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知覺群聚的神經生理基礎：整合神經造影與行為資料

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Neurophysiological foundation of Perceptual Grouping

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Annual Report

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Overview

This year, we much refined our model for human visual processing in the ventral stream to reflect current progress in the field as well as what we learned from our work. As a result, we changed the order of the experiments from what proposed in the grant proposal. We moved the experiments for local grouping and for retinotopic mapping from the second year to the current year and moved the chromatic tuning from the first year to a later day. This change reflected current thinking in the field that making local/global comparison an important and urgent issue. This move should enhance our position in international competition.

Our progress in the past nine months since the grant start includes (1) separating local/global grouping processes in the lateral occipital cortex; (2) separating retinotopic mapping areas for curve and form grouping processing; and (3) orientation tuning in local perceptual grouping. The progress (1) was reported in the Society for Neuroscience annual meeting in San Diego, California in November 2004 and the progress (2) was reported in the Vision Science Society meeting in Sarasota, Florida in May 2005. Both presentations were selected as oral presentations.

Background

1. A hierarchical processing model for visual object processing

The purpose of human vision is to identify objects in an image. However, given that cells in the early visual processing stages only respond to local line segments (Hubel & Wiesel, 1962, 1968), the question arises how the perception of complex objects can be achieved. More specifically, in the one end of the cortical visual processing, there are simple cells in the primary visual cortex that extract local orientation information in an input image. In the other end, neuroimaging evidence suggests that there are brain areas specific for certain categories of objects, such as faces, places, living things, etc. on the ventral surface of the occipital temporal complex, including the fusiform gyrus, the parahippocampal gyrus and the inferior temporal gyrus (Kanwisher et al. 1997; Aguirre et al. 1998; Grill-Spector et al. 1998). The neural information processing between the two ends is not clear. There is an inconsistency between electrophysiology and neuroimaging evidence and between one neuroimaging study and the other. Our working model for the object perception is based on the notion of hierarchical processing. That is, cells in every stage of visual processing integrate information from a group of cells in the preceding stages and hence respond to a more complex feature than cells in the previous stages. Figure 1 illustrates this model. The primary visual cortex (V1) contains

