Point-Image fMRI Experiments in Awake, Behaving Macaques

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Synopsis

Point-like image experiments were performed in awake, behaving macaque monkeys using BOLD fMRI at two different field strengths (3T and 7T). The resulting BOLD maps showed a discrete, point-like activation pattern, very similar to the stimulus and consistent with the expected map of neuronal activation.

Introduction

In order to systematically investigate the spatio-temporal characteristics of fMRI signals, and the relationship of these signals to local neuronal activity, we have been developing methodologies for imaging awake, behaving, non-human primates. Retinotopy provides a means to control the width, spacing, and location of stimuli in order to investigate functional resolution, which can be limited by neuronal or hemodynamic spread, as well as experimental factors like the contrast to noise ratio (CNR) and motion. Important questions include 1) What is the spread of neuronal activity for a point stimuli, 2) How much larger is the spread of hemodynamic activity, as measured by BOLD signal, CBV, and CBF, and 3) Are resolution limits set by biology or MRI detection thresholds? We have begun to address these issues using high-field fMRI in trained macaques.

Methods

The experiments were performed in 3T and 7T Siemens magnets, using a single surface coil as transmitter and receiver. BOLD images were acquired with a single-shot GE-EPI sequence using isotropic 1.25 mm voxels, TE = 24 ms and TE = 22 ms at 3T and 7T, respectively. Small point-image stimuli, consisting of 4 dots with finite diameter, were showed in each quadrant of the visual field along the 45° azimuthal line, and at approximately 10.9° eccentricity. The eccentricity of the stimulus' spots was chosen such that the activated cells would lie in the periphery of V1, with smaller receptive fields, Three different spot angular apertures were used: 0.57°, 0.34° and 0.12° of visual angle. Point stimuli alternated between black and white at a frequency of 3Hz. A block design (60 secs ON and 60 secs OFF) was used to maximize detection power. A fixation point was present in the center of the screen at all times, and eye position was continuously monitored and recorded. The monkey's fixation accuracy was excellent.

Results

Figure 1 shows the typical stimulus pattern, together with the corresponding activation maps in two consecutive coronal slices of the monkey's visual cortex. The activity patches are situated in the inner V1 surface, consistent with a stimulus eccentricity greater than 9°. These maps were obtained by concatenating the best fixation runs across all diameters. The CNR variability of the activated patches may be related to the relative orientation of the voxels with respect to the cortical sheet, the intrinsic neuronal and vascular characteristics of each V1 quadrant, and/or image quality.

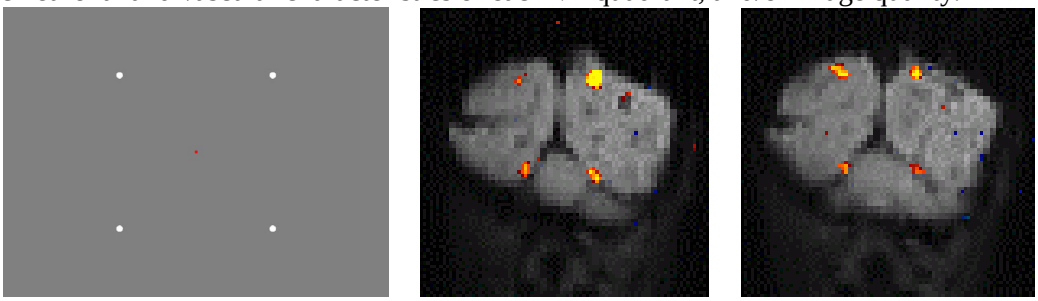

Figure 1. a) Typical stimulus. b) The anterior border of this slice (slice 6) was located approximately 7.5 mm anterior to the occipital notch. c) Slice 7 (anterior to the slice 6). Slices 5 and 8 (not shown here) showed activation patches only in the right and left sides of the brain, respectively.

The average FWHM of the retinotopic projections of the point stimuli on the visual cortex as measured with BOLD fMRI was 2.2.mm (full width at half maximum of Gaussian distribution fit to CNR). Within the resolution of this study, the average FWHM was invariant for the three angular apertures considered. There is a strong positive correlation between the size of the point stimuli and the CNR; BOLD experiments at 3T were particularly limited in this regard. Activation patches in extrastriate visual areas were also observed.

Discussion and Future Work

These results demonstrate that fMRI in trained macaques can reliably investigate retinotopy, that high-field BOLD fMRI can detect point stimuli as small as 50 arc-radians during a single scanning session, and that the fMRI spatial point spread function in macaque primary visual cortex is no larger than 2.2 mm. Further work is needed to increase the fMRI spatial resolution for these studies, and to investigate other fMRI techniques based upon blood flow and volume. Additional experimental challenges include increasing CNR and spatial resolution, and quantifying the level of blurring introduced by minor eye saccades.