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Anisotropies in peripheral vernier acuity

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Abstract—Vernier acuity for short horizontal, vertical and oblique target lines was measured in many locations in the periphery of the visual field in normal human observers. In the 10 deg periphery, the average alignment threshold with oblique vernier lines in eight locations for three observers was 2.29 times higher than that with vertical and horizontal target lines. This oblique effect was found everywhere in the visual field. Similar conclusions are drawn for configurations in which the lines were replaced by just their distal endpoints, but here, additionally, performance was distinctly better when the dot pair was collinear with the fixation point, i.e. oriented radially, than when it was oriented tangentially. Both for vernier lines and for dot pairs, in all observers, horizontal configurations showed somewhat better thresholds than vertical ones. These results suggest an inherent pattern of connectivity throughout the visual field favoring processing in the cardinal orientations over the obliques, the radial over the tangential and, to a limited extent, the horizontal over the vertical.

Keywords: Alignment thresholds; oblique effect; peripheral visual field; retinal eccentricity; radial/tangential anisotropy; vernier acuity.

INTRODUCTION

In his papers on vernier acuity in 1979 and 1985, Jacob Beck used as his departure point the fact that in vernier acuity, under many conditions, two spots can be substituted for the traditional pattern of abutting lines. That dots can replace lines in an alignment task, first reported by Ludvigh in 1953, contradicted the only viable theory of vernier acuity, that of Hering (1899), according to which it is the averaging of local signs along the length of contours that enables localization with such high precision. Properties of dot alignment formed the subject of several studies in addition to Beck's (Sullivan *et al.*, 1973; Westheimer and McKee, 1977). The possibility of associating the orientation selectivity of cortical neurons (Hubel and Wiesel, 1962) with the task of judging the orientation of lines (Andrews, 1966)

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had led to the conjecture that vernier misalignment might be seen as an orientation change and hence have a substrate in orientation-selective neurons in the primary visual cortex. Replacing lines with dots strains this interpretation. Depending on their separation, the implicit orientation of the line joining two points can be judged just as well, and sometimes even better than if the line is drawn in explicitly and this requires enquiry into the adequacy of a pair of dots as a stimulus for such cortical units. Thus it is premature to allow vernier acuity to remain as merely a subset of orientation detection. Instead it suggests that it might be better to examine it within the frameworks of mechanisms for detecting the relative feature position (Beck and Halloran, 1979). The present study concentrates on line and two-dot vernier detection in the retinal periphery. In particular, an attempt is made to seek concordance with two properties that have been found to characterize line-orientation discrimination in the retinal periphery, namely, anisotropies associated with the meridional orientation of the test pattern and whether it is lined up with the fixation point (is oriented radially) or orthogonal to that direction (tangentially). The better the match between the findings on vernier and on line-orientation discrimination, the firmer the postulate of a common substrate.

A wide variety of visual tasks show better performance with horizontally or vertically oriented contours than with oblique ones (Appelle, 1972). There is consensus that the locus for this oblique effect is cortical because it manifests itself in such thresholds as line-orientation and alignment discrimination and the orientation of streaming random dots (Matthews and Qian, 1999; Westheimer, 2003b) but not in those depending predominantly on retinal processing, such as detection of the presence or discrimination of brightness of single lines, and to some extent also of resolution (Westheimer and Beard, 1998). Most of these experiments were performed with central vision, but when specifically looked for, an oblique effect can also be found in the periphery of the visual field (Davis and Zanker, 1998; Vandenbusche *et al.*, 1986). Line orientation discrimination is better by a factor of about 2 for horizontal and vertical lines than for obliques in all locations in the retinal periphery (Westheimer, 2003a).

That foveal alignment acuity is poorer with oblique than horizontal and vertical lines has been adequately documented (Corwin *et al.*, 1977; McKee and Westheimer, 1978; Saarinen and Levi, 1995; Westheimer, 2001; Westheimer and Beard, 1998). To ascertain whether this applies throughout the visual field, measurements in the periphery of the visual field are reported for vernier acuity with patterns that are oriented along the horizontal, vertical and the two principal obliques, 45 degrees and 135 degrees (see Note 1).

METHODS

The observer's task was to judge the direction of misalignment of either two short, almost abutting, lines, i.e. the traditional vernier stimulus, or two dots with fixed separation. Trials, which occurred at regular 3-second intervals, consisted of the

200 or 300 ms presentation of a target, and the observer was required to make a binary decision by pressing a computer mouse button. Data were accumulated in runs of 150 trials in which the target location and orientation remained constant. For each stimulus condition there were at least two runs on different days, whose results were averaged and analyzed by the method of probits to yield a threshold, which represented the misalignment whose direction could be correctly identified on 75% of occasions. Observation was binocular, but all effects were present also with monocular viewing. The standard error was always very close to 10% of the threshold values. Where ratios of thresholds are quoted, values larger than 1.2 or smaller than 0.8 then differ from 1.00 at least at the $p < 0.05$ level of significance.

