Variation of the magnitude of the horizontal-vertical illusion with retinal eccentricity^{1,2}

DOUGLAS PEARCE,³ DEFENCE RESEARCH ESTABLISHMENT TORONTO⁴
LEONARD MATIN, COLUMBIA UNIVERSITY

The horizontal-vertical illusion was studied as a function of retinal eccentricity. It was found that the relation of illusion magnitude to vertical eccentricity is described by a U-shaped function with large amounts of reversed illusion for the more eccentric positions. Substantial effects due to horizontal eccentricity were also obtained, but these were not consistent across subjects. It is suggested that the flattening of the peripheral zones of the refracting surfaces of the eye may be involved in the variation of the illusion with retinal position, and that the astigmatic properties of the central portions of these surfaces may be a prime factor in the usual horizontal-vertical illusion.

This study is concerned with the effect of retinal eccentricity on the magnitude of the horizontal-vertical illusion, which is the overestimation of vertical extents relative to horizontal extents. Pearce and Taylor (1962) have suggested that the magnitude of the horizontal-vertical illusion is not constant in the near-periphery of the monocular visual field. This suggestion was based upon data obtained from comparisons between a standard horizontal interval (defined by two lights straddling the fixation point) and intervals presented at various orientations and positions in the right-central visual field of the right eye. The present study examines the question directly by presenting the usual horizontal-vertical "L" pattern in the near periphery.

PROCEDURE

After wearing red goggles for 10 min the S was seated in a dark room with his head positioned by a mouthbite. Viewing was with the left eye. Corrective spectacles were not worn. In the method of fixation, suggested by some work of Gregory (1959), a small, dim, blue light was employed. A GE-47 lamp masked and filtered by a Kodak 47B filter provided this 0.14-deg blue target that was placed 100 in. in front of the S. The light was visible when imaged on extrafoveal regions but disappeared when projected onto the blue-weak central fovea. The S attempted then to look in a direction so that the blue fixation light was invisible. It is reasonable to assume that, as long as the light was not seen, the eye was pointing within a ± 1 -deg range. In this way the eye was positioned without the complication of an additional visible light.

The horizontal-vertical "L" pattern was defined by three circular 0.14-deg targets, one at the point of intersection of the two arms and one at the outer extremity of each arm. The target defining the outer extremity of the horizontal arm was to the right of the intersection, and that defining the vertical arm was above it (Fig. 1). Each target consisted of an NE-2 neon discharge lamp transilluminating a diffusing disc of white Lucite. The horizontal arm was used as the standard stimulus, subtending a visual angle of 3.44 deg between the centers of the targets defining it. The variable stimulus, i.e., the visual angle subtended by the two targets defining the vertical arm, could be varied from 1.15 deg to 6.30 deg in steps of 0.29 deg; this was accomplished by selecting one of a vertical array of 19 lamps as the upper target defining the vertical arm. The three target lamps were connected in series and flashed simultaneously by the discharge of a 0.1 μ f capacitor charged to 405 V. A fourth NE-2 lamp, in series with

Fig. 1. The 13 locations in the visual field of the left eye at which measurements were made; + indicates the location of the intersection of the vertical and horizontal arms of the "L" pattern at each of these locations. The pattern is shown in a position with the intersection at 15 deg to the left and 5 deg above the fixation point.

the other three and visible only to the experimenter, was used to monitor the flashes. The flash duration was approximately 2 msec. The sides of the NE-2 lamps were coated with a radioactive barium compound in order to provide ionizing radiation which ensured reliable flashing behavior.

The illusion was measured with the intersection of the test pattern arms situated at each of the 13 positions shown in Fig. 1. These positions were located either on a vertical line 5 deg to the left of the primary vertical plane or on a horizontal line 5 deg above the primary horizontal plane. Either six or seven positions were employed in a session of approximately 1½ h for each S each day; the remaining positions were tested in the subsequent session. Five replications of the experiment were performed by each of the three Ss. Order of position within each replication was randomized. The S donned red goggles and closed his eyes when the room lights were turned on while the target array was moved to a new position.

