Utilization of Binocular Competition for fMRI Mapping of Human Ocular Dominance Columns

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Introduction

Ocular dominance columns (ODC) mapping in human primary visual cortex using blood oxygenation level dependent (BOLD) based fMRI, is an ideal model for testing the spatial specificity and spatial resolvability of fMRI. The ability to obtain such maps robustly is important because columnar level functional parcellation appears to be a fundamental property of cerebral function. To date, imaging of ODCs with fMRI in the human brain relied on differential mapping using the hyperoxic phase of the BOLD response to monocular photic stimulation. In this study, an alternative ODC mapping method based on the properties of neural interactions between the left and right eye ODCs is proposed. The ODCs maps in human primary visual cortex using this new method are presented. The spatial features of the mapped ODCs are compared with anatomical findings in literature and mapping reproducibility is presented.

Rationale

We have already demonstrated that the selective stimulation of one eye can considerably suppress the activity induced by subsequent stimulation of the other eye if the delay between the monocular stimulations is as short as 30-90 ms; this suppression gradually disappears when the delay exceeds 300~400 ms[1]. Since the input from the two eyes is segregated into the two ODC's in the primary visual cortex (V1), the ODCs can in principle be distinguished using high resolution fMRI combined with an appropriately designed paired-stimuli paradigm. Specifically, the fMRI data at long inter-stimulus interval (ISI) of ~300ms can generate fMRI maps including the activated pixels covering both eyes ODCs in V1, while at short ISI (~40ms), the regions activated by the eye experiencing the second stimulation is suppressed. Consequently, the separation of the left and right eye ODCs depends on the suppression ratio (SR) defined as the ratio of the BOLD responses between the two stimulation conditions (short ISI versus long ISI).

Method

All the fMRI scans were performed on a 7T 90-cm bore magnet (Magnex Scientific, UK) interfaced with a Varian INOVA console (Varian Inc., Palo Alto, CA). First, a Turboflash anatomical image adjacent to interhemispheric fissure was acquired; on the basis of this image, one oblique slice parallel to the calcarine fissure was chosen for the fMRI study. With this slice prescription, the mapped ODCs were expected to be orthogonal to the interhemispheric fissure line in an alternating pattern. On this selected slice, gradient echo planar images (GE EPI) (FOV = 12.8×12.8 cm^2, 256×256 image matrix size, TE = 28.8 ms, TR = 550 ms, 16 segments) were acquired.

The visual stimulation was generated by a pair of LED goggles. In each fMRI run, the paired-monocular stimuli to both eyes with two different ISIs, 40 ms and 300 ms, respectively, were repeatedly presented (every 600 ms) in two stimulation periods (8 images each), and sandwiched by three resting periods (8 images each) in uniform darkness. The ISIs were chosen according to the results from a separate fMRI experiment session conducted with each subject; also, from this separate fMRI session, a suppression ratio threshold (SRTh) was determined by calculating the ratio between the average amplitudes of the BOLD responses in the strongest suppression and the no suppression conditions.

The BOLD responses in the two stimulation conditions (ISI = 40 ms and ISI = 300 ms) were used to determine the suppression ratio (SR) map; this map was used to generate an ODC Index (ODCI) map using Eq. 1. In the ODCI map, any activated pixel with an ODCI value smaller than 1 (corresponding to the SR value smaller than SRTh), was designated as belonging to the suppressed eye ODCs; any activated pixel with a ODCI value larger than 2 (corresponding to the SR value larger than 1) is designated as belonging to right eye ODC; any activated pixel with a SR value between SRTh and 1 is linearly interpolated to a value between 1 and 2. The histogram of the ODCI map was also calculated.

