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BASIS OF THE HORIZONTAL–VERTICAL ILLUSION

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Three experiments were designed to determine the basis of the horizontal–vertical (HV) illusion using an L figure. Experiment I showed that there were no differences in the size of the effect in darkness, semidarkness, and in the light, a result contrary to the visual field explanation. In Exp. II the figure was viewed in the dark with *S*s upright and recumbent, and in Exp. III the L figure was oriented between 0° (vertical) and 90° (horizontal) in 15° steps. Data from Exp. II and III showed that apparent length is a function of the retinal meridians with which the lines correspond irrespective of their physical or apparent orientation to an external reference.

In an inverted T figure, in which the horizontal and vertical lines are equal, the apparent length of the vertical is about 10% greater than the horizontal. This effect, first reported by Fick (1851), is commonly referred to as the horizontal–vertical or HV illusion. However, Finger and Spelt (1947), and later Künnapas (1955a), using two figures, an inverted T and an L, showed that both the verticality of one line and its bisection of the other contribute to the effect. When bisection is eliminated, as in the L figure, the illusion is reduced, but the vertical is still consistently judged to be about 3–5% longer than the horizontal.

Following the observation that a line enclosed in a large square frame is apparently shorter than a line of equal length in a small frame (Künnapas, 1955b), Künnapas (1957b) suggested that the HV illusion is a function of the shape of the visual field. Since the visual field has the form of a horizontal ellipse, it was argued that the ends of a vertical line would be nearer to the boundary of the visual field than those of a horizontal line, provided that the point of line intersection is at the center of the field.

The purpose of Exp. I was to test the visual field hypothesis using conditions essentially similar to those of Künnapas (1957b). Failure to confirm the hypothesis gave rise to two further experiments in which the retinal orientation of the L-figure image was varied by changing *S*'s posture with figure orientation constant (Exp. II) and varying figure orientation with posture constant (Exp. III).

Experiment I

Künnapas (1957b) predicted that if overestimation of the vertical is due to the elliptical form of the visual field, the effect should be either eliminated or reduced if the figure alone is viewed in darkness. While darkness eliminates the horizontally oriented elliptical field, "force of habit" could conceivably exert some effect such that the illusion would be reduced rather than eradicated. This latter prediction was confirmed when the illusion of 7.1% in the light was reduced to 4.8% in the dark. However, in an earlier experiment, Künnapas (1957a) obtained an illusion of only 4.0% in the light. Moreover, Begelman and Steinfeld (1967) reported an illusion of 4–5% in the dark, but Finger and Spelt (1947) found only 1.0% illusion in the light. While these inconsistencies were probably due to differences in equipment, conditions, and procedures, they suggested that a reexamination of the effect with and without a bounded visual field was desirable. The purpose of Exp. I, therefore, was to determine the magnitude of the HV illusion using an L figure with a clearly defined (lighted) visual field, a poorly defined (dim) field, and an unbounded (dark) field.

Method

Subjects.—There were 14 *S*s, 12 women and 2 men, all volunteers from an introductory course in psychology.

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Apparatus.—The apparatus consisted of a metal box, in the front surface of which was cut a lighted L figure, and a support fixed to a table to which was attached an individual bite-board for the control of head posture and observation distance. In the front of the 20.5-cm.-square 15.5-cm.-deep box there were two .5 × 100 mm. slits intersecting to form an L, with the point of intersection at the bottom left of the figure. The slits were illuminated from inside the otherwise light-tight box by two filament lamps to give two sharp lines. The luminance of both lines was uniformly .15 mL. A system of sliding shutters inside the box permitted variation in the length of each line at its outer end from 50 to 100 mm., but throughout this experiment the horizontal was permanently adjusted to 75 mm. The length of the vertical could be adjusted to the nearest 1.0 mm. by means of a circular scale at the rear of the box. The box was on a table within a semicircle of black ruffled curtains, with the point of intersection of the L at approximate eye level for an *S* seated on an adjustable stool. The observation distance was 65 cm., and the visual angle subtended by the horizontal line was 6°36′.

