# 行政院國家科學委員會專題研究計畫　成果報告

## 知覺群聚的神經生理基礎

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The Neurophysiological Basis of Perceptual Organization: The Sequential Processing

Perceptual grouping refers to the phenomenon that a human observer integrates image components together to form a percept of a new object. Perceptual grouping is an essential function for the visual system. After all, to recognize objects in the input images, the visual system not only decomposes images to many components to extract essential features but also synthesizes information from individual features to form an integrated percept of an object.

This study tested the hypothesis that perceptual grouping is a multiple stage process and each stage is processed in different brain areas. The separate grouping stages in the early visual system are well known. For instance, the receptive field of a lateral geniculate nucleus (LGN) neuron has a simple concentric center-surround structure. The neurons in the primary visual cortex (v1) combined inputs from several LGN cells with collinear receptive fields to form an elongated receptive field (Hubel & Wiesel, 1962, 1968). This elongated receptive field allows a V1 neuron to extract edge information in an image. Neurons in the secondary visual cortex (V2) receive inputs from V1. Some of the V1 neurons receive inputs from V1 cells with neighboring receptive field but in different sign (excitation vs. inhibition). As a result, many V2 neurons show an end-stopping property. This end-stopping allows V2 neurons to extract curvature information in the image (Koenderink & Richards, 1988; Wilson & Richards, 1992).

Perceptual grouping beyond V1 or v2 are not well understood. In this study, we used Glass patterns (Glass, 1969) to probe perceptual grouping. Figure 1 shows examples of Glass patterns. A Glass pattern consists of randomly distributed dot pairs (dipole) with their orientation determined by a geometric transform. To perceive the structure in a Glass pattern, an observer needs to perform local grouping to find dipoles and global grouping across dipoles to perceive overall shape. Even the global grouping may involve several stages. For instance, to perceive a concentric Glass pattern, one has to integrate neighboring dipoles along

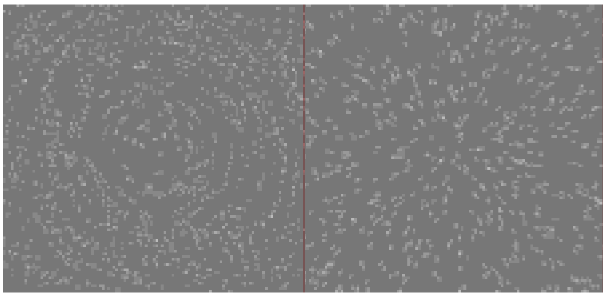

Figure 1. Examples of Glass patterns

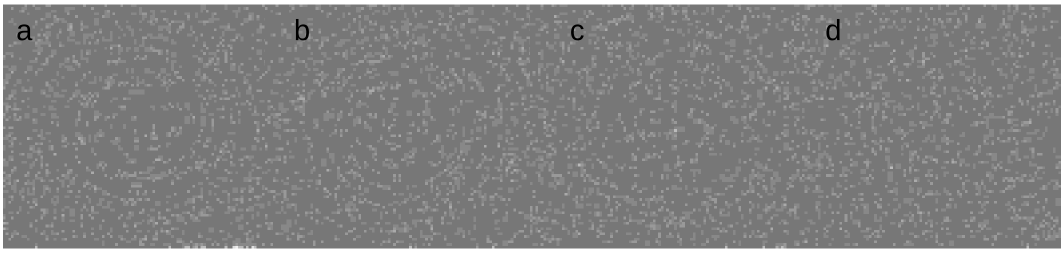


Figure 2. The visibility of concentric global form in Glass patterns reduces as the coherence

certain curvature to form curves and then link the curves to form a circle or a disk.

Different stages of perceptual grouping may be revealed by functional magnetic resonance imaging (fMRI). An fMRI experiment measured blood oxygenation level dependent (BOLD) signal change in the brain. The localized BOLD signal is correlated with the neural activity in that particular area (Logothesis et al. 2001). If we require an observer to perform a task that requires perceptual grouping, the BOLD signal should increase in the brain areas that are responsible for grouping.

