

High Resolution Retinotopy Obtained by Voltage Sensitive Dye Imaging in the Behaving Monkey

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Retinotopy is one of the most fundamental organizing principles of the visual cortex. Over the years, a variety of approaches including electrophysiological recording, tracer injection and intrinsic optical imaging have been applied to examine it. Voltage sensitive dye imaging (VSDI) provides a way to monitor neuronal population activities at a high spatial and temporal resolution. Here we present a protocol for retinotopic mapping at unprecedented resolution in the behaving monkey using VSDI. Two sets of periodic stimuli for polar and eccentricity mapping were presented to macaque monkeys performing a fixation task. VSDI signals were collected with a fast CCD camera from a region of $\sim 1 \text{ cm}^2$ over the dorsal portion of areas V1 and V2 near the V1/V2 border. Within the appropriate range of temporal frequencies, the stimuli generated periodic VSDI responses with power concentrated at the periodic stimulus frequency. Due to the systematic delay of the time at which the stimulus traveled to subsequent spatial locations, VSDI signals created waves that propagated across the cortical surface. The phase of VSDI signals obtained by FFT linked stimulus location in the visual field and its neuronal representation on the cortical surface. A total of 2-3 minutes of imaging over a 30 minute session of data collection were enough for creating a high resolution retinotopic map. We used this approach to obtain retinotopy from two rhesus macaque monkeys. Retinotopy obtained in this way had a high spatial precision of 0.17-0.24 mm with 32 trials, was consistent across experiments and could be used to reliably predict the locations of the peak response to small localized stimuli. An initial analysis showed no obvious local distortion in the retinotopic maps. However, the measurements revealed a larger cortical magnification factor (CMF) in V1 near the fovea than previous estimates obtained by several different methods. For one monkey, average CMF in V1 within 2.5-2.7 degrees of eccentricity was 8.58 mm/deg angularly (along an iso-eccentricity ring), and 12.28 mm/deg radially (along an iso-angular ray). For another monkey, within 1.8-2.1 degrees of eccentricity, average CMF was 9.08 mm/deg angularly and 7.43 mm/deg radially. Finally, by running a bootstrap procedure to infer the structure of retinotopy at the limit of an infinite number of trials, we found that most locations within the ROI had infinite resolution. This final result indicates that the circuitry from retina to LGN to V1 that establishes retinotopy does little to limit the very high spatial resolution of cortical retinotopic maps.

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