Observation conditions.—There were three observation conditions. In the first, the room was completely darkened so that only the L figure was visible. For the second condition, the door of the laboratory was left ajar so that the box, table, part of the walls and ceiling, and other objects were dimly visible. In the third condition, the curtains around and in back of the box were drawn aside and the room illuminated by overhead fluorescent sources so that all objects in the room and the walls and ceiling were clearly visible. Thus, in the first (dark) condition there were no contours defining visual field size and shape, in the second (dim) the contours were poorly defined, and in the third (lighted) they were clearly defined.

Procedure.—A variant of the up-and-down or staircase method (Wetherill, 1963; Wetherill & Levitt, 1965) was used to establish the point of subjective equality (PSE) of the vertical relative to the horizontal. In this method, two independent staircase series are run, but the order of the steps in each series is randomly determined. The procedure started with the vertical line equal in length (75 mm.) to the horizontal standard for both series. For the first part of each series, "coarse" (4-mm.) steps were used until six reversals of judgment from "longer" to "shorter," or vice versa, had been recorded, after which "fine" steps (2-mm.) were used until six further reversals occurred.

Each *S* observed under all three conditions. The order of presentation of conditions was randomized for each *S*. Throughout, *S* was instructed to close his eyes between judgments and to open them only when he was asked to judge the length of the vertical relative to the horizontal. Free inspection of the figure was permitted, but *S* was instructed to respond as quickly as possible. Judgment time seldom exceeded a few seconds.

TABLE 1

MEAN PSEs (IN MM.) OF THE VERTICAL WITH THE HORIZONTAL 75-MM. STANDARD, VARIANCES, AND PERCENTAGE OF ILLUSIONS FOR DARK, DIM, AND LIGHT OBSERVATION CONDITIONS IN EXP. I

Statistic	Observation conditions		
	Dark	Dim	Light
PSE	70.6	71.7	73.0
s^2	25.92	20.23	22.09
Percentage of illusion	5.87	4.43	2.58

Results

The PSE was derived from the mean of the six vertical lengths in the fine step sequence resulting in a reversal. The difference between this mean and 75 mm. served as an index of the illusion and was stated as a percentage. The mean PSE for each condition, the variance, and percentage of illusion are shown in Table 1 for the three observation conditions. The degrees of freedom available limited the number of comparisons that could be made legitimately (Rodger, 1967). For this reason, only the differences among mean PSEs for the three conditions were evaluated by an analysis of variance, and the difference between the mean PSE for the dark condition and 75 mm. was evaluated by a planned-contrast t test. The latter hypothesis was tested because the occurrence or nonoccurrence of the illusion in the dark was critical for the visual field hypothesis. The differences among the mean PSEs for the three conditions were not significant, $F(39, 2) = .775$, $p > .05$. However, the difference between the mean PSE for the dark observation condition and 75 mm. achieved statistical significance, $t(13) = 2.898$, $p < .05$, indicating that there was a significant illusion. Since there was no difference among the three mean PSEs and since the illusion was significant for one, it was concluded that a similar magnitude of illusion occurred for all three conditions of observation.

The results indicate that elimination and obscuring of visual field contours neither eradicate the HV illusion nor significantly reduce it. In fact, the order of the means is opposite to that predicted from the visual field hypothesis in that the mean percentage

TABLE 2

Mean PSEs (in mm.) of the Vertical with the Horizontal 75-mm. Standard, Variances, and Percentage of Illusions for Upright and Recumbent Postures in Exp. II

Statistic	Posture	
	Upright	Recumbent
PSE	71.4	76.3
s^2	1.16	4.50
Percentage of illusion	5.06	−1.90

of illusion is greater in the dark than in the light.

Experiment II

In a further test of the visual field explanation of the HV illusion, Künnapas (1958) positioned *S*'s head horizontally. It was argued that since the visual field would then be rotated through 90°, a vertical line would be judged *shorter* than the horizontal. This proved to be so. In Exp. I, however, there was no difference in the magnitude of the HV illusion with and without a visual field. Therefore, a change in the illusion from vertical longer with head upright to shorter with head horizontal suggests that the critical determinant of the HV illusion is not the shape and size of the visual field, but the orientation of the two lines relative to the retina. The purpose of Exp. II was to determine the magnitude of the HV illusion in the absence of a defined visual field with head upright and horizontal.

