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Summation of concentric orientation structure: seeing the Glass or the window?

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Abstract

Rotational Glass patterns are discriminable from noise at substantially lower signal-to-noise levels than translational patterns, a finding that has been attributed to the operation of concentrically tuned units in cortical area V4 (Wilson, Wilkinson, & Asaad, Vis. Res. 37 (17) (1997) 2325; Wilson & Wilkinson, Vis. Res. 38 (19) (1998) 2933). Under experimental conditions similar to Wilson et al. we found this advantage to be largely contingent on the pattern being viewed through a circular aperture. Because rotation of a random dot set cannot lead to the presence of unmatched dots at the boundary of a circular aperture, the integrity of low spatial frequency information at the boundary reliably indicates the presence of rotational, but not translational, structure. When we removed this cue, either using a square aperture or surrounding a round aperture with noise dots, none of the nine subjects tested showed any statistically significant advantage for rotational Glass patterns (although at least two did take longer to master the task with translational compared to rotational patterns). We go on to show generally similar patterns of global integration for both rotational and translational patterns. We conclude that this paradigm presently offers no concrete psychophysical evidence for specialised concentric orientation detectors.

Keywords: Form vision; Pattern discrimination; Glass patterns; Global form

1. Introduction

Glass patterns are composed of a field of dot pairs (or dipoles) whose orientations are determined by some geometrical transformation (Glass, 1969). The impression gained from inspecting these patterns is of orientation structure corresponding to the transformation (e.g. rotation in Fig. 1b) indicating that the visual system is grouping members of the same dipole. For high-density patterns this grouping problem is compounded by the fact that dots will typically have a large number of dots closer to them than their dipole correspondent (Stevens, 1978). Various manipulations of the spacing, density, and contrast of Glass patterns have allowed the visual grouping processes underlying this phenomenon to be probed. Results are largely consistent with structure being derived not by specialised symbolic token matchers, but from the output of spatial filters (Dakin, 1997a,b, 1999; Prazdny, 1986; Zucker, 1985). In particular one of us has shown that observer's precision at judging the orientation of translational Glass patterns requires that they can access the output of oriented spatial filters at a narrow band of spatial frequencies (Dakin, 1997a). This shift in theoretical perspective is unsurprising given the success with which a variety of similar correspondence problems have been recast in terms of spatial filtering, (e.g., stereo, Ohzawa, DeAngelis, & Freeman (1990), and motion, Adelson & Bergen (1985)).

Filtering models focus on the idea that it is the local statistics of Glass patterns that limit subjects' performance on this task. However, Wilson and co-workers (Wilson & Wilkinson, 1998; Wilson, Wilkinson, & Asaad, 1997) have recently reported a finding that challenges the sufficiency of such an explanation. These authors showed that subjects' ability to report the presence of circularly windowed Glass patterns (composed of a large number of widely separated dot-pairs) depended on the type of orientation structure present in the pattern. Specifically, subjects' threshold signal to

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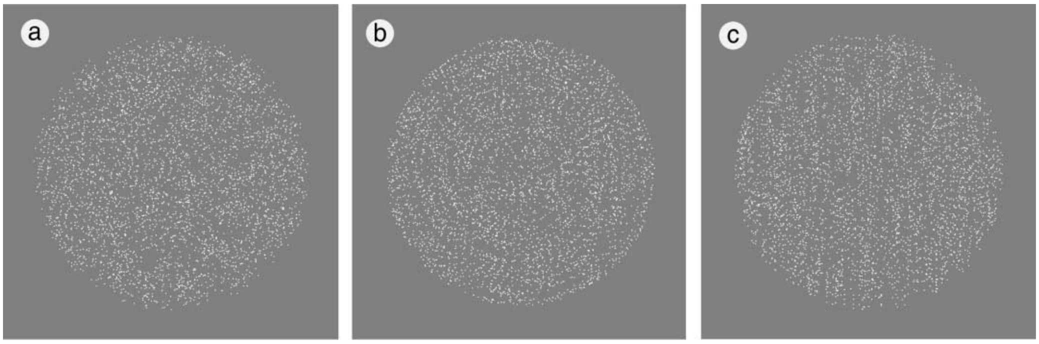