Patterns were generated under computer control on Sony 15" Trinitron monitors. Screen luminance of areas with full brightness was 45 cd/m². Experiments were conducted in a semi-dark room which gave the unilluminated areas of the screen a luminance of about 1 cd/m², but left the outlines of the monitor quite dim. A small fixation square was continually visible. Target lines were white on black and anti-aliasing ensured smoothness regardless of orientation. Observation distance was adjusted according to the eccentricity.

The psychophysical method of constant stimuli was employed. For the determination of line-vernier thresholds, each presentation was chosen at random from an ensemble of seven patterns bracketing actual alignment, in three equal steps in either direction, and one completely aligned. Because the lines provided a reference, no comparison was needed to aid the observer in the decision of the direction of perceived misalignment. The two-dot vernier task does not contain such an explicit standard, hence a two-interval forced choice procedure was adopted. The observer was shown successively two patterns, separated in time by 500 ms, each consisting of two dots a fixed distance apart. The first was the standard configuration with the implicit line joining the distance having the orientation being tested in that particular run. In the second presentation, one of the dots was randomly displaced in a direction orthogonal to the line joining them. The observer had to decide on the direction in which that dots appeared to have been displaced relative to the implicit line joining the two dots seen in the first presentation. The stimulus ensemble here also consisted of seven members; it was actually generated by blocking out all but the distal end of the two lines making up the line-vernier patterns. Fortunately there is experimental evidence (Morgan *et al.*, 2000) that the two versions of the constant-stimulus psychophysical procedure yield comparable results.

Observers included the author and several undergraduate biology students, at least two of whom were unaware of the purpose of the research. Fragmentary results on two other observers, not further reported here, confirmed the findings. All observers wore refractive corrections as needed and had otherwise unremarkable visual status.

RESULTS

Line vernier thresholds

In each retinal location, vernier thresholds were obtained for target lines in four orientations: vertical, horizontal, 45 deg, i.e. lines tilted 45 deg clockwise from the horizontal as seen by the observer, and 135 deg. A full set of these thresholds was acquired in each of eight peripheral locations at a fixed eccentricity along the 0, 45, 90, 135, 180, 225, 270 and 315 deg meridians. In some observers, locations at other eccentricities were also probed. In trained observers there are no difficulties judging target configurations in the retinal periphery, but such thresholds are subject to perceptual training (Beard *et al.*, 1995). It was, therefore, ensured that all observers had sufficient practice in the task and in each location so that threshold levels had adequately stabilized before the results reported here were accumulated. The length of each of the vernier lines was ~ 1.5 degree in the 8–10 degree periphery, and it was ascertained in separate tests, not further reported here, that the salient findings are robust to line length. The two lines were separated by a gap of 5 arcmin.

The principal data for line vernier patterns for three observers are given in Figs 1–3. It is apparent that all observers in all locations exhibit a pronounced oblique effect. Overall, for all observers and peripheral locations, the average line-vernier threshold for the oblique orientations is 2.29 times higher than the average for the horizontals and verticals. The data were also analyzed for possible

Figure 1. Vernier alignment thresholds for targets with horizontal, 45 deg, vertical and 135 deg orientation in each of eight locations in the peripheral visual field at an eccentricity of 10 degrees. Lines 85 arcmin long, 200 ms exposure. Observer AL.

radial/tangential preference, that is, whether vernier lines oriented collinearly with the fovea yielded thresholds different from that for their orthogonals, because there are indications for that in the related threshold of line-orientation discrimination (Westheimer, 2003a). The results here were not conclusive (Table 1) with one observer showing a worse performance for radial vernier pattern than for tangential ones, and the other two a small difference the other way. In all three observers there was a small but consistent advantage for horizontal vernier lines compared to vertical ones.

For two of the observers, measurements were also obtained at different eccentricities. All locations tested, up to an eccentricity of 60 deg, exhibited a prominent oblique effect.

Figure 2. Vernier alignment thresholds for observer JM. Conditions similar to those in Fig. 1.

Table 1.

Anisotropies in two-line vernier task, for three observers, averaged for eight locations in the 8–10 degree periphery of the visual field

Observer	Cardinal/oblique	Radial/tangential	Horizontal/vertical
GW	0.48	1.39	0.68
AL	0.42	0.92	0.84
JM	0.47	0.94	0.96
Average	0.46	1.08	0.82

Figure 3. Vernier alignment thresholds for observer GW. Eccentricity 9 degrees, line length 80 arcmin.