Method

Subjects.—There were two groups of 14 *S*s each. All *S*s (12 men and 16 women) were volunteers from introductory courses in psychology.

Apparatus.—The apparatus consisted of two components, the box containing the lighted L figure as in Exp. I and a cabin for positioning *S* upright and recumbent. The latter apparatus has been described in detail elsewhere (Wade, 1968). The cabin was open in front, containing adjustable leg, hip, shoulder, and head supports, and a bite-board for controlling head position. The whole could be rotated about a horizontal axis and fixed at any angle including the vertical and horizontal positions, with *S* firmly but comfortably positioned inside. The box with the lighted L figure was mounted on a horizontal axis attached to steel supports fixed on the top of the cabin. This arrangement permitted *E* to maintain the lines in the gravitational vertical and horizontal during tilt. The fixed distance between *S*'s eyes and the figure was 100 cm. so that the horizontal standard of 75 mm. subtended a visual angle of 4°18′.

Observation conditions.—There were two observation conditions, *S* upright so that the vertical line was projected on to the normally vertical meridian of the eyes and *S* recumbent so that this line was oriented approximately at right angles to the same meridian.[3] Only the L figure was visible in the otherwise dark room.

Procedure.—The *S*s were randomly allocated to one of the two groups. Those in one group were upright throughout, and those in the other were recumbent. The psychophysical procedure and the method of computing the PSEs were the same as for Exp. I. Throughout, *S* was required to close his eyes and to open them only when called on to judge whether the vertical was longer or shorter than the horizontal.

Results

Mean PSEs, variances, and percentage of illusions for the upright and recumbent groups are shown in Table 2. The data show that in the upright posture, the mean PSE was less than the horizontal standard (i.e., the illusion was positive) and that in the recumbent posture, it was greater (i.e., the illusion was negative). The differences between each mean PSE and 75 mm. were examined using a *t* test. Both differences were found to be statistically significant: upright position, $t\ (13) = 5.006$, $p < .01$; recumbent position, $t\ (13) = 2.229$, $p < .05$.

The results show that when *S* is upright, a vertical line in the dark is apparently longer than a horizontal line of the same objective length, but when he is recumbent, a vertical line is apparently shorter than the horizontal. In other words, a line falling along a particular meridian of the eye is apparently longer than one of the same length which is at right angles to it.

Experiment III

The results from Exp. II indicate that the primary determinant of the HV illusion is the orientation of lines relative to the retina. If this is so, it would be expected that with variation in the orientation of the L figure

[3] When *S* is recumbent, the eyes undergo countertorsion through an angle of about 5–6° so that the vertical meridian would have rotated through about 84–85° (Miller, 1962).

from the position in which a line is vertical to that in which it is horizontal, the illusion would change from positive to negative. This prediction was tested in Exp. III.

Method

Subjects.—There were 98 *S*s, 38 men and 60 women, volunteers from an introductory course in psychology. They were allocated to seven groups. None had taken part in the previous experiments.

Apparatus.—The apparatus was the same as that described for Exp. II, with *S* always upright in the cabin and depending on the group, the L figure oriented in the vertical (0°) position or at 15°, 30°, 45°, 60°, 75°, and 90°, as shown in Fig. 1. The figure could be oriented by means of a protractor scale. Apart from the figure itself, the room was dark.

Procedure.—The staircase method described in detail for Exp. I was used throughout. So that *S* would not be confused about which line to judge (since the term "vertical" was not always relevant), the appropriate slit was indicated to him at the outset. As in the previous experiments, *S* was instructed to open his eyes only when requested to do so and to keep them closed at other times.

Results

Mean percentage of illusions derived from the mean PSEs for each group are shown as a function of figure orientation in Fig. 1. A trend analysis (Edwards, 1967) showed that while there was a significant linear trend, $F(1, 78) = 35.233$, $p < .001$, there were no significant higher order components in the trend. The least squares line of best fit was $X = 7.321 + .006Y$. This line, together with the data points, is shown in Fig. 1.

