

# Analysis of Spatial Structure in Eccentric Vision

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**The analysis of spatial structure, ie, the encoding of relative positions between pattern elements, was studied in central and eccentric vision. In a two-alternative forced-choice task the observer had to discriminate between two patterns consisting of short line segments. At each trial the two patterns were flashed for 140 msec and the observer indicated whether the patterns were identical or mirror symmetric. Psychometric functions were measured by changing pattern size at each eccentricity in order to find the threshold size allowing 75% of correct responses. The scaling factor, required for discriminating between mirror symmetric and identical patterns independent of eccentricity, was found to be similar to the size-scaling proposed by Levi et al (Vision Res 25:963, 1985) for vernier acuity tasks. Invest Ophthalmol Vis Sci 30:293-296, 1989**

During the last 10 years, there has been a considerable interest in investigating performance differences between central and eccentric vision in various visual tasks, and relating these differences to the anatomy and physiology of the visual system. Two groups of tasks have been studied extensively at different eccentricities. They are grating detection tasks<sup>1-4</sup> and tasks requiring not only the detection of a stimulus pattern but also the processing of positional relationships between pattern elements.<sup>5-9</sup>

Grating detection studies<sup>2-4</sup> have shown that detectability can be made similar at various locations of the visual field when the size of the stimulus grating is magnified in eccentric vision in inverse proportion to a cortical magnification factor estimated from cone and ganglion cell distributions,<sup>10</sup> under the assumption that areal representation in the striate cortex is in man directly proportional to the ganglion cell density of each retinal location (M-scaling). Tasks requiring the processing of positional relationships do not obey this rule, however; eccentric vision is inferior to central vision in performance even when stimulus patterns are M-scaled.<sup>5,7-9,11</sup> On the basis of the studies on the monkey striate cortex,<sup>12,13</sup> Levi et al<sup>7</sup> proposed that the cortical representation of the fovea is greater than that<sup>10</sup> estimated from the density of retinal ganglion cells corrected for foveal displacement. When the stimulus patterns in a vernier acuity task were size-scaled by means of the new estimates of the cor-

tical magnification factor, performance was similar in central and eccentric vision.<sup>7</sup>

Quite a different approach to the problem of size-scaling is to perform psychophysical measurements in which the pattern size is varied systematically in order to find constant performance at various eccentricities.<sup>14,15</sup> In the present study, we measured the proportion of correct discriminations between mirror symmetric and identical patterns at various eccentricities as a function of the pattern size. The stimulus patterns consisted of short line segments.<sup>11</sup> The discrimination between these patterns requires proper encoding of positional relationships between the line segments.

## Materials and Methods

### Apparatus and Stimuli

Stimulus patterns were generated using a Z80-based microcomputer (GVP-65 Graphic Video Processor, Lohja Corporation, Helsinki, Finland) on a medium resolution monitor (Finlux SM 9510H, Lohja Corporation) with a noninterlaced frame frequency of 50 Hz and tricolor phosphor (P22). Its green phosphor (P1) was used for generating patterns on a continuously present, white background (produced by P22). The width and height of the screen were 32 × 26 cm.

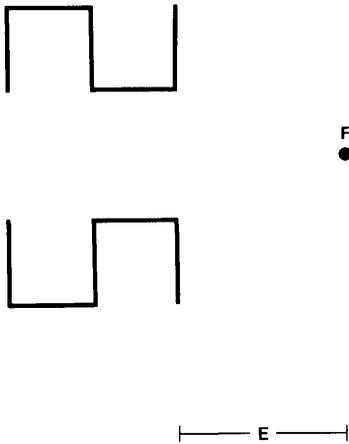
At each trial, two S-shaped patterns (see Fig. 1) were presented at corresponding eccentricities for 140 msec. The sideways S-patterns were shown one above the other. The patterns were either identical or mirror symmetric. The height of the sideways S-pattern was half of its total width; pattern size refers here to the width of the pattern. The vertical gap between the patterns was always 6.2 cm. The line width was approximately 1.5 mm. The luminance of the patterns,

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**Fig. 1.** An illustration of the stimulus patterns used in the experiments. The observer had to decide at each presentation whether the stimulus patterns were identical or mirror symmetric. Eccentricity (E) refers to the angular separation between the nearest edge of stimulus pair and the fixation point (F).

measured from a field densely packed with line segments, was approximately 80 cd/m<sup>2</sup>. The luminance of the background was 5 cd/m<sup>2</sup>.