Two-dot vernier

Two-dot vernier thresholds were obtained for three observers in four locations (along the 0, 45, 90 and 135 degree meridians) in the 8–10 degree periphery. The patterns differed from the ones used above only by having all but the distal ends of the lines obscured and, as explained in the Methods section, by the provision of a prior presentation of the standard for comparison purposes. In each location, thresholds were obtained with two-dot vernier patterns for which the virtual line connecting them, whose orientation change had to be detected, were horizontal, at 45 degrees, vertical and at 135 degrees.

Data were analyzed for each observer and location to obtain three ratios: cardinal/oblique, i.e. $(\text{horiz} + \text{vert}) / (45 \text{ deg} + 135 \text{ deg})$; radial/tangential; and horiz/vert. The results (Table 2) again show a prominent superiority of the cardinal orientations over the obliques and a small but consistent advantage for horizontal compared with vertical arraying of dots. But for dot pairs, unlike for the line-vernier pattern, a marked radial/tangential anisotropy is evident.

Table 2.

Anisotropies in two-dot vernier task, for three observers, averaged for 4 locations in the 8–10 degree periphery of the visual field

Observer	Cardinal/oblique	Radial/tangential	Horizontal/vertical
GW	0.62	0.67	0.80
EYL	0.43	0.72	0.73
TK	0.54	0.52	0.79
Average	0.53	0.61	0.77

DISCUSSION

The unequivocal demonstration of a diminished sensitivity in vernier alignment discrimination for obliquely-oriented pattern in the peripheral visual field matches the equivalent oblique effect in orientation discrimination. A traditional interpretation of such results has so far been to assign the deficit to a relative paucity of orientation-selective neurons in the primary visual cortex.

It is as well to be reminded that there are difficulties with this proposition. Not all spatial visual thresholds that may reasonably be associated with the activity of orientation-selective neurons in the primary visual cortex exhibit an oblique effect; for example, the discrimination of length or separation of short lines does not (Westheimer, 2001). On the other hand, there are prominent oblique effects for the discrimination of orientation of configurations devoid of lines (Li and Westheimer, 1997; Westheimer, 2003b).

The detection of vernier misalignment has been linked to that of line orientation (Andrews *et al.*, 1973) on the premise that a misaligned pair of abutting lines has overall average orientation that differs from an aligned pair. Indeed, there are similarities between the performance in the two tasks as regards robustness to contrast reduction (Westheimer *et al.*, 1999) and the oblique effect (the current study and Westheimer, 2003a). In addition, while the overall geometrical average light distribution of a pair of misaligned abutting lines can to a certain degree be regarded as approximating that of a slightly tilted single line, their appearance nevertheless is that of a pair of parallel lines, albeit somewhat displaced from collinearity. Thus, whatever substrate in the orientation discrimination apparatus may be shared by vernier and line-orientation acuities, the final percepts involves additional components. On the other hand, the universality throughout the visual field suggests that the oblique effect in both orientation and alignment discrimination is a manifestation of a generalized anisotropy inherent in the structure of the visual system.

Threshold differences between radially- and tangentially-oriented patterns that have been reported in a three-dot *bisection* task in the retinal periphery (Yap *et al.*, 1987) were in the opposite direction to the one found here for dot vernier patterns. But these authors also measured three-dot *vernier* thresholds in the periphery in one location and one observer, and then, in agreement with the current findings,

the better performance was for the radial orientation. Further confirmation of this difference in locational acuity for perturbations in radial versus tangential configurations is contained in Fahle's (1986) findings on curvature detection.

That a prominent radial/tangential anisotropy is exhibited only with the two-dot vernier patterns and not with the traditional line verniers is just an additional item in the long list of differences in the visual processing of explicit and implicit lines (Westheimer, 1996). Its demonstration requires experiments conducted in the peripheral visual field, because this kind of dichotomy by definition is not represented in the fovea. But the target arrangement raises the possibility that the observer is aided in the radial task by aligning the two dots with the fixation point rather than comparing the implicit orientation difference between the two dots in the standard and test configurations. Hence a check experiment was performed in one observer in a location along the 38 degree meridian, but with a 45 deg target orientation. The radial/tangential anisotropy was unaffected by this shift in location. It is concluded that neural processing in the visual system (as well as the oculomotor system – see discussion in Westheimer, 2003a) is served by an inherent pattern of connectivity favoring the cardinal directions over the obliques, the radial over the tangential and, to a limited extent, the horizontal over the vertical.