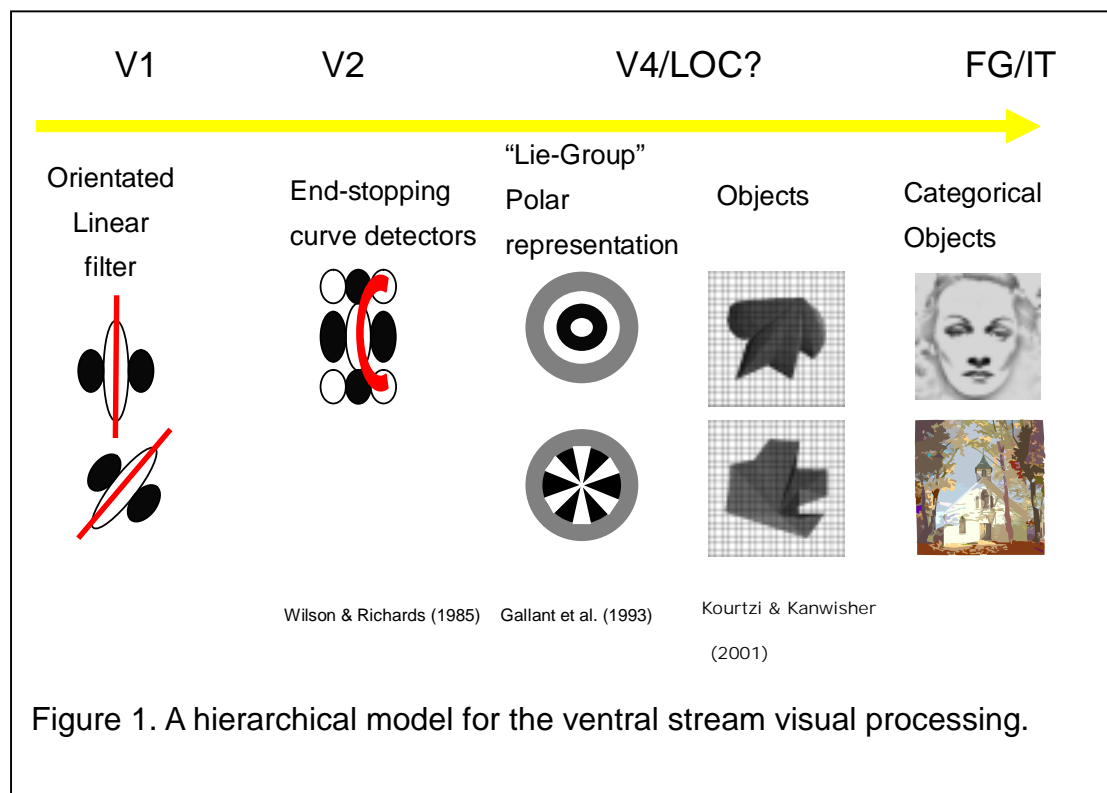


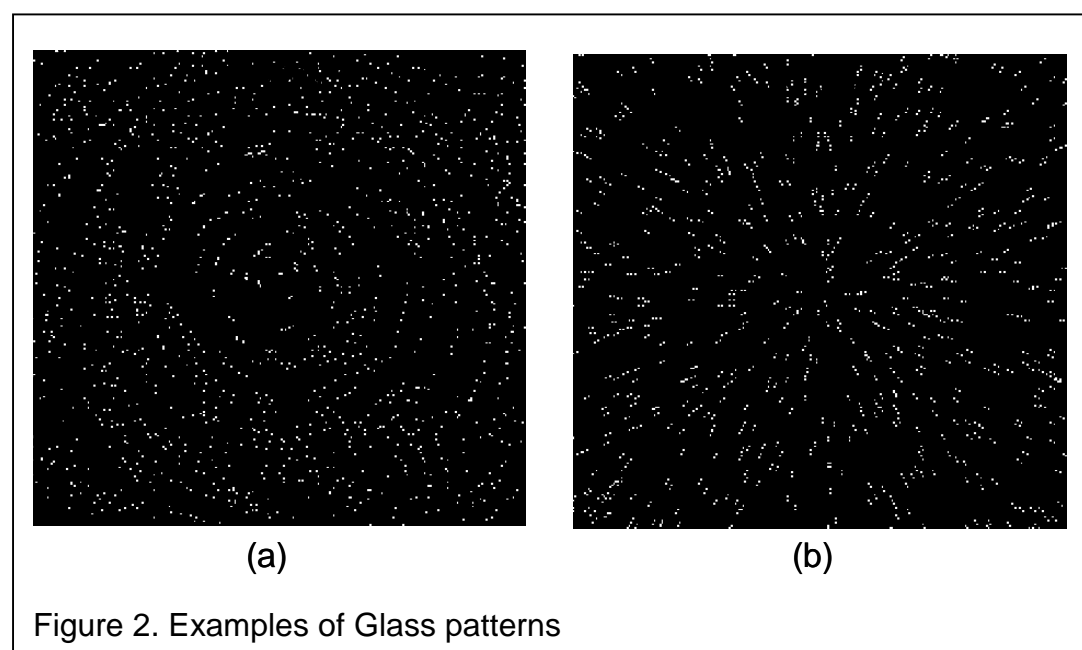
Figure 1. A hierarchical model for the ventral stream visual processing.

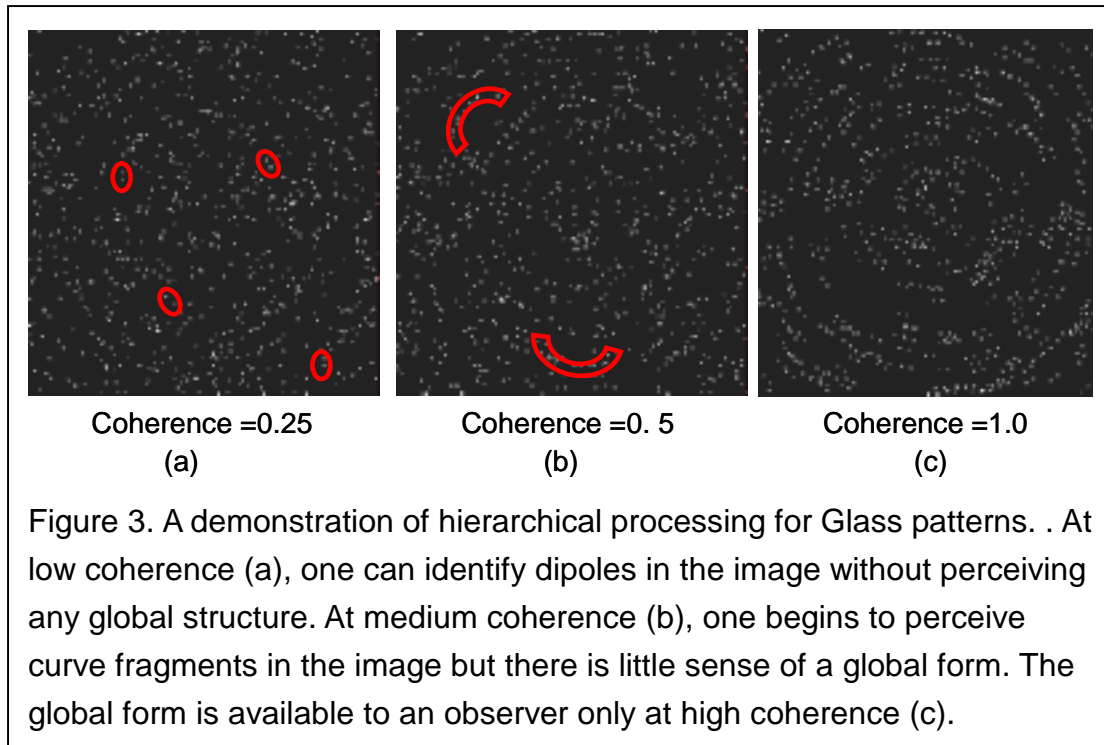
orientation selective cells that responding only to local line elements. The complex cells receive inputs from simple cells of all phases but in the same orientation and location. As a result, the complex cells display an end stopping properties that is sensitive to curves and corners (Wilson, 1985) in an image. A combination of a series of curve detectors feed into cells that specialize for circular or radial patterns in V4 (Wilson et al. 1997, Gallant et al., 1993, 1996). Cells that integrating information from those circular specific cells should respond to a more complex features in the images and eventually one will arrive with cells that specializing for certain categories of objects.

If this model is correct, we should expect that the further downstream a visual stage is, the more holistic and more global information it should process. Here, we reported two experiments using Glass patterns (Glass, 1969) to test this notion. The first experiment separates local orientation grouping (dipole formation) from the shape and form processing while the second experiment separated the curve and the form processing. In addition, we report an experiment that shows how local variability affecting global processing.

2. Glass pattern and hierarchical processing

A Glass pattern (Glass, 1969), as illustrated in Figure 2, is consisted of randomly distributed dot pairs, or dipoles. The orientations of dipoles conform certain designated geometric transform. For instance, in Fig 2a, the orientations of dipoles are always tangent to concentric circles about the center of the image. A human observer has no difficult to perceive a concentric structure in this image. In Fig 2b, the orientations of dipoles are orthogonal to





those in Fig 2a. Hence, an observer can easily perceive a radial pattern in this image.