We tested the hypothesis that perceptual grouping involves multiple stages in a sequence and different stages may be processed by different areas. Our strategy is to measure the BOLD activation as a function of coherent level of Glass patterns. The coherent level is defined as the proportion of dipoles with orientation determined by a geometric rules that required by the Glass pattern. For instance, a concentric Glass pattern with a coherent level of 75% will have 75% of dipoles with orientation tangent to a circle while 25% of dipoles are

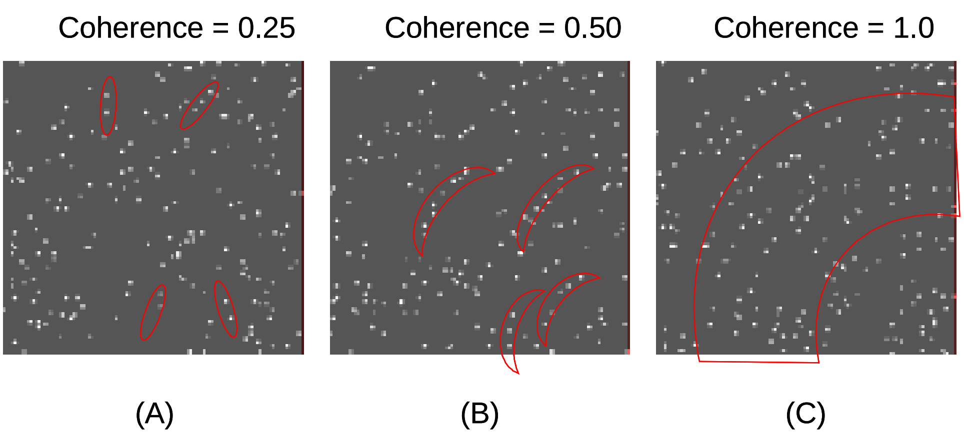


Figure 3. Glass patterns at different coherence levels activated different feature detectors. See text for detail

randomly orientated. Figure 2 shows Glass patterns at different coherent levels. A Glass pattern at a low coherent level, as shown in panel (A) of Figure 3, can only activate oriented filters that respond to the dipoles. As the coherent level increases, the pattern may contain enough curve fragments to activate local curvature detectors (Fig 3 (B)). However, only Glass patterns with very high coherent levels have sufficient information to activate the global shape detector. Hence, different brain areas should have different dynamic range in coherence. An area for line detection should have the same activation regardless the coherent level and therefore should saturate even at very low coherent levels. Areas for curve processing should begin to respond and saturate at moderate coherent levels where the Glass patterns contain sufficient amount of curve fragments. Finally, areas with global form detectors saturate only when the global is good enough. Therefore, the dynamic range of the coherence response function indicates the stage of perceptual grouping.

**Main Results**

Method. The Glass patterns contained randomly distributed dipoles covering 2% of image. Each dipole contained two 5.4' square dots separated by 27'. The size of the Glass pattern was $9^o$x$9^o$. The coherence of a Glass pattern was defined as the proportion of dipoles oriented tangent to a concentric global form. We used five coherent levels, 1.0, 0.87, 0.75, 0.63, and 0.5 in the test conditions and 0 coherence (completely random) in the control condition.

BOLD activation was collected on a Bruker 30/90 Medspec 3T scanner (Bruker Medical, Ettlingen, Germany) with a cylindrical head coil. The scanner is located in National Taiwan University. The functional scan (T2*-weighted, BOLD) and anatomical (T1-weighted, 256 x 256) was acquired in identical planes. The images were collected in 15 or 18 transverse planes parallel to the AC-PC (anterior commissure-posterior commissure) line with a 30cm FOV and an image matrix of 128 x 128. An Echo-planar imaging sequence (Stehling, Turner & Mansfield, 1991) will be used to acquire the functional data (TR = 3000ms, TE = 60ms, flip angle = 90o, voxel resolution = 2.34 x 2.34 x 3mm).

Each of the six block design run had one Glass pattern at one of the six coherences alternated with their zero coherence counterparts in a 36s period. There were six periods in each run. There were nine second (3TR) burning scans ahead of each run that were not included in data analysis. Totally, there were 252s in each run.

We used SPM99 software (Friston et al., 1995) to correct for head movement for each functional scan session. The corrected functional images were then coregistered with the T1-weighted images of the same observer. Both functional and T1-weighted images were normalized to the standard template. The normalized functional images from the same conditions were then averaged across observers.