The data summarized in Fig. 1 indicate that as the orientation of the L figure changes through 90°, the illusion changes from positive to negative. These results confirm those of Exp. II in which the retinal position was varied by changing the orientation of *S*.

Discussion

It is reasonable to assume with Künnapas (1957b) that if the HV illusion using an L figure is determined by the dimensions of the visual field, the effect would be reduced or eliminated in darkness. In the dark, the visual field would have no contours defining its boundaries. The data from Exp. I showed that the magnitude of the effect was constant in a dark, dim, and lighted field. These results cast doubt on the tenability of the visual field explanation of the illusion. However, the results from Exp. II supported those of Künnapas (1958) in showing that the vertical line was apparently longer than the horizontal line with

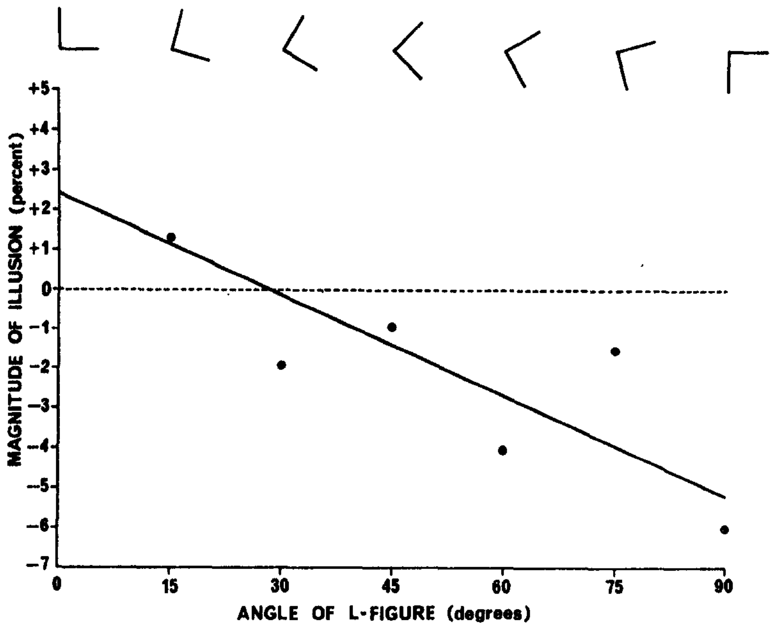

FIG. 1. Percentage of illusion as a function of L-figure orientation between 0° (judged component vertical) and 90° (judged component horizontal).

S upright, but apparently shorter when he was recumbent. Taken together, the data from Exp. I and II indicate that the relative apparent lengths of the two lines of an L figure are determined by the orientation of the retinal image. Irrespective of its orientation relative to gravity, the line which corresponds to that retinal meridian which is vertical when *S* is upright, and nearly horizontal when he is recumbent, is apparently longer. This conclusion was supported in Exp. III in which the L figure was rotated from its normal position through 90° in 15° steps.

Three further comments can be made in conclusion. First, when *S* is tilted laterally to the recumbent position, there is relatively little change in the apparent orientation of a figure in a dark field (Wade, 1968). Thus, the term horizontal–vertical illusion is misleading in that the apparently longer of two equal lines is not necessarily physically or apparently vertical; it is the line which corresponds to a particular meridian of the eye.

Second, one feature of the visual field hypothesis has been overlooked. The argument that an enclosing boundary, that of the visual field, determines overestimation of one line reduces the HV illusion to a special instance of the Delboeuf illusion. This latter effect is a change in the apparent size of a circle as a function of an inscribed or circumscribed circular frame. While it is often useful and revealing to classify effects in one category, this is only preliminary to explanation.

Finally, Koffka (1935) maintained that the HV illusion is one instance of what he called the anisotropy of perceived space. Phenomenal space, he contended, has different properties in different directions. The data reported in the present experiments show that this anisotropy is probably a function of retinal directions rather than directions relative to an external reference.

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