To perceive a Glass pattern, an observer has to group image elements at several levels. First, the observer needs to group neighboring dots to form dipoles. And then, the observer will need to group neighboring dipoles to form curves and eventually a global form. Figure 3 illustrated this hierarchical processing. Coherence in a Glass pattern is defined as the proportional of dipoles whose orientation conform the designated geometric transform. At low coherence (Fig 3a), one can identify dipoles in the image without perceiving any global structure. At medium coherence (Fig 3b), one begins to perceive curve fragments in the image but there is little sense of a global form. The global form is available to an observer only when coherence of the Glass pattern is high enough. This simple demonstration shows that the visual processing of Glass patterns involves at least three stages: (1) the dipole stage, in which the observer combines neighboring dots to form dipoles; (2) the curve stage, in which the observer links neighboring dipoles of certain orientation to get curve fragments; and (3) the form stage, in which the observer connects curve fragments to form a global form.

If the hierarchical model for object perception holds for Glass patterns, one would expect that the dipole, curve and form stages are processed in different areas of the ventral with the dipole stage being processed at an earlier visual cortical area and the form stage at a more down stream area.

Here, we reported three experiments each is designed to test the brain response to a stage of the Glass pattern processing.

General Methods

Image acquisition and analysis

The images were collected with a Bruker 3T scanner located at National Taiwan University. A high-resolution anatomical (T1-weighted) MRI volume scan of the entire head was run once on each observer (voxel size = 1 x 1 x 2 mm). Within each scanning session, both functional (T2*-weighted, BOLD) responses and anatomical (T1-weighted) images were acquired in identical planes. The images were collected in 18 transverse planes parallel to the AC-PC (anterior commissure – posterior commissure) line. An echo-planar imaging sequence (Stehling, Turner, & Mansfield, 1991) was used to acquire the functional data (TR = 3000ms, TE = 40ms, flip angle = 90°, voxel resolution = 2.34 x 2.34 x 3 mm). The main experiment lasted 225 s (75 images). The first 9 s (3 images) were excluded from further analyses. Thus, the data analyzed for each scan spanned 216 s (72 images). We used SPM (Friston, et al. 1995) to realign the EPI images. The EPI images were coregistered with the T1-weighted image with a public available software (Wandell, Chial, & Backus, 2000), which also was used to perform the data analysis and the 3D rendering. Statistical analysis of the BOLD activation was based on spectral correlation between the time series and the experimental sequence (Engel et al., 1997).

Stimulus

Here is the general configuration of the stimuli. Each experiment in this project changed certain aspects of the stimuli.

A Glass pattern consisted of 1'x1' random dots. The size of the image was 10° x 10° or 600x600 possible dots. The density of dots was 0.04. Half of dots of the Glass pattern was generated with a random number generator and distributed evenly in space. The other half is a shifted copy of the first half. The direction and the size of the shift were determined by the desired global structure. For a concentric pattern, the shift was achieved by rotating the first dot set about the center of the image by 7°. Hence, the orientation of each dipole was tangent to an imagery circle. For a radial Glass pattern, the shift was achieved by moving the first dot sets away from the center of the image by 7°. The zero coherence patterns had each dot in the second dot set shifted away from the corresponding dots in the first set in a random direction.

