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EFFECT OF SIZE ON VISUAL SLANT[1]

ROBERT B. FREEMAN, Jr.

Pennsylvania State University

2 experiments were conducted to determine the generality of the finding by Stavrianos (1945) that judged slant of plane rectangular figures varies directly with size. In Experiment I, equal-slant contours were obtained from 54 undergraduate Ss for 14 rectangles whose lengths varied in equal log steps from 1.0 to 42.2 cm. with a reference stimulus of 7.5 cm. In Experiment II, 72 Ss were tested on 9 rectangles varying linearly in 4-cm. steps from 8 to 40 cm., with a 24-cm. reference. Observation was monocular and under complete reduction conditions from a distance of 135 cm. The effect of size on judged slant was only partly reliable in Experiment I, but highly significant in Experiment II. The "size effect" was attributed to the "perspective" cue to slant which was shown to vary with physical size as well as slant, and was probably more discriminable in the stimuli in Experiment II than in Experiment I.

In a study by Stavrianos (1945) on the shape-slant invariance problem, the investigator used standard and comparison plane rectangles of different sizes to avoid the possibility that *S* could make a retinal match in equating slant. Even under unreduced conditions of observation, the results of the experiment indicate that *S*s consistently overestimated the slant of the larger of the two rectangles. This finding raises the possibility that (*a*) visual slant is a function not only of physical slant, but is also some function of size, and (*b*) a more general explanation of visual slant may be found in visual cues which can be shown to vary with both size and slant of plane rectangles.

An earlier study (Freeman, 1962) replicated the Stavrianos effect under complete reduction conditions similar to those used in the experiments reported here, and with monocular observation. For slants of approximately 60° "backwards" (with the top away from *S*), the effect of size on judged slant was highly significant even under monocular conditions. The purpose of the experiments described below is to determine the generality of the size effect on visual slant for a variety of sizes and slants of plane rectangles.

METHOD

Apparatus

The apparatus consisted of two light boxes, one for the standard stimulus and one for the comparison stimulus, in each of which a luminous rectangle can be exposed at any slant, but without effective cues deriving from texture effects, "edges," illumination gradients, or background.

The light boxes are illustrated in Fig. 1. The light in Box A arose from a bank of lights (7-w. General Electric white lamps wired in parallel) at the rear of the box, was diffused by a flashed opal glass screen, and was occluded by a mask with a rectangular aperture in it. The light then passed through a first-surface, half-silvered mirror which was set at a 45° angle to the visual axis of *S*. The light from Box B followed a similar path, but was reflected from the first surface of the mirror into *S*'s eye. The optical direction of the centers of the two rectangles was therefore the same. The optical distance of both stimuli from *S*'s viewing hole was 135 cm. Each rectangle was exposed for 1 sec., with

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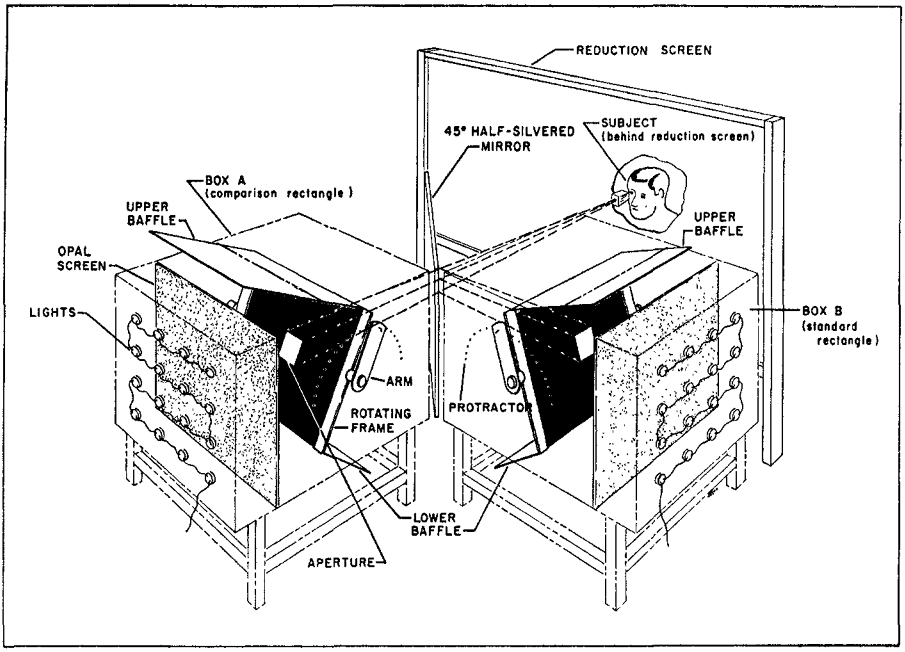