The analysis of functional data was based on a spectral correlation algorithm (Engel et al., 1997). Since our experiments were block designs with six periods, the correlation coefficient of one voxel is essentially the amplitude of the sixth harmonic of the Fourier spectrum normalized by the total Fourier amplitude of that voxel time series. If the spectral correlation of a voxel is greater than 0.475 ($t(70)=5.132$, uncorrected $\alpha \sim 1x10\text{-}6$), the activation of this voxel was considered as driven by the experimental condition. The activated voxels were marked with pseudo-color and overlaid on T1 weighted images and a 3D rendering of the averaged brain. The 3D rendering is made with vista software (Wandell et al., 2000) provided by Stanford University.

Result and discussion. Figure 4 shows the averaged activation map to Glass patterns at 1.0 coherent levels. Compared with the zero coherent patterns, the Glass patterns with 0.5 to 1.0 coherent levels activated the middle occipital gyrus (MOG), and the inferior temporal gyrus (ITG) in both hemisphere and the superamariginal gyrus (SMG) in sthe right hemisphere. The activation in MOG and ITG increases with coherence.

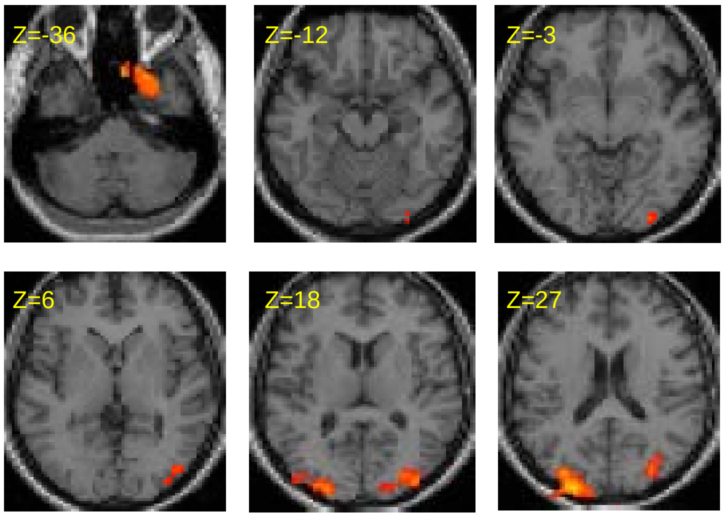

Figure 4. Activation map to 1.0 coherent Glass patterns. The pseudo-color spots denote activated areas

The activation time series in each area was fitted with a sinusoidal function. The amplitude of the sinusoidal function is then taken as the response strength in that area. Figure 5 shows the averaged coherence response function for six observers. The error bars in Figure 5 denote the inter-observer standard deviation. The response functions were fitted by a cumulated Gaussian functions with the mean representing the location and the scale ("standard deviation") representing the slope of the response functions (lager scale factor means shallower slope). While the location of the response function is different (from 0.3~0.7) in each area (see Figure 6), the slope is about the same for IT and MOG (scale factor around 0.1~0.2). Hence, we show that not only there are multiple cortical sites for processing global features of Glass patterns but also show that these sites do have different dynamic ranges. All these results are consistent with the sequential processing model of Glass pattern processing in particular and perceptual grouping in general.