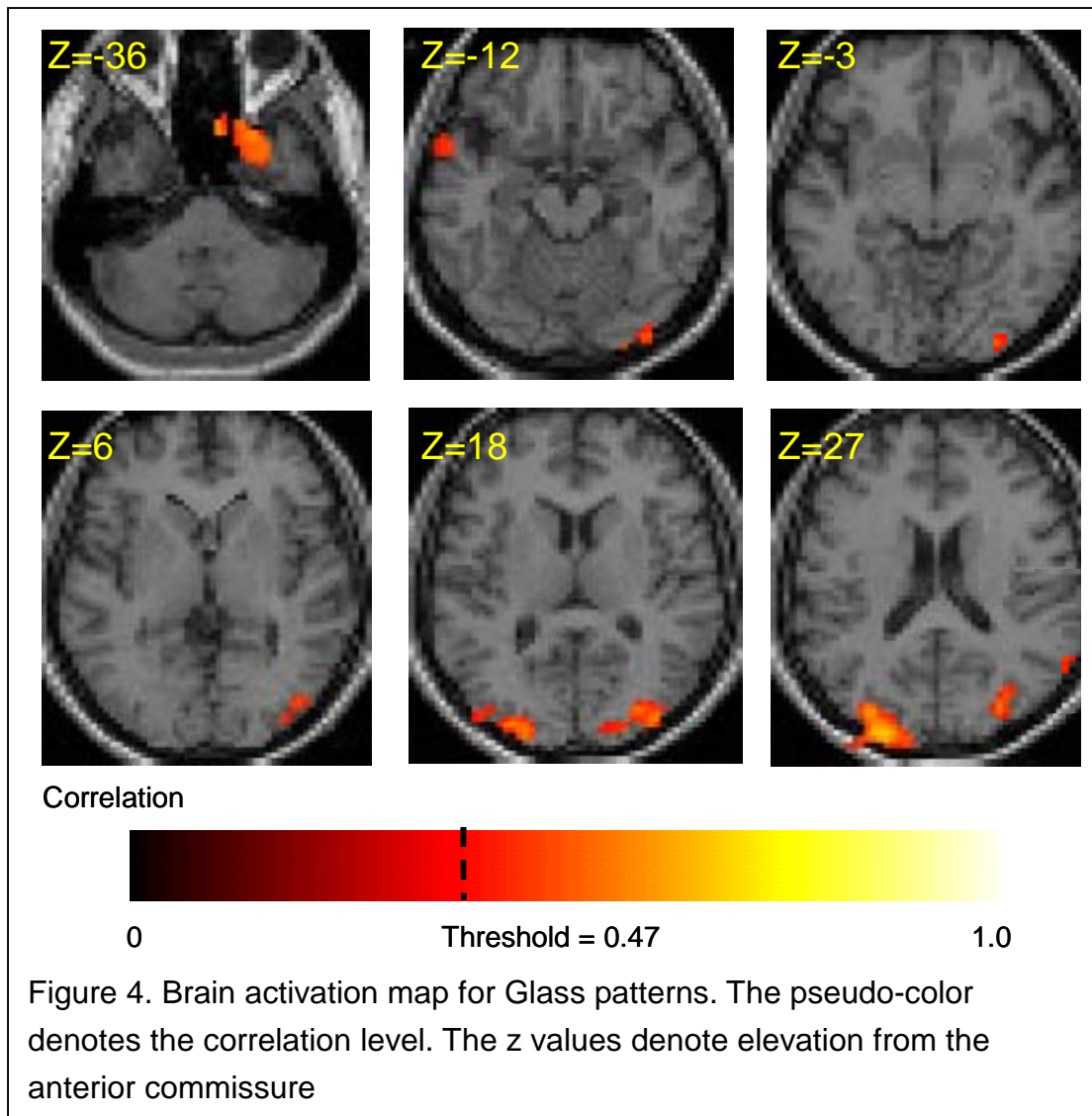


Figure 4. Brain activation map for Glass patterns. The pseudo-color denotes the correlation level. The z values denote elevation from the anterior commissure

Result and discussion

Cortical activation to Glass patterns

Figure 4 shows activation map for Glass patterns. The pseudocolored patches denote the voxels showing significant ($|r| > 0.45$) differential activation between Glass patterns and the zero coherence controls. Compared with the zero coherence control, the Glass pattern activated the middle occipital gyrus, the inferior temporal gyrus and the supramarginal gyrus. Panel a and b of Figure 5 shows this activation pattern on a 3D rendered cortical surface. We compared this activation pattern to the known function area of the lateral occipital complex (LOC). The LOC was mapped with the image of common objects and their scrambled versions. The LOC is shown as bluish patches in Figure 5 c and d. There were a lot overlap between the activation pattern for

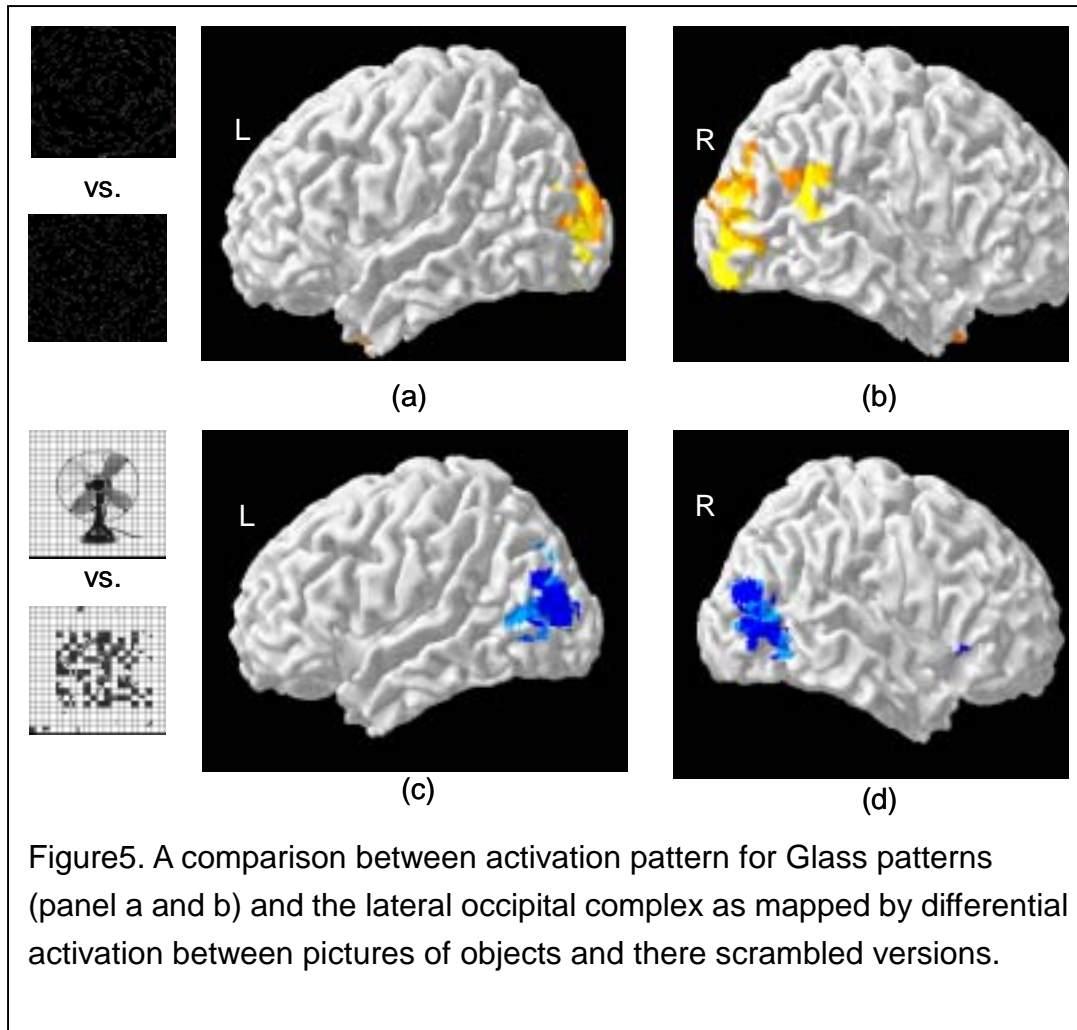


Figure 5. A comparison between activation pattern for Glass patterns (panel a and b) and the lateral occipital complex as mapped by differential activation between pictures of objects and their scrambled versions.

the Glass pattern and the LOC. However, the center of activation for the Glass pattern is posterior to that of the LOC. This activation pattern for Glass pattern would be used as a reference for the subsequent experiments.