FIG. 1. Schematic diagram of the apparatus. (Timers not shown.)

a .7-sec. dark period between them. The interval between trials was somewhat variable depending upon the speed of judgment of *S*, but averaged approximately 4.5 sec.

A frame was mounted inside each box which could be rotated about its horizontal axis. One axle was attached rigidly to an exterior arm which was positioned in the plane of the interior frame. The arm, and the frame attached to it, could be set at any slant (in 1° intervals). The maximum error of settings is difficult to measure, but was on the order of .5°. In the rotatable frame inside the box was a cradle which received a sheet of single-strength glass whose first surface was in the plane of rotation of the frame. The first surface of the glass was painted with several coats of flat black paint rendering the glass opaque. Then a rectangle of specified size was scraped out of the layer of paint.

Light passing over and under the frame inside the box was masked out by fiberboard light baffles hinged to the upper and lower edges of the rotating frame and inserted through silent rollers in slots in the top and bottom of the light boxes. Light leaks around the sides of the rotatable frame were masked by rigid baffles at the front of the box. The stimuli could be exposed either in order AB or BA by means of a switch installed in the light circuit. The luminance of the images at 0° was 1.0 footlambert (ftl.). Luminance decreased with increasing slant, reaching approximately .5 ftl. at 80°.

The height-to-width ratio of all rectangles in both experiments was 4:3. The experimental parameter was linear size. The apparent slant of each of a series of rectangles of different sizes was matched to the slant of a reference stimulus of intermediate size to yield equal-slant contours. A "direct" measure of the size effect was obtained (Part A) when the reference stimulus was used as the variable (Box A). An "indirect" or inverse measure was obtained (Part B) when the reference stimulus was used as standard (Box B).

Procedure

Two experiments will be reported. The principal differences between the experiments lay in the size range of the stimulus rectangles and certain information provided to *S* in the instructions. The instructions (in part) for both the experiments were as follows:

> The purpose of this experiment is to find out how people judge the orientation of objects in space. You will be shown two

