Determinants of the rod-and-frame effect: Role of organization and subjective contour

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In Experiment 1, performance on a conventional (full) rod and frame was compared with that on three other displays. These included a closure condition in which only the corners of a luminous frame were present, a subjective contour condition in which the rod was seen against a black square subjective surface, and a pattern condition in which four luminous disks were arranged to form the corners of a square pattern. In all cases, a square-like form was perceived. The rod-and-frame effect (RFE) was greatest on the full frame, which differed significantly from all the rest. Closure produced the next greatest influence, while the responses to subjective and pattern conditions did not differ from each other. Experiment 2 showed that a subjective frame was no more effective than the subjective surface of Experiment 1, and verified the importance of 90-deg corner elements in the rod-and-frame display. The conclusion drawn was that equivalent form organizations are not sufficient to produce equivalent levels of the RFE, but certain luminance-difference contours appear to be essential.

In research on the rod-and-frame effect (Witkin & Asch, 1948), it has been shown recently that the influence of the tilted frame can be modulated by varying the retinal size of the frame (Ebenholtz, 1977; Ebenholtz & Benzschawel, 1977) such that the smaller the projected angle, the lower the rod-and-frame effect (RFE). In this study, large changes in apparent size, with retinal size held constant, were without influence on the RFE, thereby indicating that changes in apparent size were not sufficient to account for the modulating influence of retinal size on the RFE. The failure to find evidence for apparent size in the RFE is theoretically significant in that it suggests that the influence of retinal size occurs at a stage of processing prior to the point at which size constancy information is extracted.

The present research raises an analogous question about the role of form perception in the RFE. Will the perception of a square-like configuration suffice, or is the actual presence of the frame pattern on the retina necessary for the occurrence of the RFE?

EXPERIMENT 1

Method

Apparatus. In addition to a complete rod-and-frame display, three additional frame types were used. These are all represented in

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Figure 1. All the display elements were made of electroluminescent panels and were shown with a luminance somewhat under 1 nit. The full frame was 101.6 cm in length and 2.5 cm wide. The rod dimensions were 96.5 × 2.5 cm and were identical in all conditions. In the closure condition (Figure 1b), the outer edge of each corner was 9.6 cm and this also was the dimension of one

Figure 1. Luminous displays used in full frame (a), closure (b), subjective surface (c), and pattern (d) conditions.

side of each corner of the subjective surface (Figure 1c). The latter simulated a square surface, 101.6 cm per side. In the pattern condition (Figure 1d), the disks had a radius of 9.6 cm and were stationed at the corners of a square configuration with a center-to-center separation of 101.6 cm.

Each display was viewed, with head in a chin- and foreheadrest, at a distance of 190.5 cm, with the center of the display at a height of 120.6 cm, which also was at eye level for all observers. The angular subtense of one side of each display at the retina approximated that of a 101.6-cm line at 190.5 cm, or 29.9 deg.

Procedure. Subjects adjusted a rod to the apparent gravitational vertical from starting positions at 30 deg clockwise (cw) and counterclockwise (ccw) of true vertical, with bracketing permitted. The upright orientation of the rod was measured first within an upright display and then again within a display tilted 22 deg either cw or ccw, the direction of tilt being counterbalanced over subjects. The RFE was defined in terms of the algebraic difference between the average of the two settings taken with the upright and tilted displays, respectively. All subjects were exposed to the full frame and to only one of the remaining three displays. After the rod settings were completed, all subjects were asked to describe the visual displays from memory. In the closure and subjective surface conditions, subjects were shown a Kanizsa triangle (Kanizsa, 1974, 1976) prior to the start of the study and the subjective surface and contours were pointed out. Reference to the subjective surface was made during subsequent questioning at the conclusion of the study.

Design. Twenty-four subjects in each of two groups were exposed to the full frame and to either the closure or subjective surface conditions, and 32 additional subjects were exposed to the full-frame and the pattern conditions. Within each group, half were exposed first to the full frame and then to the other display type, with the sequence reversed for the remaining subjects. In the closure and subjective surface conditions, the 12 subjects per sequence were composed of 5 males and 7 females each, whereas the sexes were evenly distributed in the pattern condition, which was run after the previous conditions were completed. In order to reduce variance, the scores of any subject whose RFE on the full frame was 15 deg or higher were eliminated from the data set. There was one such instance in the closure and subjective surface conditions each and two in the pattern condition. In the former cases, the mean of the remaining 11 subjects of the subgroup was substituted. In the latter case, two new subjects were run in place of the high scorers.

Results

Sequence effects. Initial analyses (Grant, 1949) showed no significant sequence effects in any of the three conditions. However, there was a tendency for the frame type that followed the full frame to yield a higher RFE than when it occurred prior to the full frame. Since this tendency seemed to be enhanced in female subjects, separate sequence analyses were performed by sex. Again, no significant sequence effects emerged, and hence subsequent analyses were based upon data pooled over sequence.

Full vs. partial frames. In each of the three conditions, frame type was significant in favor of the full frame [$F(1,22) = 11.86$ and 21.68 , $p < .01$, for the closure¹ and subjective surface conditions]. In the pattern condition, $F(1,30) = 48.31$, $p < .01$. The mean RFE and standard error for each condition are presented in Table 1.