Activation pattern for dipole summation

In order to perceive a Glass pattern, an observer has to first integrate neighboring dots to form dipoles. The experiment reported here is to investigate the activation pattern for this stage. This experiment contrasted the brain activation to Glass patterns and texture patterns. As shown in Figure 6, the Glass patterns were concentric and radial Glass patterns as described in the method section. The texture patterns have the same global structure as the Glass pattern, however, there were Gaussian bars in place of dot dipoles. The half height full width of a Gaussian bar was 5° wide and 25° long. By using Gaussian bars, we eliminated the need for local grouping at the dipole level. Hence, the brain areas showing differential activation for these two conditions should be responsible for local grouping.

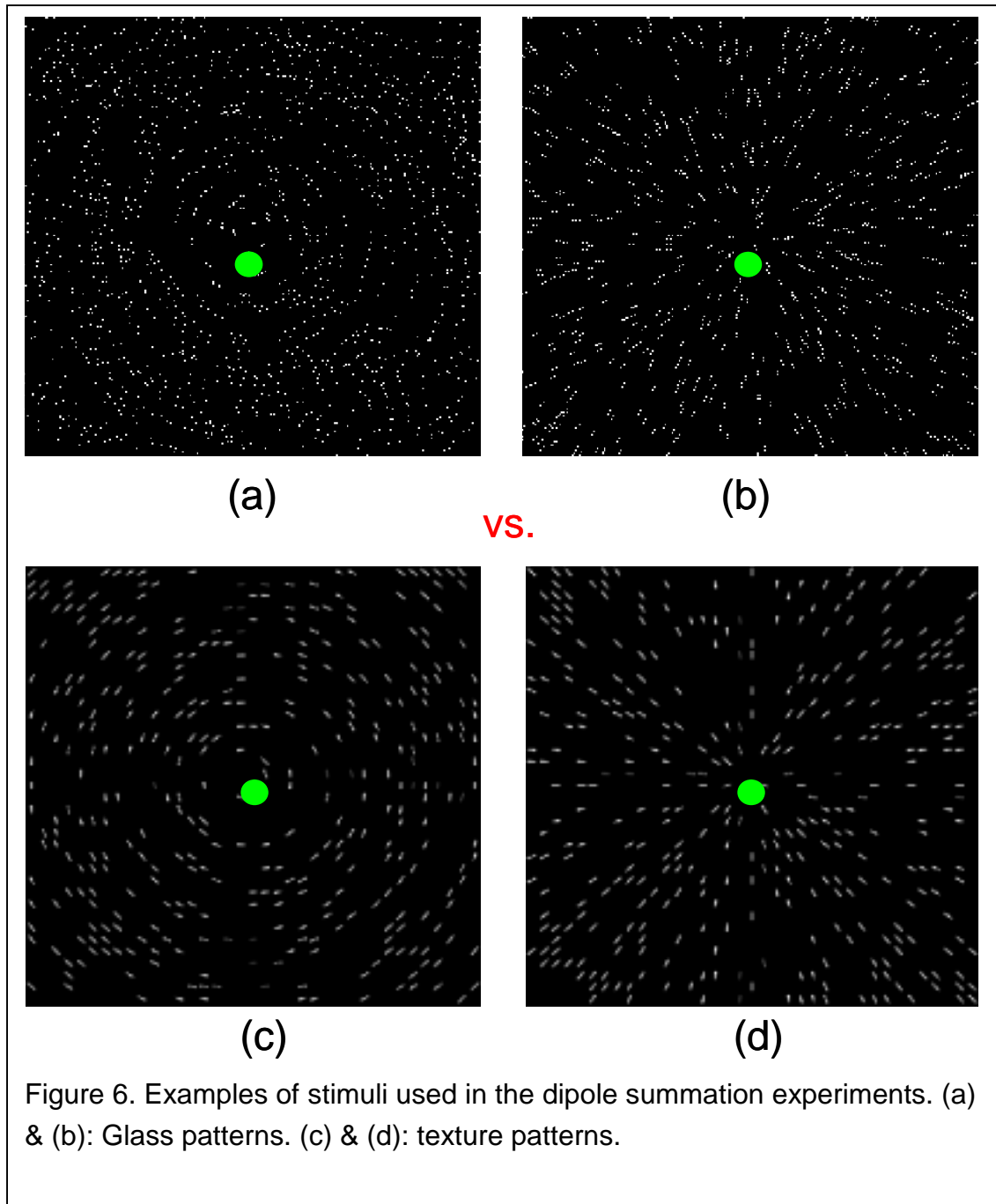
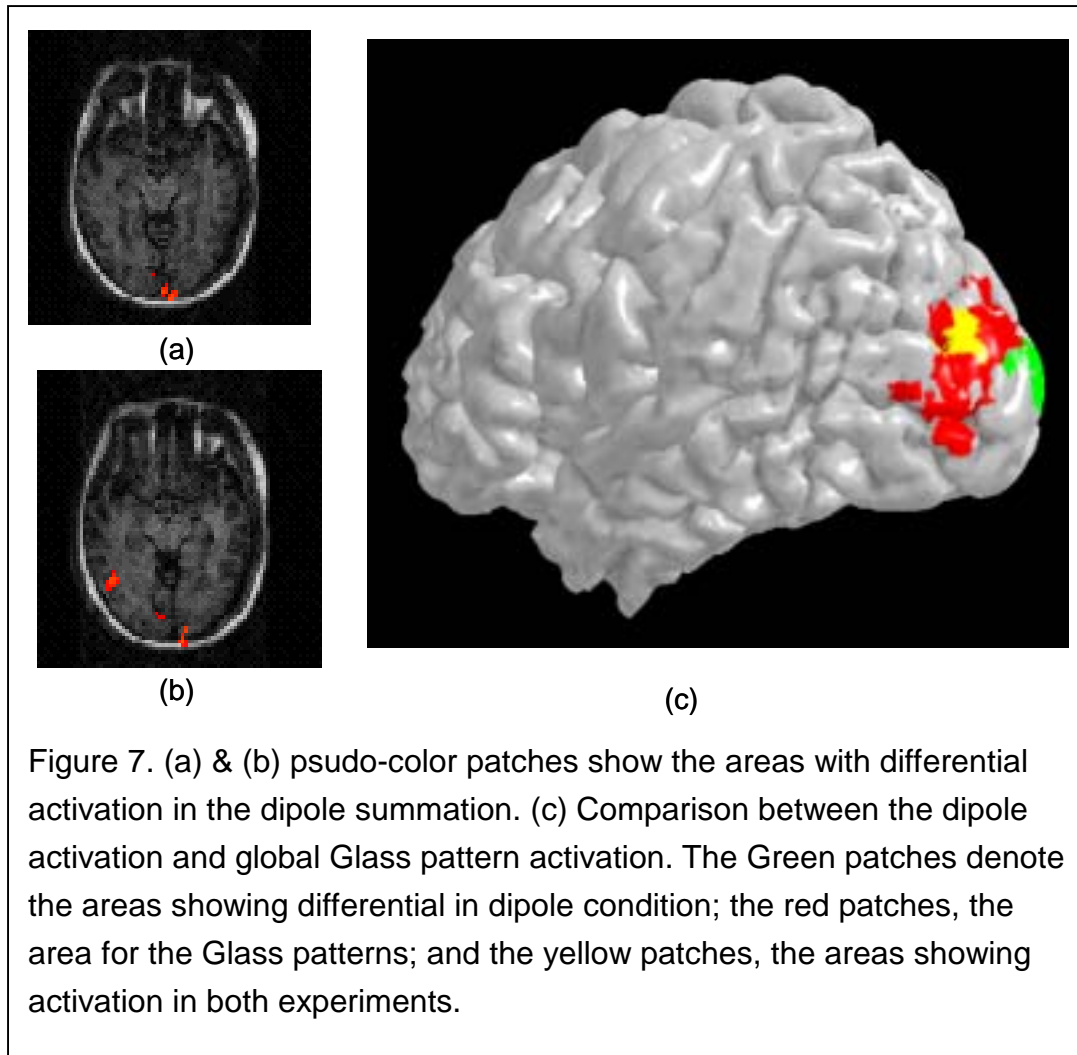