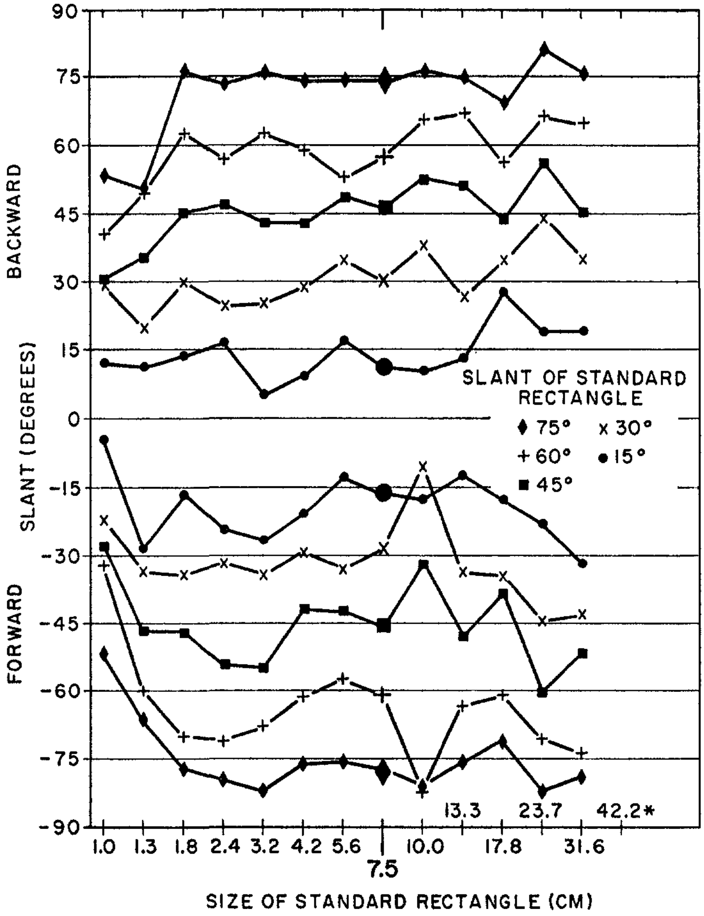

FIG. 2. Judged slant as a function of size. (Exp. I, Part A—the 7.5-cm. reference stimulus was the comparison stimulus and placed in Box A. *Reliable judgments were not obtained for the 42.2-cm. standard.)

rectangles at a slant, one after the other. They will both be slanted backward (forward) and one will always be more slanted than the other. Your task is to judge which one of the two rectangles is more slanted. To indicate your judgment, there will be two buttons in front of you, one farther away than the other. If the *first* rectangle is more slanted, press the *far* button. If the second rectangle is more slanted, press the *near* button. . . .

The *S* sat on a chair of adjustable height and observed the stimuli monocularly through a 6-mm. hole. The stimuli appeared to *S* as luminous, horizontally symmetrical quadrilaterals without gradient or texture, whose size and shape depended upon the size and slant of the rectangular aperture in the painted mask. The standard, which was always in Box B, was set at either 15°, 30°, 45°, 60°, or 75°, either forward or backward. For the first of *S*'s judgments, the comparison stimulus in Box A was set at the same slant as the stimulus in Box B. Thereafter the slant of the comparison rectangle was adjusted in 2° steps according to the staircase method (Dixon & Massey, 1951). The *S* was presented 60 pairs for each standard slant setting, and the mean of the last 40 settings of the variable was obtained as the slant of apparent equality. Protocols were