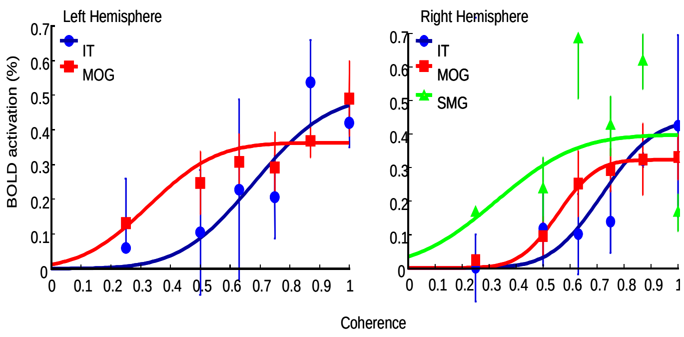


Figure 5. BOLD activation vs. coherence function

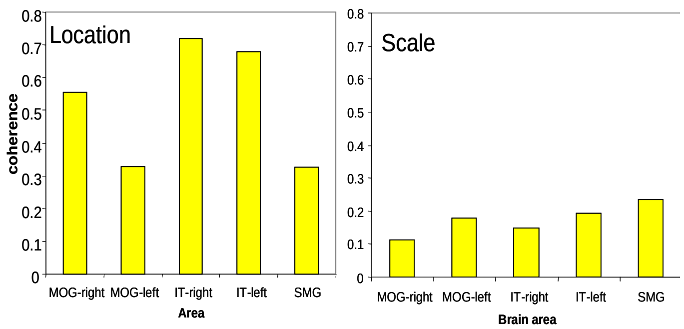


Figure 6. Location and scale parameters of BOLD coherence response function in different brain areas.

**Other results**

BOLD activation without local grouping. To further demonstrate that the MOG and IT are processing different levels of global features, we eliminated the local grouping in a Glass patterns using line segments in place of dipoles. The result with coherent level 1.0 is shown in Figure 7. Removing local grouping does not change the result at all. We still get IT and MOG activation. Hence, the mechanisms for local grouping should occur earlier than MOG and IT. The failure to show the activation for local grouping is consistent with the hypothesis that the mechanisms for local grouping for the high coherent Glass patterns are the same

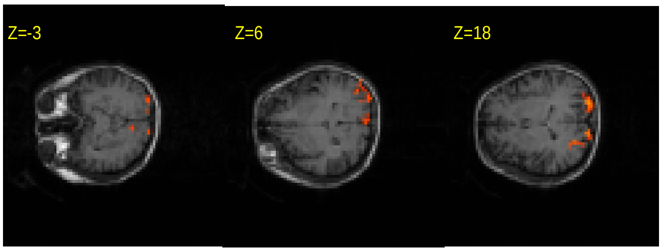


Figure 7. BOLD activation to global patterns consisted of line elements

as those for zero coherence patterns. Thus, the global features in Glass patterns have no effect on the local grouping. This again is consistent with the sequential processing of the Glass patterns but not a distributed processing model.

Psychophysics. Psychophysical evidence also suggests a local vs. global processing of Glass patterns. Figure 8 shows psychophysics functions for two experiments. We used a two-alternative forced-choice paradigm. In the detection experiment, one interval, determined randomly, contains a zero coherent pattern while the other a non-zero coherent pattern. The task of the observer was to determine which one of the two intervals contained a concentric structure. The discrimination experiment required the observer to choose the interval with a concentric structure against the other interval which had a hyperbolic structure. The detection task was achieved by perceiving very localized curvature fragments while the discrimination task required more global features to allow the observer telling the difference between the two structures. The result clearly shows the psychometric functions (probability of correct response against coherence) for the two tasks do have different dynamic ranges with the discrimination tasks operating in a higher coherent range than the detection.

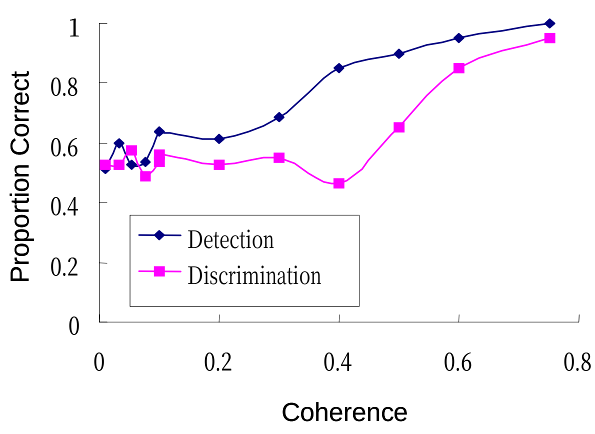


Figure 8. Psychometric function for two behavior test conditions.

**Conference Presentation**

The study was presented in the annual meeting of the Vision Sciences Society meeting held in Sarasota, Florida in May 2004. This study attracted much attention from the audience. One reason was that Tjan et al. showed another sequential processing model for natural images based on the slope of the response rather than the dynamic range. Our result clearly indicates the slopes do not change across different cortical sites but the dynamic ranges. Hence, we pretty much refuted that study.

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