Figure 6. Examples of stimuli used in the dipole summation experiments. (a) & (b): Glass patterns. (c) & (d): texture patterns.

The differential activation occurred both at the medial and the lateral occipital surfaces (Fig 7a and b). The medial surface activation was at the primary visual cortex. This activation is not surprising given that the local difference between the Glass pattern and the texture pattern conditions matches the localization properties of the neurons in the primary visual cortex. The activated area at the lateral surface overlapped with that for the Glass pattern itself. The Green patches in Fig 7c denote the areas showing differential activation between the Glass pattern and the texture patterns. The red patches denote the area showing differential activation between the Glass

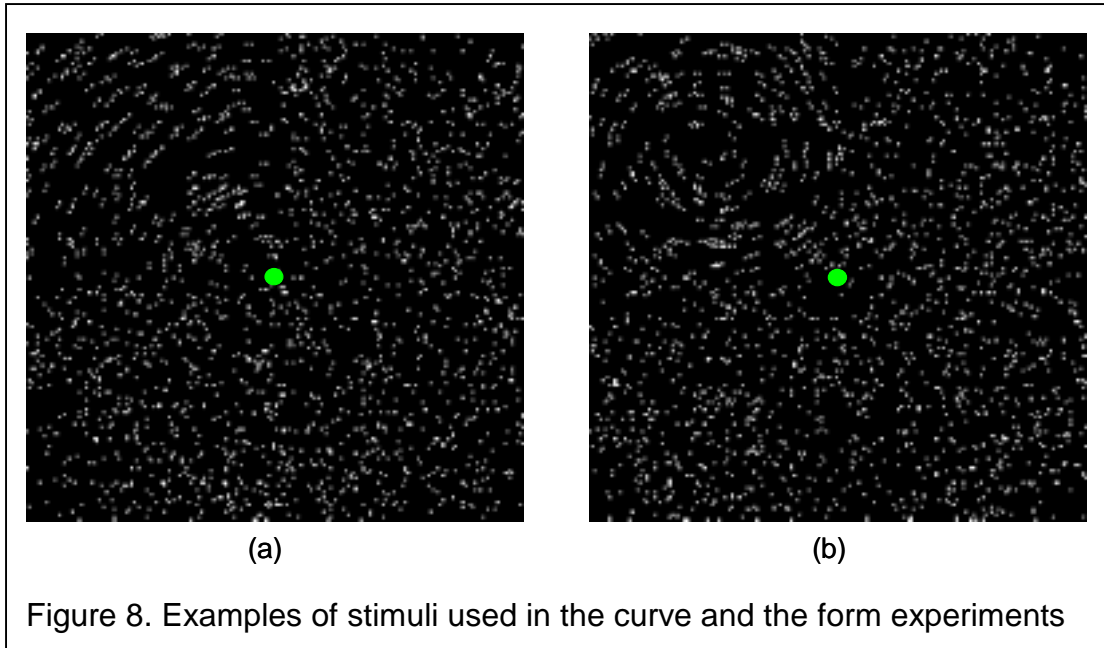


pattern and its zero coherence control. The yellow patches are the areas showing activation in both experiments. The overlapped area is at the dorsal proportion of the Glass pattern activation. The significance of the dorsal activation will be discussed below.

The result of this experiment was already presented in the annual meeting of the Society for Neuroscience in Nov. 2004.