Fig. 1. (a–c) Glass patterns composed of 1966 dot pairs with a separation of 17.6 pixels. Dipoles are oriented according to (a) a random distribution (b) a rotation and (c) a 90° translation. It was observers task to discriminate between unstructured patterns (e.g. (a)) and structured patterns (e.g. (b)).

noise ratio for discrimination of Glass patterns from a field of randomly oriented dipoles was lowest for rotations, and highest for translations. Wilson et al. went on to model these data using concentric orientation summation units inspired by the response properties of cells in areas V4 of the macaque (Gallant, Braun, & Van Essen, 1993).

Previously (Maloney, Mitchison, & Barlow, 1987) used a similar experimental paradigm (estimation of threshold S/N ratios) but did not report substantial differences in performance that were dependent on transformation type. Dakin (1999) modelled these data using simple orientation statistics derived from the output of spatial filters, but also reported data from a similar experiment showing a small advantage for rotational patterns over translations. It is informative to note that the main difference between studies that have shown any effect (Dakin, 1999; Wilson & Wilkinson, 1998; Wilson et al., 1997) and those that have not (Maloney et al., 1987) is that the former used round, and the latter square, stimulus windows. Below, we show that windowing Glass patterns introduces low spatial-frequency artefacts near the pattern boundary that could confer a substantial advantage for rotational Glass patterns under the experimental conditions of Wilson et al.

Fig. 1 shows examples of the stimuli used in the experiments reported. Following Wilson and co-workers we used dense patterns (6% coverage = 3932 dots for a 256 pixel radius pattern with 2×2 pixel elements), with wide separations between members of each dipole (17.6 pixels = 10.0′ under experimental viewing conditions), and a circular stimulus window. There is an issue with the generation of these patterns similar to that encountered with random-dot motion stimuli: what does one do with elements that fall-off the edge of the display? One can either plot them regardless (as Wilson et al. did; Wilson, personal communication) or leave unmatched/singleton dipole elements at the pattern edge. Fig. 2a–c illustrates why this is never an issue for rotational patterns, placing dipoles in a circular region simply cannot lead to individual dots falling outside the delineated region. As a consequence this type of pattern will have more clearly defined edges than either a translational pattern or a Glass pattern composed of randomly oriented dipoles. Clearly such boundary cues will be stronger in the unusually dense patterns used in the Wilson et al. studies. This difference in edge-integrity is highlighted in Fig. 2d–f. Here we have convolved the Glass patterns shown in Fig. 1, with an isotropic spatially band-pass filter to highlight information at low spatial frequencies. Notice that the blobs around the edge of Fig. 2e are longer and of higher contrast than corresponding features around the edge of either the translational or random orientation textures (Fig. 2d and f). Given that observers' task is to discriminate between structured and unstructured patterns (e.g. Fig. 1a versus b) we sought to test if this edge integrity cue could confer an advantage for rotational compared to translational patterns.

In the following sections we describe the results from various experiments bearing on the edge integrity hypothesis. The first uses stimuli closely matched to Wilson et al. and shows that the advantage for rotational patterns is contingent on the stimulus window being circular. When gross edge effects are corrected, we go on to report that 9/9 subjects show no significant advantage for rotational Glass patterns. Finally we show that reported differences in spatial summation between translations and rotations, cannot explain these findings. Subjects' summation shows some variation but is basically similar for both classes of patterns.

2. Methods

2.1. Equipment

An Apple Macintosh G3 computer controlled stimulus presentation and recorded subjects' responses. The programs for running the experiment were written in the Matlab environment (Mathworks Ltd.) using code from