Detection of Glass pattern configurations by the primary visual cortex

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Introduction

The neurons in the primary visual cortex that respond to the orientation of visual stimuli were discovered in the late 1950s by Hubel and Wiesel[1,2], but how they achieve this response is poorly understood.

Recently, psychophysical experiments[3] have demonstrated that the visual cortex may use both the image processing techniques of cross or auto-correlation to detect oriented streaks in noisy dot patterns. The experiments showed that the techniques could be inferred from how the threshold of detection of specially constructed patterns using arrays of coherently arranged dots in the presence of random noise varied as a function of the dot density. The types of patterns used were parallel Glass patterns and sinusoidally modulated random dot patterns (see Figure 3 and 4).

In the present study, the detection thresholds have been measured for other types of patterns including circular, hyperbolic, spiral and radial Glass patterns.

What is cross-correlation?

- For two-dimensional images, this is given by:

$$\gamma = \frac{1}{N}\sum_{x,y}\frac{\left(I(x,y)-\bar{I}\right)\left(T(x,y)-\bar{T}\right)}{\sigma_I\sigma_T}$$

and arises from the established fact that simple cells act as oriented spatial filters[4,5] .

What is auto-correlation?

- For two-dimensional images, this is given by:

$$\alpha = \frac{1}{N}\sum_{x,y}\frac{\left(I(x,y)-\bar{I}\right)\left(I(x-u,y-v)-\bar{I}\right)}{\sigma_I^2}$$

It has been suggested that this is an important mechanism for detecting motion[6] and Glass patterns[7](see Figure 1).

Figure 1: Original demonstration of a Glass pattern resulting from rotating a copy on a transparency of an image produced by spraying black paint on white paper and superimposing on the original.

Methods

(a) *Procedure:* The psychophysical experiments performed in this study have been described elsewhere[3]. Essentially, a series of randomly chosen dot patterns (in three separate sets of experiments) were presented on a monitor in a quiet room and a subject (at a fixed distance from the monitor) was requested to indicate whether the pattern was (1) circular or spiral (2) expansion or hyperbolic (3) parallel or grating (see Figure 4) in a two-alternative forced-choice procedure (2AFC) with a single temporal presentation to determine the threshold of detection (the coherence threshold) as a function of dot density - the average number of dots per location in the pattern. Figure 2 shows how the coherence, *C* - that is the strength of the Glass pattern relative to the noise given by (2 x Number of pairs) / Total number of dots - is calculated.

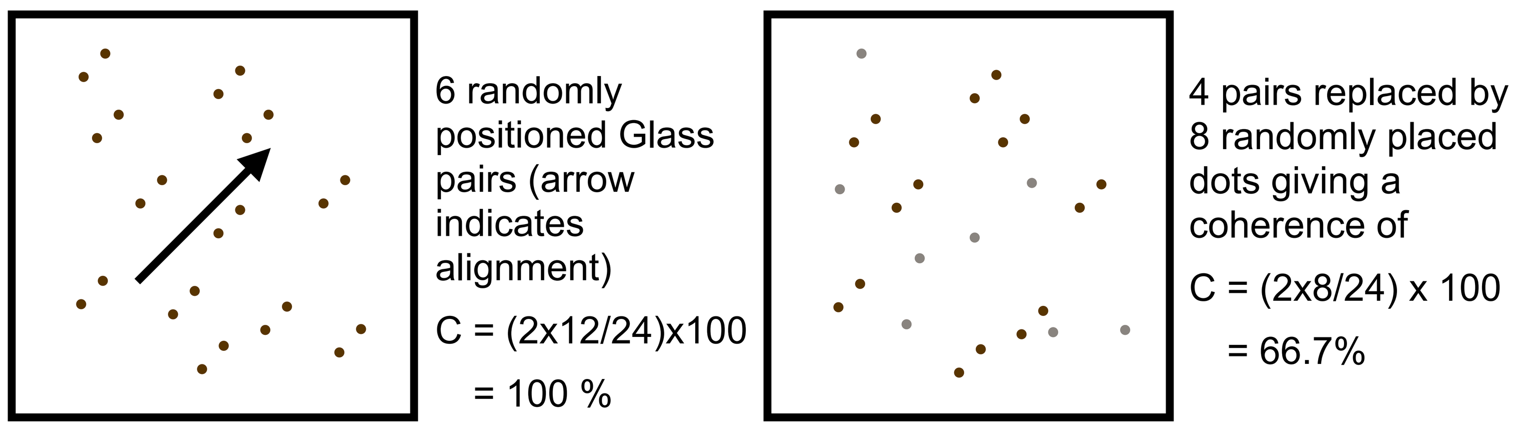

Figure 2: Constructing a Glass pattern using pairs of dots separated by a fixed distance

Figure 3 demonstrates the effect of reducing coherence, *C*, on the patterns. The programs were written in MATLAB using the psychophysics toolbox extension[8].