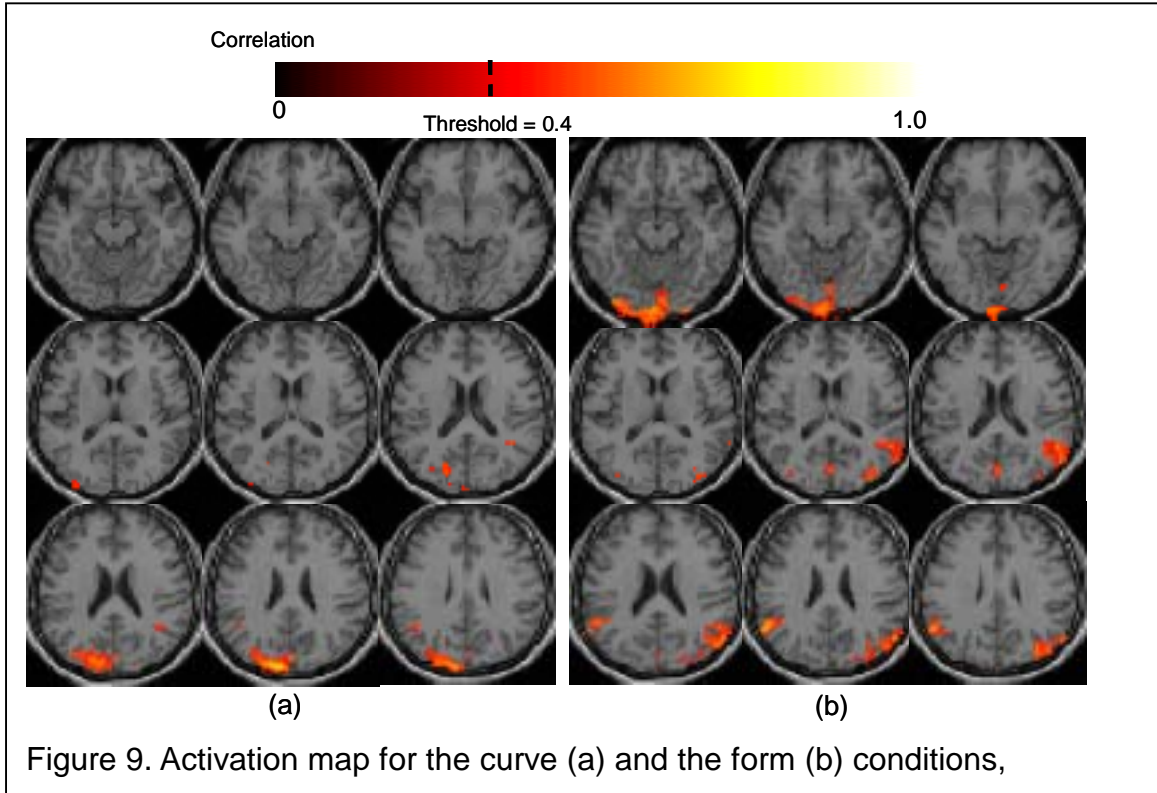
Activation to curves and forms

Next, we examined the brain activation to curves and forms. In the curve condition, the stimuli were consisted of a quarter of the concentric Glass pattern discussed in the General Method section in one quadrant and zero-coherence pattern in the other three quadrants (Fig 8a). The quadrant showing Glass curves rotated 90° clockwise every nine seconds (3TR). It took 36 s for the Glass curves to rotate a full cycle and there were six cycles in one experimental run. For a fair comparison, the shape condition has the same spatio-temporal configuration as the curve condition except that there is a



concentric Glass pattern in place of Glass curve in the designated quadrant (Fig 8b).

Figure 9 shows activation map for these two experiments. Fig. 9A shows the activation map for the curve condition while Fig. 9B shows the activation map for the form condition. The form condition activated the inferior occipital gyrus and the middle occipital gyrus. The curve condition activated the middle occipital gyrus. However, there is little overlap between the curve and the form



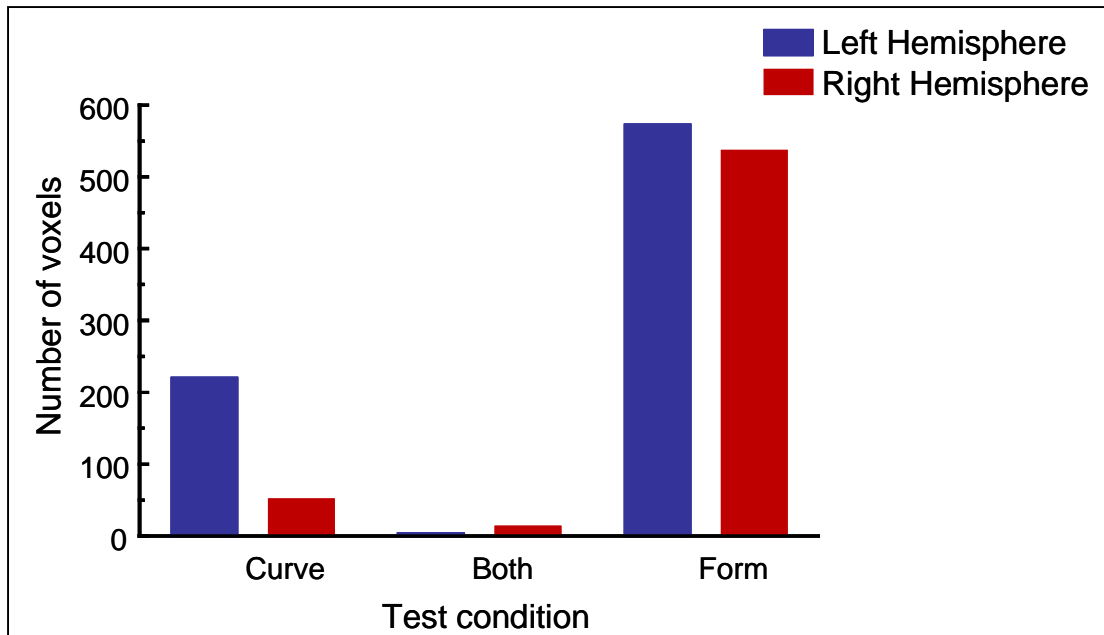


Figure 10. Histograms of voxels activated in curve, form or both conditions.

activations. As shown in Fig 10, while there were hundreds of voxels activated in either the curve or the form condition, there were only about 20 voxels showing activation in both conditions. In general, areas activated by the form condition were anterior and ventral to those activated by the curve condition.

