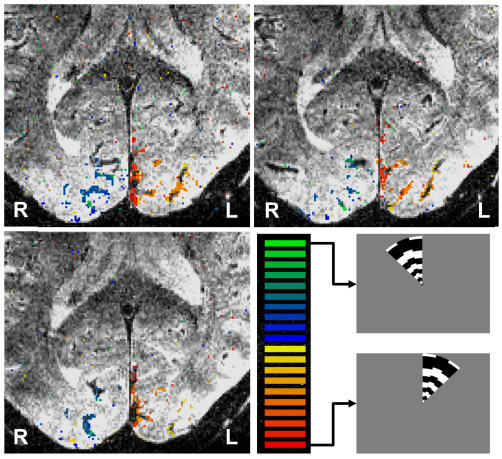

Fig. 2 Neural response for the clockwise rotating wedge

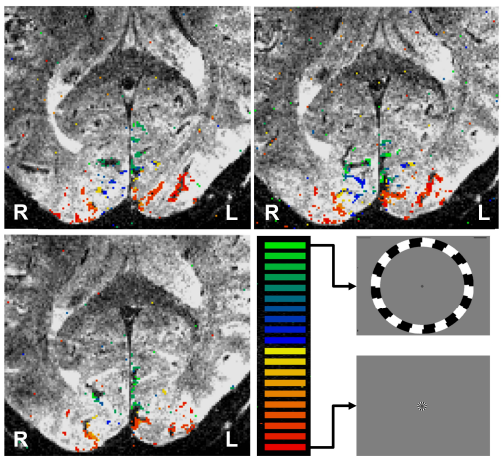

Fig. 3 Neural response for the expanding ring