**Procedure**

The observer viewed the screen with the right eye in a darkened room. The continuously present fixation point was a black dot on the screen in foveal viewing and a green, light-emitting diode in eccentric viewing. A bite-board stabilized the head and aided steady fixation. The eccentricities studied were 0°, 4°, 8° and 12° on the nasal half of the horizontal visual field meridian.

At each trial, the observer had to make a two-alternative forced-choice by deciding whether the two patterns presented were the same or mirror symmetric: in half of the trials the patterns were identical and in half they were mirror symmetric. Because the two alternatives were equiprobable, the proportion of correct discriminations was 50% when the observer performed at a chance level. The observer indicated his decision to the computer by pressing one of two keys on the computer keyboard. A warning tone preceded the presentation of stimulus patterns and another tone indicated the wrong responses.

At each eccentricity, the pattern size (the width of the sideways S-pattern) required for 75% of correct responses was estimated in the following ways:

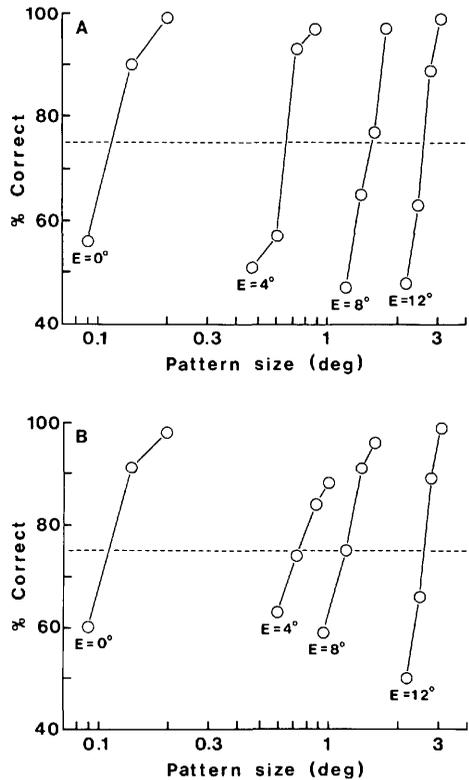
In central vision viewing distance was 5 m and the proportion of correct discriminations was measured

for the pattern sizes of 0.09°, 0.14° and 0.20°. Measurements were made in one to three blocks of 50 trials.

In eccentric vision, the patterns were made equally visible before the estimation of threshold pattern size started. This was achieved by M-scaling the patterns. M-scaling was performed by reducing viewing distance with increasing eccentricity in proportion to the cortical magnification factor M. The values of monocular M were calculated from Rovamo and Virsu's<sup>10</sup> equation:

$$M = 7.99 / (1 + 0.33E + 0.00007E^3) \quad (1)$$

where E is nasal eccentricity in degrees of visual angle. Hence, at the eccentricities of 4°, 8° and 12° the viewing distances used were 215, 136 and 98 cm. The smallest pattern sizes at which the estimation of



**Fig. 2.** The percentage of correct discriminations at eccentricities (E) of 0°, 4°, 8° and 12° on the nasal half of the horizontal visual field meridian. The broken line indicates the level of 75% of correct responses. Observers: JS (A), JL (B).

threshold size started were 0.20°, 0.32° and 0.44° at 4°, 8° and 12° eccentricities. After equalizing the visibility of the stimulus patterns, their physical size on the monitor was changed in steps of 5 mm, corresponding to 0.13°, 0.20° and 0.30° increments or decrements at 4°, 8° and 12° eccentricities. The proportion of correct responses for each pattern size was then measured in the same way as in central vision.

**Observers**

Two observers participated in the experiments. JS, one of the authors, was highly trained. JL had less experience in this kind of discrimination task. Both observers wore glasses with appropriate foveal refractive corrections.

**Results**

Figure 2 shows the proportion of correct discriminations as a function of pattern size at each eccentricity for the two observers. These results indicate that it is also possible to discriminate between mirror symmetric patterns in eccentric vision when the pattern size is large enough.

The pattern size that produces 75% of correct responses at each eccentricity was estimated graphically from the results of Figure 2. This threshold pattern size is plotted as a function of eccentricity in Figure 3, which also shows two predictions for threshold sizes. The predictions were calculated from Rovamo and Virsu's<sup>10</sup> and Levi et al's<sup>7</sup> versions of the cortical magnification factor in the following way: the pattern size corresponding to 75% of correct responses in central vision was first transformed into cortical terms with the magnification factor of the central-most fovea. The constant cortical threshold size thus estimated was then transformed into degrees of visual angle with the magnification factors of the eccentricities of 4°, 8° and 12° used in the experiments.