The results of these two experiments were already presented in the annual meeting of the Vision Sciences Society in May 2005.

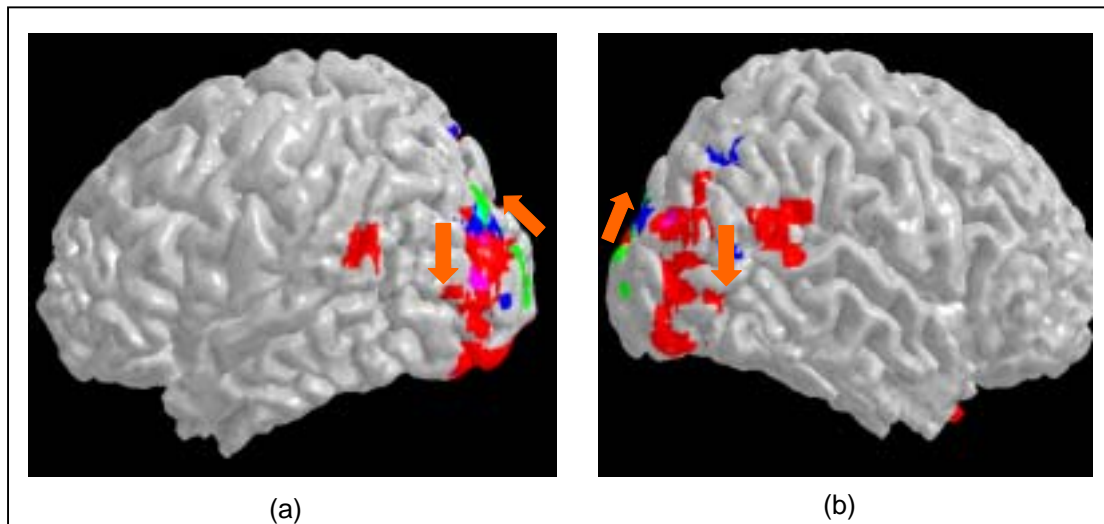


Figure 11. Summary of the three experiments. The green patches denote the voxels showing differential activation between the Glass pattern and the texture patterns. The blue patches denote voxels showing significant activation in the curve condition and the red denotes voxels activated in the form condition.

Evidence for Hierarchical Processing in Form Perception

Figure 11 sums up the result of all the experiments reported here. The green patches denote the voxels showing differential activation between the Glass pattern and the texture patterns. Hence, those are voxels responsible for local dipole grouping. The blue patches denote voxels showing significant activation in the curve condition and the red denotes voxels activated in the form condition. It is obvious that the voxels activated by the dipole condition are either posterior or dorsal to those activated by the curve and the form conditions. The voxels activated by the curve conditions are either posterior or dorsal to those activated by the form condition. Given that the dipole, curve and form condition each targets a stage, from local to global, in form perception processing, we can conclude that the flow of the ventral stream, from local to global, goes from posterior to anterior and from ventral to dorsal on the lateral occipital surface.

Reference

- Aguirre, GK, Zarahn, E & D'Seposito, M. (1998). An area within human ventral cortex sensitive to "building" stimuli: Evidence and implications. *Neuron* 21: 373-383.
- Friston, K.J. Holmes, A.P., Worsley, K.J., Poline, J.P., Frith, C.D., and Frackowiak, R.S.J. (1995). Statistical parametric maps in functional imaging: a general linear approach. *Human Brain Mapping* 2, 189-210.
- Gallant JL, Braun J, Van Essen DC. (1993). Selectivity for Polar, Hyperbolic, and Cartesian Gratings in Macaque Visual-Cortex. *Science* **259**: 100-103.
- Gallant JL, Connor CE, Rakshit S, Lewis JW, Van Essen DC. (1996). Neural responses to polar, hyperbolic, and Cartesian gratings in area V4 of the macaque monkey. *J Neurophysiol* **76**: 2718-2739.
- Glass L. (1969). Moire effect from random dots. *Nature* **223**: 578-580.
- Grill-Spector, K, Kushnir, T, Edelman, S, Avidan-Carmel, G, Itzchak, Y & Malach, R. (1998). A sequence of object-processing stages revealed by fMRI in the human occipital lobe. *Human Brain Mapping* 6: 316-328.
- Hubel DH, Wiesel TN. (1962). Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. *J Physiol* **160**: 106-154.
- Hubel DH, Wiesel TN. (1968). Receptive fields and functional architecture of monkey striate cortex. *J Physiol* **195**: 215-243.
- Kanwisher, N. McDermott, J. & Chun, MM (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *J. Neuroscience* 17, 4302-4311.
- Stehling MK, Turner R, Mansfield P. (1991). Echo-planar imaging: magnetic resonance imaging in a fraction of a second. *Science* **254**: 43-50.
- Wandell, B.A., Chial, S. and Backus, B.T. (2000) Visualization and measurement of the cortical surface. *Journal of Cognitive Neuroscience* 12, 739-52.
- Wilson HR, Wilkinson F, Asaad W. (1997). Concentric orientation summation in human form vision. *Vision Res* **17**: 2325-2330.
- Wilson HR. (1985). Discrimination of contour curvature: data and theory. *J Opt Soc Am A* **2**: 1191-1199.