Detection of tuning and discrimination of visual signal by human cortex

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INTRODUCTION

a: The new fMRI analysis technique for cortical tuning: The visual cortex is organized into an intricate network of sub-voxel functional columns (e.g. orientation, ocular dominance, color, etc.) Their spatial scale (order of a few hundred microns) relative to fMRI voxels implies that individual voxels should have weak but distinct functional tuning (Fig 1). The large trial-by-trial variability in the fMRI signal normally obscures this tuning in individual voxels. The pattern of relative response strengths across a multi-voxel 'vector' should remain identifiable, however, despite large variations in the overall signal strength (Fig 1). Further, different visual stimuli would lead to different, characteristic patterns of relative signal strengths across the same multi-voxel vector (Fig 1). Thus a pattern classifier such as Linear Discriminant Analysis (LDA), acting within this high-dimensional space, can be used to categorize the fMRI response on any single trial and thereby identify the stimulus that was shown on that trial (ref 1). The sharpness with which different stimuli can be discriminated, in a voxel vector from any particular cortical region, gives a measure of tuning for the given visual stimulus in that cortical region.

b: Mapping higher-order visual features: This new analysis technique has been used to measure tuning in human visual cortex for simple visual 'primitives' such as orientation (ref 1) and direction of motion which are well known to have functional cortical columns. Earlier work from our lab, amongst others, suggests that more complex visual features are processed through cross-columnar interactions amongst neurons, shaped by the geometry of interconnections within the columnar network. These higher-order intra-cortical interactions may, in themselves, produce systematic maps of tuning for the more complex features (ref 2). The aim of the current study was to measure cortical tuning for such high-order stimuli in human fMRI signals using multi-voxel analysis techniques.

MATERIALS AND METHODS

A birdcage RF coil was used to acquire images in a GE Signa 3T scanner. Subjects were fixated passively viewing flashing gratings of either different orientations (study 1) or aligned vs. misaligned lines (study 2) giving a strong visually driven signal. The gratings were presented with random phase jitter so as to avoid retinotopic differences. The most responsive voxels, selected by signal to noise (defined = power at the frequency of stimulation divided by the power at all other frequencies) were grouped into contiguous clusters (200 voxels, into 5 clusters, shown superimposed on structural MRI). Each cluster was tested separately for stimulus tuning using Fisher LDA after demeaning and normalizing by the (trial-wise) standard deviation

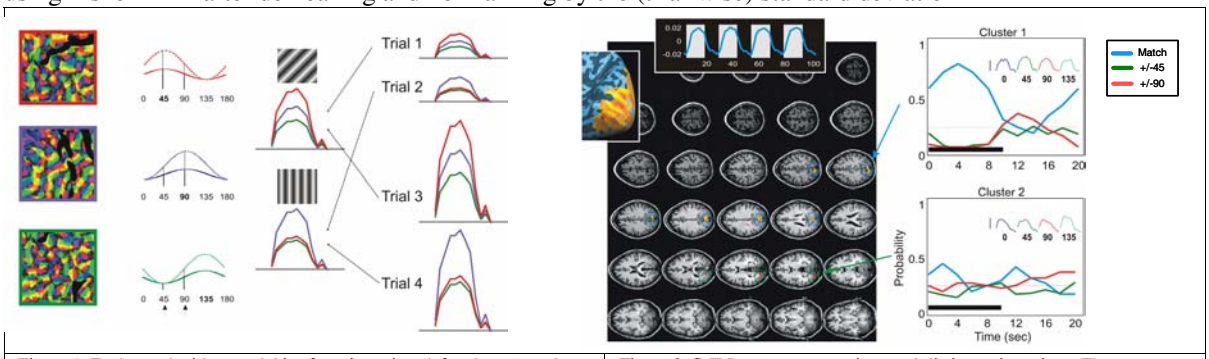

Figure 1. Each voxel with a weak bias for orientation (left column) can be used to infer the stimulus. In a 3-voxel "vector", different stimulus orientations will give characteristic patterns of relative response strengths across the set of voxels (middle column) that can be identified correctly despite large overall variations in mean signal strength (right column)

Figure 2. fMRI response to gratings at 4 distinct orientations. The most responsive voxels were grouped into contiguous clusters (left) Each cluster was tested separately for orientation tuning using LDA Whereas all clusters show robust BOLD responses, only clusters centered on the calcarine sulcus, i.e. early visual areas, show tuning for orientation (right)

RESULT AND DISCUSSION

With stimuli consisting of gratings at different orientations, LDA revealed sharp orientation tuning, with expected metric behavior. The tuning was selectively strong, as expected, near the calcarine sulcus, i.e. early visual cortex. With stimuli that differed only in a high-order feature, i.e. having "aligned" vs. "misaligned" bars, LDA again revealed tuning that was strong in early visual cortex and weak in more lateral and ventral visual cortex. Independent of the tuning, the amplitude of the fMRI BOLD signal was suppressed for aligned bars compared to misaligned. This is true both in lower and higher visual areas. This suppression is removed when the elements alternate contrast sign. Tuning, however, was invariant to a change in contrast. Our finding could be summarized as (1) intracortical interactions underlying "aligned" vs. "misaligned" may have a functional architecture with the spatial scale of cortical columns (b) the measured tuning may be carrying signals specific to the presence/absence of contours rather than specific inter-element interactions.

REFERENCES

1. Kamitani and Tong, Nature Neuroscience 2005, 8:(5):679-685. 2 Das and Gilbert, Nature 1999, 399:655-61.