Results

$$\text{ODCI} = \begin{cases} SR - SRTh + 1 & \text{if } SR < SRTh \\ 1 + \dfrac{SR - SRTh}{1 - SRTh} & \text{if } SRTh \le SR \le 1 \\ SR - SRTh + 2 & \text{if } SR > 1 \end{cases} \qquad \text{Eq. 1}$$

Fig. 1 shows one ODC map created using the proposed method in one representative subject. Alternating ODC-like patches or stripes are clearly observed in the mapped ODCs and most of mapped ODCs are largely orthogonal to the interhemispheric fissure, as expected. Fig. 2 shows the ODCI histogram of all the activated pixels displayed in Fig. 1. Strikingly, the histogram indicates the ODCIs of the activated pixels mainly distribute around 1 or 2, which are the thresholds assigned for the suppressed eye ODCs and the unsuppressed eye ODCs, respectively. This pattern is far from the normal distribution of random noise and suggests that our ODC map represents the real anatomical structure. Judging from Fig. 1 and Fig. 3, most of the undesignated pixels with ODCI between 1 and 2 (colored as orange) are located at the boundaries of the two different ODCs, which is likely due to the partial volume effect. Reproducibility was examined on the second subject. Fig. 3 displays the ODC maps acquired on two different days. Besides preserving all the ODC features observed in Fig. 1, the majority of mapped ODCs were highly reproducible across the two different fMRI sessions.

Discussion

ODCs in human primary visual cortex were mapped using neural interactions between the two ODCs that receive the input from the two different eyes. The mapped ODCs were largely orthogonal to the interhemispheric fissure and displayed an alternating ODC-like pattern; the intercolumn distance was ~1mm as expected from ODC's in the human barin; most mapped ODCs are highly reproducible between two different fMRI sessions. All these features were consistent with the literature finds in post mortem human brains, considering the slice prescription we chose. The result indicates that appropriately using the characteristics of neural interaction opens a new door to fMRI mapping down to the column level. It also gives us sufficient confidence in reliable mapping column structures using submillimeter fMRI.

Acknowledgements

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Reference

[1] *Zhu XH et al (2001), ISMRM, Glasgow, UK, p 287*

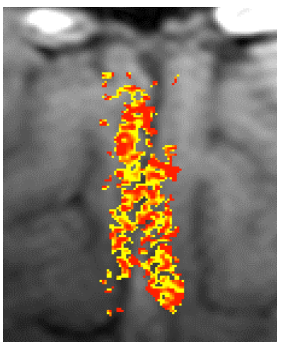

Fig. 1 ODC mapping using the proposed method.

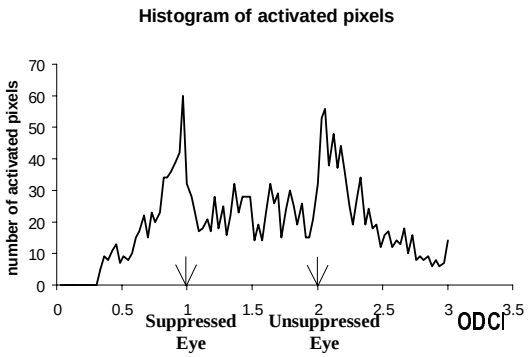

Fig. 2 ODCI histogram of the activated pixels in Fig. 1.

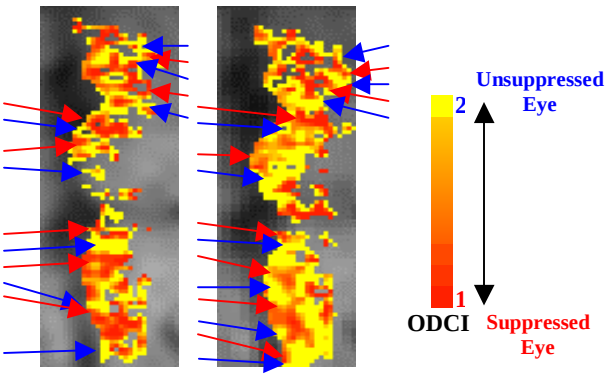

Fig. 3 Examination of mapping reproducibility