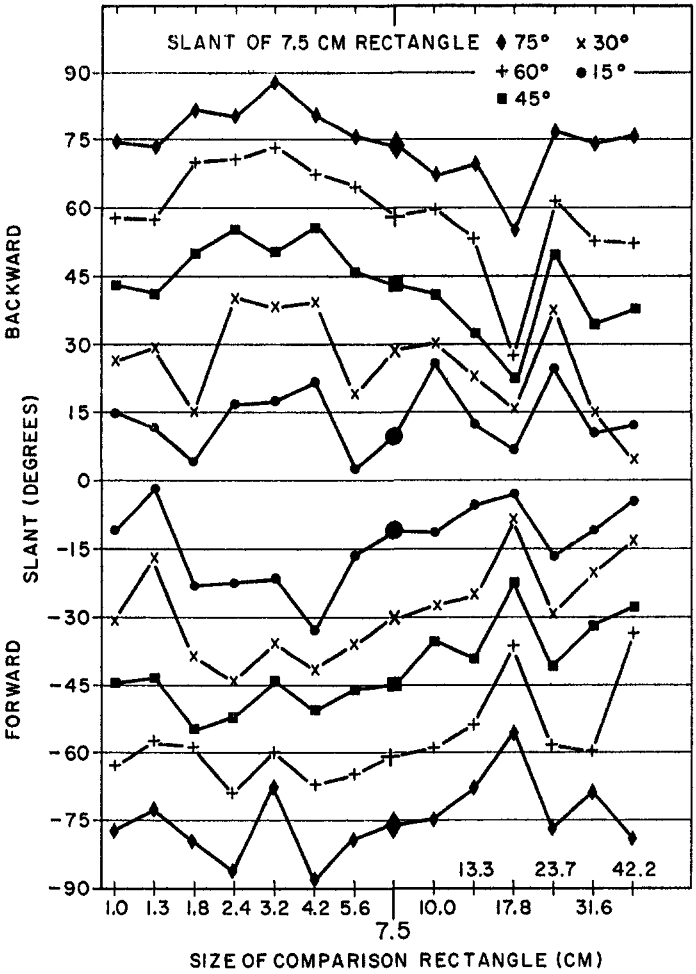

FIG. 3. Judged slant as a function of size. (Exp. I, Part B—the 7.5-cm. reference stimulus was the standard stimulus and placed in Box B.)

rejected as unreliable if they showed *less* than 20 reversals among 60 judgments made at two or more of the five slants in a given direction (forward or backward). In all, the protocols of 15 *S*s in Exp. I and 6 *S*s in Exp. II were rejected.

In Exp. I, each of the 54 *S*s (university undergraduates) was tested with stimulus rectangles slanted both backwards and forwards in two separate 1-hr. sessions. Also, prior to testing, *S*s were shown the shape of both rectangles oriented in the frontoparallel plane. In Exp. II, each of the 72 *S*s was tested in one direction only (36 *S*s forward, 36 *S*s backward), and pretest exposure of the rectangles in the frontoparallel plane was omitted. The assignment of *S*s to the various experimental conditions (parametric size, direct or indirect method, and direction of slant) as well as slant of the standard rectangle was determined by chance. The *S*s in Parts A and B of each experiment were thus run intermixed.

RESULTS

Experiment I

The size parameter in Exp. I varied from 1.0 cm. linear height to

42.2 cm. in equal-ratio intervals. The reference size in the series was 7.5 cm. The results of Part A are shown in Fig. 2. The expected increase in apparent slant with increase in size was found in some, but not all, of the contours. The effect in general was rather weak. Although there appears to be some tendency for matched slant to increase with stimulus size, the curves are not on the whole monotonic and there appears to be considerable inter-*S* variability. No match was possible for the 42.2-cm. condition. Three *S*s were run without success in obtaining reliable data, after which no more *S*s were run.

The results of Part B are shown in Fig. 3. In this part it was expected that a decrease in required slant would occur as a function of size. The results in this part of the experiment appear to be somewhat clearer, especially in the middle range of stimuli, but there are reversals at the upper end of the scale.[2]

To analyze the statistical reliability of the results, a trend analysis for repeated measures (Grant, 1956) was performed. In this analysis, the trends analyzed were the effects of the physical slant of the standard stimulus within *S*s. Since the same *S*s were tested at all five slants in both forward and backward directions, the results for forward and backward directions were summed for each *S* and slant (omitting results for the 42.2-cm. stimulus). Since it was expected that the slant of the comparison stimulus would increase in Fig. 2 and decrease in Fig. 3, a significant variance ratio was expected in either the level or some component of trend attributable to the Size × Box interaction. An interaction variance ratio of F (12, 26) = 1.744 for level fell short of significance at $p = .05$. A Size × Box interaction effect on Linear slope was, however, significant with F (12, 26) = 2.891, $p < .05$, indicating that the curves in Fig. 2 and 3 deviate significantly from parallelism as a function of size. The effect of neither Size nor Box alone on Linear slope was significant. The only other significant ratio was attributable to the effect of size on Cubic trends, F (12, 26) = 2.301, $p < .05$, which is difficult to account for. This finding may have been limited to the particular conditions of Exp. I as a similarly reliable variance ratio was not found in Exp. II.