(b) *Simulations:* Parameters for cross- and autocorrelation were set at their optimum parameters: for cross-correlation the template was matched exactly to to the size, shape, spatial frequency, phase and orientation of the test patterns: for autocorrelation, the test pattern was multiplied by its copy shifted by one Glass pair separation in the direction of the separation - see insert. For comparison with experimental thresholds, we determined the modulation or coherence for which the discriminability index $d' = (M_{SN} - M_N) / S_N$ is equal to 2, where M_{SN} is the mean of the distribution of values of cross- or auto-correlations determined for sample populations at specified values of modulation or coherence. M_N and S_N are the means and standard deviations of equivalent distributions of sample populations for zero modulation or coherence.

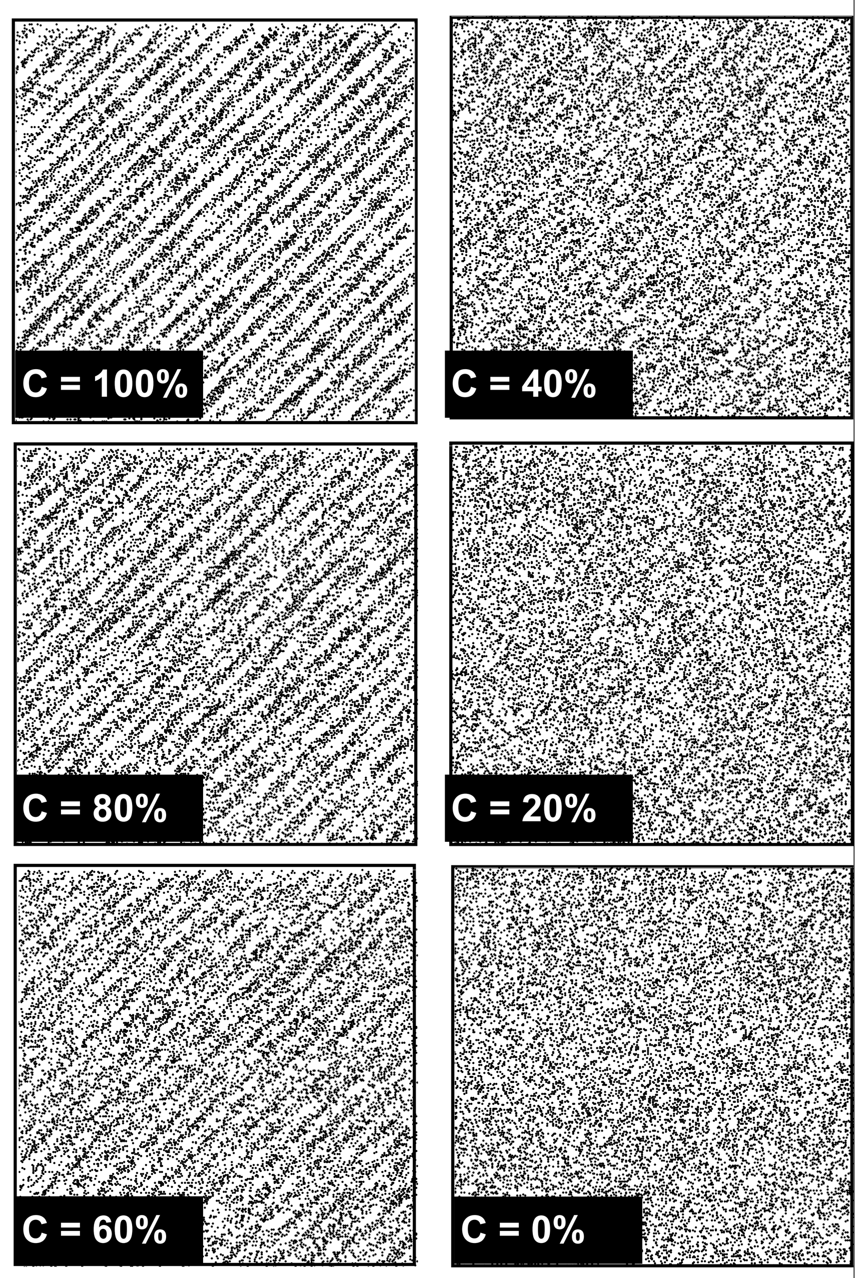

Figure 3: Effect of coherence on a sinusoidally modulated parallel Glass pattern: As coherence is reduced, the streaky appearance gradually disappears.

