Multi-resolution classification analysis of ocular dominance columns obtained from human V1 at 7 Tesla: mechanisms underlying decoding signals

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Introduction

Recent studies have demonstrated the ability of classification algorithms applied to Gradient Echo (GE) fMRI data obtained at 3T to decode visual stimuli (Kamitani and Tong, 2005; Haynes and Rees, 2005). Surprisingly, these algorithms decoded information segregated in cortical columns, e.g. ocular dominance and orientation, although the voxel size was large (3×3×3 mm^3) relative to the width of columns (1 mm or less) in humans. The mechanism by which low-resolution imaging decodes information represented at higher resolution is not clear. Biased sampling of cortical columns by the large voxels has been hypothesized. Alternatively, draining regions of blood vessels (BV) that cover functional regions non-homogeneously could cause selective responses of BV, which might be captured by the large voxels.

The present study aimed at testing these two hypotheses on the mechanism underlying selective signals at low-resolution, and at comparing the decoding performance obtained at low- and high-resolution.

Methods

High-resolution (0.5 mm) GE and Spin Echo (SE) fMRI data were obtained from 3 subjects. Each scan included an epoch of baseline, and alternating epochs of left- or right-eye stimulation. Ocular dominance columns (ODC) were imaged in one slice overlapping the upper or lower bank of the calcarine sulcus. A multi-variate support-vector machine algorithm was applied to single fMRI images from the average scan at 3 different spatial resolutions (0.5, 1.0 and 2.0 mm). Voxels were sorted according to a rank that characterized them as belonging to gray matter (GM) or BV regions. The relative Fisher information score for decoding the stimulated eye was computed for signals sampled from ODC within GM and from BV.

Results

Decreases in the effective contrast between ODC were observed with decreasing resolution, due to partial volume effects. The decreased contrast was associated with decreases in the success rate of decoding the stimulated eye when using small volumes of data. At the lowest resolution (2 mm), the success rate was slightly above chance level when using data from < 0.1 cm^3 volume of cortex. In contrast, high correct decoding rates of >0.8 for SE and GE data were achieved using even a small volume of data (less than 1 mm^3) obtained at a resolution of 0.5 mm. When using larger amount of data (> 0.15 mm^3), the success rate of decoding was virtually equal for resolutions of 0.5 and 1.0 mm. The successful decoding at 1.0 mm was possible, because although the contrast between different ODC decreased, the standard deviation of this contrast decreased too. Therefore the CNR of the selective signals remained on the same order of magnitude as that obtained at the higher resolution (0.5 mm). Using GE data, GM and BV regions carried approximately the same amount of information on the stimulated eye.

Conclusions

Using fMRI GE signals, the mechanism underlying the decoding signals involves contributions from both GM and macroscopic BV. We hypothesize that draining regions biased towards ODC with preference to one eye underlie the stimulated eye specificity of BV. Given that the BOLD signal at 3T includes contributions from blood, we would expect an even larger contribution from macroscopic BV to decoding signals at that magnetic field compared to 7T. Decoding at high-resolution is superior to low-resolution when applied to data from small cortical volumes.

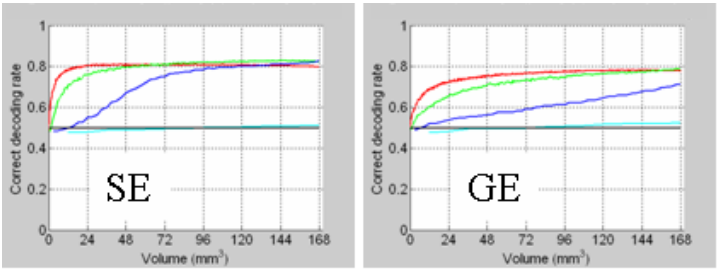

Fig. 1: Success rate of decoding the stimulated eye as a function of the volume used for the analysis and the resolution.

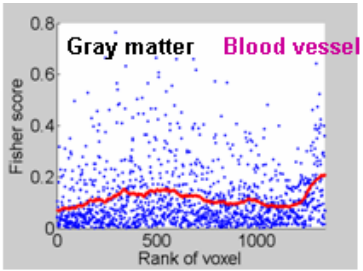

Fig. 2: Success rate of decoding by voxels in ODC and in vessels.