Although the results of Exp. I were in the expected direction and in part statistically significant, inter-*S* variability was high, and the results as a function of size were not clearcut. One explanation for the lack of consistency of results lies in the difficulty that *S*s had in judging the slant of the small stimuli, including the 7.5-cm. reference stimulus. Some of the *S*s who were tested on the smaller rectangles reported that the stimuli seldom appeared slanted to them at all. Therefore the experiment was rerun with a series including larger stimuli.

Experiment II

In this experiment, the reference stimulus was 24 cm. in height, and the stimulus sizes varied in equal-interval steps from 8 cm. to 40 cm. in 4-cm. intervals, for a total of nine

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[2] The individual data and group means, as well as statistical analyses, presented for both experiments in four tables, have been deposited with the American Documentation Institute. Order Document No. 8552, from ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington, D. C. 20540. Remit in advance $1.25 for microfilm or $1.25 for photocopies and make checks payable to: Chief, Photoduplication Service, Library of Congress.

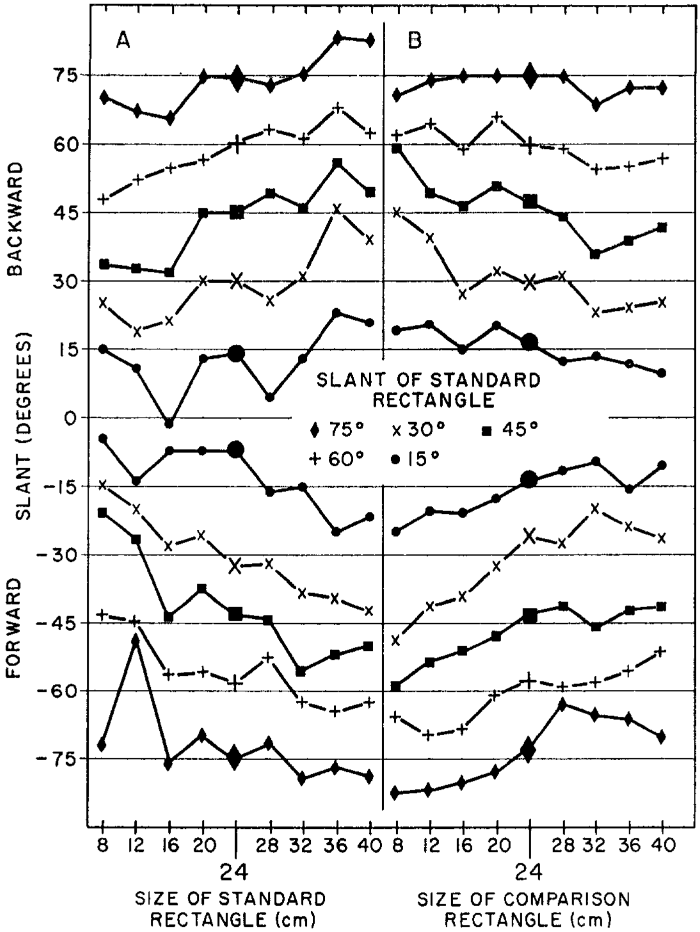

FIG. 4. Judged slant as a function of size. (Exp. II, Part A on the left and B on the right—the 24-cm. reference stimulus was the comparison stimulus in Part A and the standard stimulus in Part B.)

stimuli. The results of Exp. II are shown in Fig. 4. The effect of Size was marked for both Box conditions, and in opposite directions as expected. Three significant variance ratios were obtained. (*a*) The Size×Box interaction in the level of the curves was highly significant, F (8, 36) = 14.17, $p < .001$, as expected. (*b*) The Box main effect was significant, F (1, 36) = 5.51, $p < .05$, showing that the curves, when the reference rectangle was in Box B, were on the average higher than when in Box A. This effect is probably due to the nonlinearity of the measure of slant when the reference stimulus was in Box B. In general terms, the required adjustment of the 8-cm. stimulus in one direction to match the 24-cm. reference standard does not necessarily equal the required adjustment of the 40-cm. stimulus in the other direction. (*c*) There was a significant Size×Box interaction in the Quadratic Component of Variance, F (8, 36) = 3.74, $p < .01$. This ratio is the result of the bunching of the curves at the left end of the curves near 0° in Part A and near 90° in Part B. Finally, although a test of direction (and its interactions) was possible in this experiment, it did not yield significant F ratios.