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NOTES

1. Planes that include the foveal line of sight generate a set of radiating straight lines in a fronto-parallel viewing plane that intersect in the fixation point, normally imaged on the center of the fovea. The left part of the horizontal meridian, as seen by the observer, is designated as the zero degree meridian. Angular measures of meridians increase in a clockwise manner, again as seen by the observer. Distances out from the fixation point along the meridia are called eccentricities and are measured in degrees of visual angle. A location in the visual field is, therefore, identified by its coordinates: the meridian passing through it and the eccentricity along that meridian.

At each location, pattern elements were arrayed in four directions: horizontal, vertical, 45 deg and 135 deg. To obviate confusion, the word orientation in this paper has been confined to describe these directions.

REFERENCES

Andrews, D. P., Butcher, A. K. and Buckley, B. R. (1973). Acuties for spatial arrangement in line figures: Human and ideal observers compared, *Vision Research* **13**, 599–620.

- Appelle, S. (1972). Perception and discrimination as a function of stimulus orientation, *Psychological Bulletin* **78**, 266–278.
- Beard, B. L., Levi, D. M. and Reich, L. N. (1995). Perceptual learning in parafoveal vision, *Vision Research* **35**, 1679–1690.
- Beck, J. and Halloran, T. (1985). Effects of spatial separation and retinal eccentricity on two-dot vernier acuity, *Vision Research* **25**, 1105–1111.
- Beck, J. and Schwartz, T. (1979). Vernier acuity with dot targets, *Vision Research* **19**, 313–319.
- Corwin, T. R., Moskowitz-Cook, A. and Green, M. A. (1977). The oblique effect in a vernier acuity, *Perception and Psychophysics* **21**, 445–449.
- Davey, M. P. and Zanker, J. M. (1998). Detecting the orientation of short lines in the periphery, *Australian and New Zealand J. Ophthalmol.* **26**, S104–107.
- Fahle, M. (1986). Curvature detection in the visual field and a possible physiological correlate, *Experimental Brain Research* **63**, 113–124.
- Li, W. and Westheimer, G. (1997). Human discrimination of the implicit orientation of simple symmetrical patterns, *Vision Research* **37**, 565–572.
- Ludvigh, E. (1953). The direction sense of the eye, *Amer. J. Ophthalmol.* **36**, 139–143.
- Matthews, N. and Qian N. (1999). Axis-of-motion affects direction discrimination, not speed discrimination, *Vision Research* **39**, 2205–2211.
- McKee, S. P. and Westheimer, G. (1978). Improvement in vernier acuity with practice, *Perception and Psychophysics* **24**, 258–262.
- Morgan, M. J., Watamaniuk, S. N. and McKee, S. P. (2000). The use of an implicit standard for measuring discrimination thresholds, *Vision Research* **40**, 2341–2349.
- Saarienen, J. and Levi, D. M. (1995). Orientation anisotropy in vernier acuity, *Vision Research* **35**, 2449–2461.
- Sullivan, G. D., Oatley, K. and Sutherland, N. S. (1972). Vernier acuity as affected by target length and separation, *Perception and Psychophysics* **12**, 438–444.
- Vandenbussche, E., Vogels, R. and Orban, G. A. (1986). Human orientation discrimination: changes with eccentricity in normal and amblyopic vision, *Investigative Ophthalmology and Visual Science* **27**, 237–245.
- Westheimer, G. (1996). Location and line-orientation as distinguishable primitives in spatial vision, *Proc. Roy. Soc. London* **B263**, 503–508.
- Westheimer, G. (2001). Relative localization in the human fovea: radial-tangential anisotropy, *Proc. Roy. Soc. London* **B268**, 995–999.
- Westheimer, G. (2003a). The distribution of preferred orientations in the peripheral visual field, *Vision Research* **43**, 53–57.
- Westheimer, G. (2003b). Meridional Anisotropia in visual processing: implications for the oblique effect, *Vision Research* **43**, 2281–2289.
- Westheimer, G. and Beard, B. L. (1998). Orientation dependency for foveal line stimuli: detection and intensity discrimination, resolution orientation discrimination and vernier acuity, *Vision Research* **38**, 1097–1103.
- Westheimer, G., Brincat, S. and Wehrhahn, C. (1999). Contrast dependency of foveal visual functions: orientation, vernier, separation, blur and displacement discrimination and the tilt and Poggendorff illusions, *Vision Research* **39**, 1631–1639.
- Westheimer, G. and McKee, S. P. (1977). Spatial configurations for visual hyperacuity, *Vision Research* **17**, 941–947.
- Yap, Y. L., Levi, D. M. and Klein, S. A. (1987). Peripheral hyperacuity: isoeccentric bisection is better than radial bisection, *J. Opt. Soc. Amer. A* **4**, 1562–1567.