The range of stimuli to be used at a given position in a particular session was determined at the beginning of the session from preliminary exploration with the method of limits. Points of Subjective Equality (PSEs) were then obtained from data taken by the method of constant stimuli, employing eight values of the comparison stimulus presented four times each. Thus, for the entire experiment 160 measurements were made with the target array at each position for each S.

During the determination of PSEs, the S was self-paced, pressing a microswitch to flash the stimuli when "fixation" was

Table 1
PSEs and SDs (measured in degrees of visual arc) as a Function of Eccentricity for the Three Observers

			GEM		LM		DP		
			PSE	SD	PSE	SD	PSE	SD	
Vertical Eccentricity	Up	↑	15	5.20	1.23	3.87	0.71	5.13	0.88
			10	4.87	1.46	3.62	0.13	5.35	0.40
			5	3.84	0.73	2.58	0.21	3.91	0.27
	Down	↓	0	3.15	0.19	2.13	0.21	3.16	0.45
			5	3.30	0.20	2.65	0.33	3.02	0.36
			10	3.50	0.45	3.16	0.35	3.44	0.37
			15	4.12	0.47	3.41	0.26	3.75	0.63
Horizontal Eccentricity	Right	↑	15	2.86	1.19	2.38	0.26	3.77	0.52
			10	2.61	0.59	2.52	0.56	4.34	0.44
			5	3.30	0.65	2.61	0.40	3.70	0.30
	Left	↓	0	3.97	0.63	2.63	0.29	3.63	0.35
			5	3.84	0.73	2.58	0.21	3.91	0.27
			10	3.97	0.98	2.39	0.49	3.90	0.30
			15	3.25	0.75	2.37	0.45	4.66	0.66

attained. Each trial required approximately 10 sec. On each trial the S reported whether the vertical comparison distance appeared to be larger than, smaller than, or equal to the horizontal standard distance.

RESULTS AND DISCUSSION

For each position, only the frequencies of "larger than" (L) and "smaller than" (S) were used; the few "equal" judgments given were ignored. A normal ogive was fitted to the L/L + S proportions for each position by the method of least squares and the stimulus value corresponding to the 50% point of this fitted ogive was used as the PSE. The PSEs and SDs of the fitted curves are shown for vertical and horizontal eccentricity in Table 1. The PSEs are plotted in Fig. 2 and Fig. 3 as a function of vertical and horizontal eccentricity, respectively. For the three Ss the usual illusion is present near the center of the visual field (Fig. 2). The relation between vertical eccentricity and PSE for each S is

Fig. 2. PSE as a function of vertical eccentricity for three Ss.

Fig. 3. PSE as a function of horizontal eccentricity for three Ss.

described by a U-shaped function, however, and as vertical eccentricity increases, the illusion reverses. The relation of PSE to horizontal eccentricity is not uniform among the Ss (Fig. 3): for LM the usual illusion appears over the entire range; for DP the reverse illusion appears over the entire range; and for GEM the reverse illusion is found in the center of the visual field and the usual illusion for the extremes. The data do support the suggestion of Pearce and Taylor (1962) that the usual horizontal-vertical illusion does not appear throughout the monocular visual field and that, in fact, the illusion reverses for sufficiently large vertical eccentricities.

With the exception of the work of Valentine (1912), the dioptrics of the eye have typically been ignored in analyses of the horizontal-vertical illusion. It has been assumed that the distortion in the mapping between distance in physical space and perceived space is a distortion in the mapping between retinal distances and perceived distances (see Künnapas, 1957, for reference to these analyses). Consideration of the refracting surfaces of the eye raises the possibility that the retinal image itself is distorted in a fashion that accounts for the horizontal-vertical illusion as well as accounting for the presently reported variation of the illusion with retinal position.

The anterior surface of the cornea decreases in curvature with increased distance from the optic axis (Mandell, 1965; Bennett & Francis, 1964). The flattening of the cornea as it approaches the sclera implies that as eccentricity from the optic axis increases vertically, the vertical curvature decreases relative to the horizontal curvature, and since the pupil would restrict entry of light to a bundle more peripherally located on the cornea when the target's vertical eccentricity is greater, would thus result in a decrease in the vertical magnification relative to horizontal magnification with increasing vertical eccentricity from the central zone. Such a condition could account for the decrease and eventual reversal of the horizontal-vertical illusion with increasing

vertical eccentricity. The same argument, however, predicts an increase in the illusion with increasing horizontal eccentricity; although such a pattern is discernible for Ss GEM and LM, a reversed pattern is present for DP.