Discussion

The purpose of these experiments was to determine the generality of the findings of Stavrianos that judged slant varies with the size of plane rectangles under monocular conditions of observation. Although the effect was highly significant in Exp. II, the fact that the larger range of sizes in Exp. I yielded less clearcut results suggests that it is not the variation of size of the stimulus per se which affects visual slant, but rather some aspect of the projective shape of the stimulus which varies with size and which was more effective in eliciting slant judgments in Exp. II than in Exp. I.

One possibility is "perspective" or what has been called "retinal gradient of outline" (Clark, Smith, & Rabe, 1955). This cue alone has been shown to be effective in inducing apparent slant. Furthermore, there are two different measures of perspective which differ from each other but both of which vary with size as well as slant. First, consider the angle which the sides of the projective image of a rectangle slanted backwards form with the base of the image. It can be shown that

$$\tan \pi = \frac{c \operatorname{ctn} \theta}{d} \qquad [1]$$

where π is the angle formed by the sides and the base of the projective trapezium, θ the angle of slant of the rectangle, c the distance of the axis of rotation of the rectangle from the eye, and d half the width of the rectangle (Freeman, 1962). As d increases, $\tan \pi$ and therefore π decrease thus increasing the perspective effect. Since the width of a rectangle increases with size, perspective by this measure increases with size. Notice that π does *not* vary with the height of the rectangle although, of course, the height of the projective image does.

Another possible measure of the perspective effect, to which the eye might be sensitive, is the difference in projective length of the near and far edge of the slanted rectangle, and is given by

$$\tan \delta = \frac{2ad \sin \theta}{c^2 + d^2 - a^2 \sin^2 \theta} \qquad [2]$$

where δ is the visual angle of the nearer minus the visual angle of the farther edge, d, c, and θ are as defined above, and a is half the height of the rectangle. This relationship shows that, for constant width, δ varies directly with the height of the rectangle as well as width and the other parameters of the equation. When size varies without variation in shape as in these experiments, both a and d vary proportionately.

Assuming that perspective is the effective stimulus to slant, the solution of either Equation 1 or 2 for the small stimuli reveals a possible reason for the difficulty of discrimination of their slant. The value of π for the 1-cm. stimulus and 60° slant is 89°43′ or nearly 90°. The value of δ for the same stimulus and slant is 0°0′2.5″, which is well below the limits of visual acuity. The small values of both measures of perspective for the small stimuli and the concurrent difficulty *S*s had in making judgments further support the perspective hypothesis of visual slant.

Gradients other than outline perspective must be ruled out as possible contributors to apparent slant in these experiments. First, it was shown above that the experimental conditions eliminated both texture and luminance gradients as stimulus correlates of physical slant. Texture was negligible and constant. Furthermore, although it can be shown that some gradient in luminance will occur for large stimuli whose slant exceeds 40°, due to differential reflectance which varies with angle of incidence (i), there is *no* gradient for angles less than 40°. Yet some of the strongest effects of size were obtained in this range. Secondly, if the height of the visual image is to be considered a special case of Gibson's (1950) density gradient, the results were opposite to what might be predicted.

Finally, the results of this experiment and those of Clark et al. (1955) indicate the necessity for care in selection of comparison stimuli in investigations of shape and slant. For example, in the experiments of Epstein, Bontrager, and Park (1962) on the shape-slant invariance hypothesis, the different shape (and size) of the comparison stimuli in measurements of apparent shape and slant may account in part for the poor correspondence found between judged shape and judged slant. Similarly, Flock (1964) used a comparison stimulus whose method of presentation differed altogether from that of any of the standard-stimulus surfaces.

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