In eccentric vision, the threshold sizes actually measured were distinctly larger than the sizes predicted from the ganglion cell density distribution corrected for foveal displacement.<sup>10</sup> The threshold sizes measured here were, however, similar to the sizes predicted from the values of the cortical magnification suggested by Levi et al.<sup>7</sup>

**Discussion**

The current results show that size-scaling which produces equal contrast sensitivity at various locations of the visual field<sup>3,4</sup> does not make discrimination between clearly suprathreshold mirror symmetric patterns similar in central and eccentric vision.

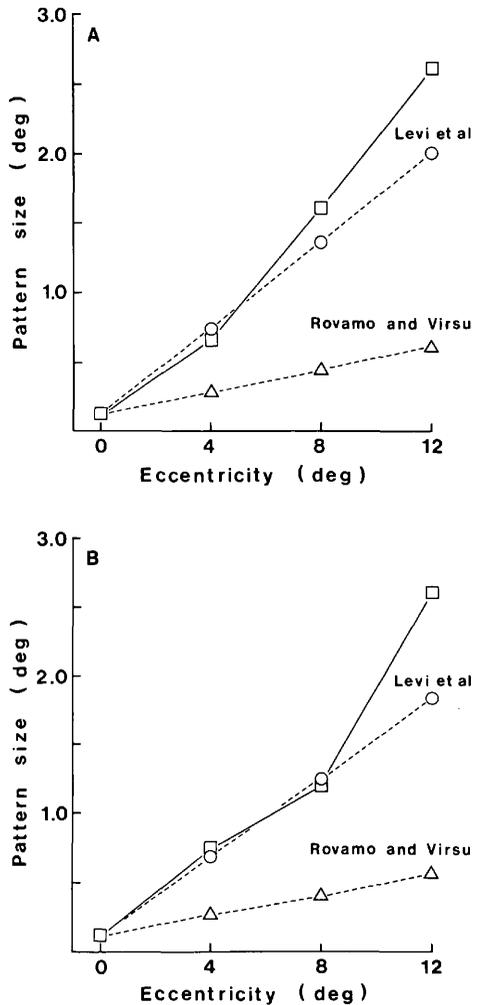


Fig. 3. The threshold pattern size (for 75% of correct responses estimated graphically from Fig. 2) as a function of eccentricity. The broken lines show the predictions for the threshold sizes calculated using Rovamo and Virsu's<sup>10</sup> (triangles) and Levi et al's<sup>7</sup> (circles) versions of the human cortical magnification factor. Observers: JS (A) and JL (B).

This result agrees with the notion that M-scaling of the stimulus patterns does not eliminate the performance differences between central and eccentric vision in tasks requiring the processing of positional relationships.<sup>5,7,8</sup>

There are many possible reasons for the failure of M-scaling.<sup>9</sup> For instance, the representation of the

fovea in the striate cortex may be larger than the prediction from the cone and ganglion cell density distributions.<sup>12,13,16,17</sup> However, the recent estimates of the magnification factor of the human striate cortex derived from positron emission tomography<sup>18</sup> support Rovamo and Virsu's<sup>10</sup> estimates. On the other hand, it is also possible that there are qualitative differences between central and eccentric vision in the neural network, ie, differences in the connections between cells. One further possibility is that the striate cortex or the precortical visual system is not the principal limiting structure in the processing of positional relationships. The neural basis of the analysis of relative positions may lie instead in other cortical areas having their own magnification factors. Neurophysiological evidence from the monkey visual cortex shows that there are differences between the magnification factors of different cortical areas,<sup>19</sup> and different attributes of a visual stimulus may be processed by different cortical areas.<sup>20,21</sup> However, it is not clear which cortical areas would underlie the processing of relative positions between pattern elements. It also has to be emphasized that although the present results support the scaling factor proposed by Levi et al,<sup>7</sup> the cortical mechanisms underlying vernier acuity and the discrimination between mirror symmetric patterns are not necessarily the same.

There is also additional psychophysical evidence supporting the view of multiple scaling factors. Levi et al<sup>22</sup> measured the thresholds for detection and discrimination of unreferenced grating displacement in eccentric vision. These thresholds declined with increasing eccentricity at a slower rate than grating acuity. Hence, different scaling factors may be required, not only for grating detection and analysis of spatial structure, but also for some aspects of motion perception.

**Key words:** psychophysics, peripheral vision, form perception, striate cortex, cortical magnification factor

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