Since the experiment was conducted in a dark room the pupil would have been nearly maximally dilated. Since both surfaces of the crystalline lens also decrease in curvature from center to periphery (Bennett & Francis, 1964), a similar argument can be constructed with regard to the influence of increasing target eccentricity on the size of the illusion as mediated by eccentricity of the ray bundle in the lens.

These considerations regarding astigmatic properties of the refracting surfaces of the eye derive some support from Valentine's (1912) finding that more than two diopters of corneal astigmatism increased the vertical-horizontal illusion with central viewing. In addition, in the present experiment SLM, with marked astigmatism (uncorrected in the experiment but requiring for correction a -3.00 diopter cylinder, axis 16 deg), showed a considerably greater illusion at all eccentricities than did the other two Ss whose clinically measurable astigmatism was negligible. This increase in illusion for LM is in accordance with prediction from his astigmatism. Valentine's finding that only strong corneal astigmatism seems to increase the illusion seems to be contradictory to an argument that relatively minor variations in corneal and lenticular curvature are responsible for variation in the horizontal-vertical illusion. Valentine's astigmatism measurements, however, were made only on the corneal "cap." The "average" difference in curvature between the horizontal and vertical meridians may be measurably greater if a larger area of the cornea (the entire area involved in image formation) is examined. Such a procedure might demonstrate a stronger relation between corneal astigmatism and the magnitude of the horizontal-vertical illusion.

It will remain for further experimentation to determine the relative contribution of dioptric factors and distortion in the mapping between the retina and perceived space to the vertical-horizontal illusion, as well as to the presently reported variation of illusion magnitude with variation in eccentricity.

One final point is worth noting. It is frequently suggested that

the perceptual distortions produced by the introduction of optical devices in front of the eye are subject to reduction with time as a consequence of adaptation. Such suggestions imply that the mapping from retina to perceived space is changed in a fashion that compensates for the distortion introduced by the optical device. If the horizontal-vertical illusion is, in fact, due to some of the characteristics of the dioptrics of the eye, it would seem that compensatory adaptation should take place that would null the perceptual effect of such aberrations. The universality of the horizontal-vertical illusion suggests, however, that there is no adaptation or, if there is, it is incomplete. If adaptation to optical distortion does occur, the interesting question is raised as to why failure to adapt should be found in the case of the horizontal-vertical illusion.

REFERENCES

- BENNETT, A. G., & FRANCIS, J. L. The eye as an optical system. In H. Davson (Ed.), *The eye*, Vol. 4. *Visual optics and the optical space sense*. New York: Academic Press, 1962.
- GREGORY, R. L. A blue filter technique for detecting eye movements during the autokinetic effect. *Quarterly Journal of Experimental Psychology*, 1959, 11, 113-114.
- KUNNAPAS, T. M. The vertical-horizontal illusion and the visual field. *Journal of Experimental Psychology*, 1957, 53, 405-407.
- MANDEL, R. B. *Contact lens practice: Basic and advanced*. Springfield, Ill.: Charles C Thomas, 1965.
- OGLE, K. N. *Researches in binocular vision*. New York: Hafner, 1964.
- PEARCE, D. G., & TAYLOR, M. M. Visual length as a function of orientation at four retinal positions. *Perceptual & Motor Skills*, 1962, 14, 431-438.
- VALENTINE, C. W. The effect of astigmatism on the horizontal-vertical illusion, and a suggested theory of the illusion. *Journal of Psychology*, 1912, 5, 308-330.

NOTES

1. This research was supported by National Science Research Foundation Grants GB-18120, GB-5947-01 and PHS Research Grant No. 1-R01-NB07547 from the National Institute of Neurological Diseases and Blindness, National Institutes of Health.
2. DRET Research Paper No. 727.
3. Address: Defence Research Establishment Toronto, P. O. Box 2000, Downsview, Ontario, Canada.
4. Formerly Defence Research Medical Laboratories.

(Accepted for publication March 10, 1969.)