Results

Figure 6 shows the results for the determination of the coherence threshold as a function of dot density (log-log coordinates) for two subjects.

The dotted lines in graphs (a) - (d) are lines of linear regression; in all these graphs, the slopes of these lines are approximately zero. This is also the case for graph (e) - the results for the parallel Glass patterns, but included in this graph are the results of an autocorrelation model (solid line) adjusted to fit to the data (fitting factor = 13.9). The solid line in graph (f) - the results for the grating patterns - is determined using a cross-correlation model also adjusted to fit the data (fitting factor = 6.3).

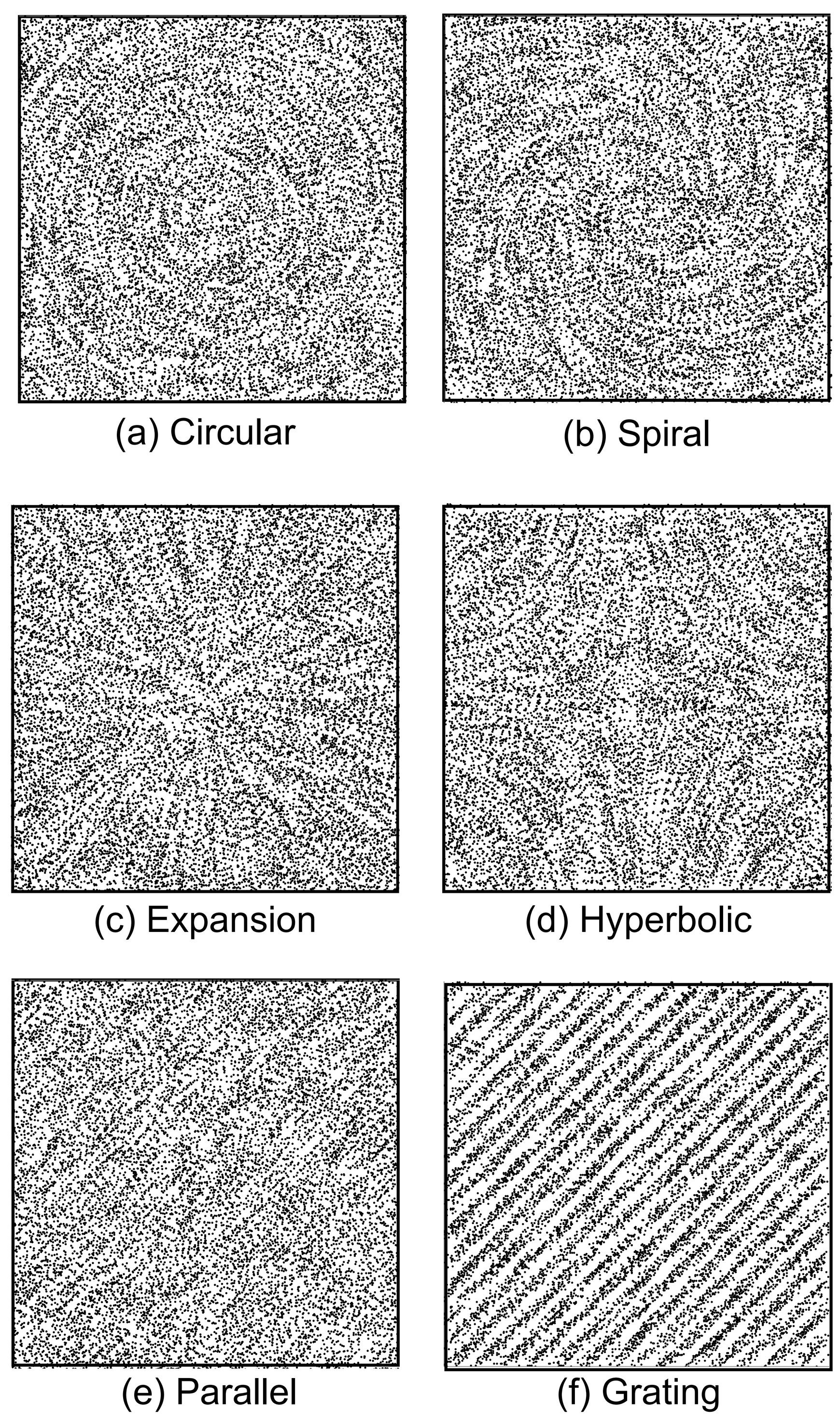

Figure 4: Types of Glass patterns used in this study

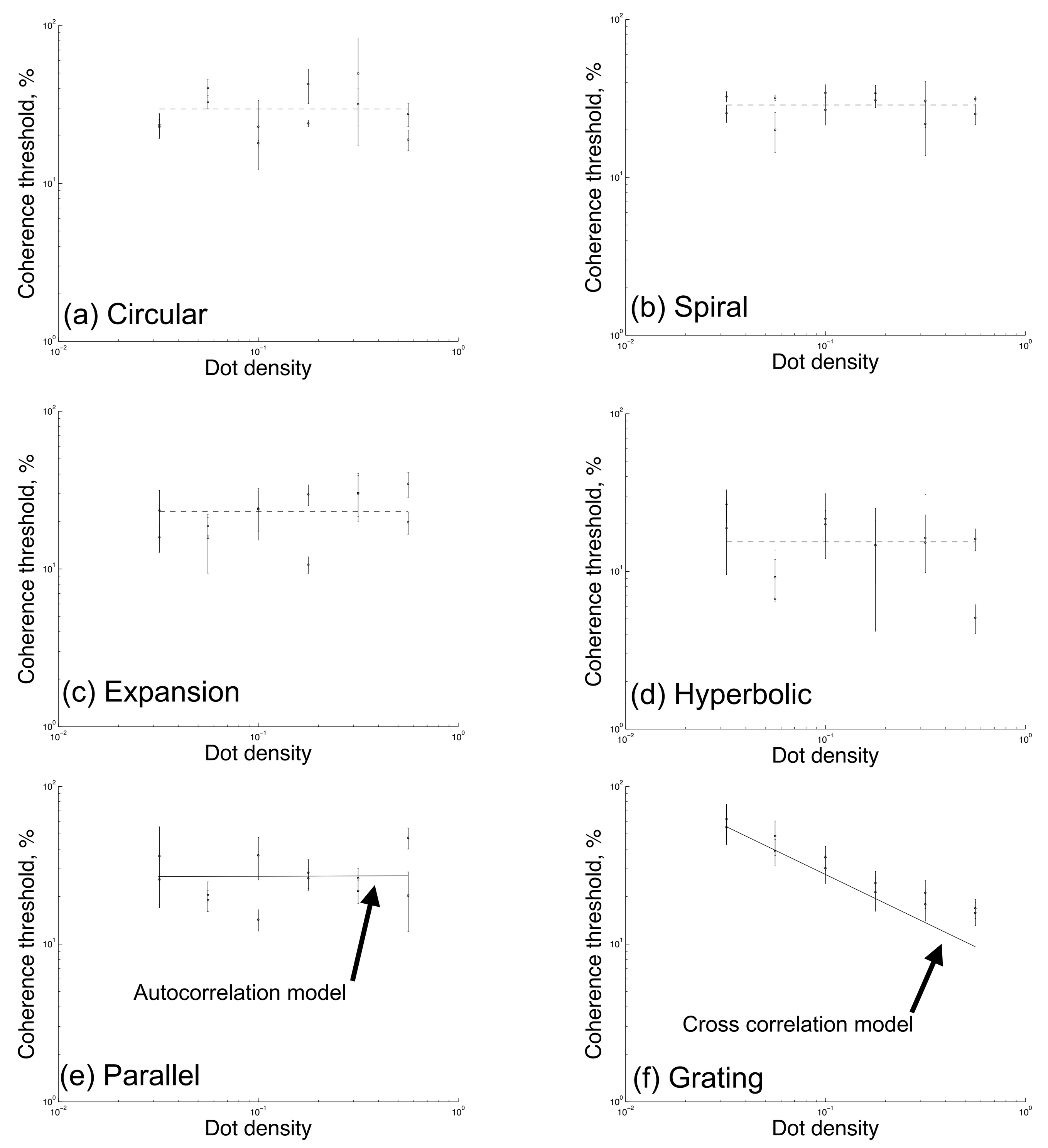

Figure 5: Detection thresholds for various types of Glass patterns

Discussion

The psychophysical results indicate that the early vision uses two types of processing for detecting patterns created by modified random dot patterns. Clearly, the streaks produced by coherent pairs of dots in the Glass patterns demonstrated in Figure 5 (e) are detected by an auto-correlation mechanism - the detection threshold is invariant to dot density. It is proposed here that the modified Glass patterns in Figures 5(a)-(d) are also detected by an autocorrelation mechanism but how this is achieved is unclear. What is particularly interesting here is that the grating modified Glass pattern demonstrates a different variation of detection threshold with dot density, indicative of a cross-correlation mechanism and which provides a much more powerful response than that of the auto-correlation detection mechanism.

References

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