Comparisons among partial frames. Because of the large individual as well as sex differences typically associated with performance on the RFE (e.g.,

Witkin, Goodenough, & Karp, 1967), it was necessary to determine whether the groups differed on the full frame before proceeding to compare performance on the partial frames. Analysis of variance of the full-frame data was made over the three groups by sex. Experimental condition (i.e., groups) was not significant [$F(2,74) = 2.02$, $p < .05$], although female subjects yielded a significantly higher RFE than did males [$F(1,74) = 13.25$, $p < .01$]. The presence of significant effects of sex on the full frame, given the somewhat uneven numbers of males and females in the three groups, suggested the use of a covariance technique in order to ensure that any differences among partial frames were not due merely to a failure of random sampling to provide evenly distributed subject characteristics between the three conditions. Accordingly, for each group, the Spearman rank correlation between full and partial frame was determined. This yielded values of .47, .57, and .41 for the closure, subjective surface, and pattern conditions, respectively, with $p < .05$ in each case. Given the presence of significant correlations between full and partial frames, it was appropriate to use full-frame performance as the covariate in the analysis of the partial-frame data.

In the covariance analysis, frame type was significant [$F(2,73) = 12.08$, $p < .01$], but neither the effect for sex nor the interaction of the two was significant. Thus, the covariance technique was highly successful in eliminating the basis for sex differences. The means, adjusted for the covariate and averaged over male and female subjects, were 3.4, 1.4, and .90 for closure, subjective surface, and pattern conditions, respectively. The difference between closure and subjective surface was significant [$t(46) = 3.06$, $p < .01$], as was the difference between closure and pattern conditions [$t(54) = 5.09$, $p < .01$]. Subjective and pattern conditions did not differ significantly [$t(54) = 1.27$, $p > .05$]. Thus, the obtained effect of frame type was exclusively attributable to the relatively large effect of the closure condition.

Appearance of the partial frame. In response to the request to describe what they saw, 20 out of 24 subjects in the closure condition described the display as appearing like a square, a box, or a frame. No response was recorded for 3 subjects and one response was only partially recorded. Every subject responded

Table 1
Mean RFE (in Degrees) and Standard Error (SE) Under
Full- and Partial-Frame Conditions

RFE	Full	Closure	Full	Subjective	Full	Pattern
Mean	6.47	3.73	4.36	1.25	4.65	.80
SE	.90	.59	.80	.46	.58	.17

Note—For the last full and pattern conditions, $N = 32$. For all other conditions, $N = 24$.

negatively when subsequently asked whether they saw a subjective surface or contour. In the subjective surface condition, 21 out of 24 subjects reported the impression of a square or a box. Of the remaining 3, 1 described the display as "a line surrounded by four circles," another as a "bar inside boundaries," and the third as a "rod surrounded by a clock." In all, 17 subjects reported that they had seen a subjective surface similar to that of the Kanizsa figure.

In the pattern condition, the 32 subjects described the display as a square, a diamond, or a box. These subjects had not previously been shown a subjective contour, and hence they were questioned further only about whether the pattern suggested a surface to them. No report indicated the presence of a subjective contour. Overall, it is clear that the displays were processed for form in that they were perceptually organized and not merely seen as a set of unevenly distributed luminous elements against a black background. For example, even though 7 subjects failed to report a subjective surface in that condition, a square-like organization nevertheless was described by 4 of these observers.

Discussion

In all three groups, the full frame produced a significantly higher RFE than the partial frame, even though perceptually the partial displays all had a square-like configuration. Thus, to a certain extent, all four displays may be said to constitute an equivalence class with respect to form, although the particular stimulus pattern varied from case to case along with the underlying principle of perceptual organization. It can be concluded therefore that perceptual form equivalence is not a sufficient condition for equivalence in the magnitude of the RFE.

It is of interest that the closure condition produced the greatest effect among the partial frames. It would appear that the presence of square corners or linear elements plays an important role in the RFE. The relatively low effect under the subjective surface² condition in which square corners also were present probably can be attributed to the simultaneous presence of circular contours which do not convey orientation information.

The additional problem of accounting for the greater RFE associated with the full frame in comparison with the closure display also remains. Recently, Nyborg (1977) has examined the role of structure in a rod-and-frame task by varying the number of small line elements composing one side of the frame. In one condition, only four elements were present, one at the vertex of each corner. In a second and third condition, approximately 5 and 23 elements, respectively, were used to construct each side of the frame, and finally a continuous contour also was represented. On the basis of his measure (ϕ), most closely related to that used in the present study, Nyborg found that as

completeness of the frame configuration increased so did the frame-tilt effect, provided subjects were previously classified as frame dependent, with no significant relation present for frame-independent observers. One implication for the present problem is simply that, in comparison with the full frame, the closure condition constituted an insufficiently dense pattern.

EXPERIMENT 2

The failure of the subjective surface conditions to be as effective as either the full frame or even the closure condition may be related to certain properties of the subjective surface itself. It is possible, for example, that a pattern producing a simulated frame, with surrogate contours on *both* inner and outer edges, would serve as a more adequate stimulus for the rod-and-frame effect than the subjective surface with only an outer contour. Thus, a further test of the role of subjective contours in the rod-and-frame effect was provided in Experiment 2 with the use of patterns represented in Figure 2. Comparison of performance under Conditions 2b and 2c permitted, in addition, a test of the role of curved and cornered elements in the rod-and-frame effect.

Method

Apparatus. The full frame measured 106.7 cm on a side, and was constructed of electroluminescent panels with a width of 2.4 cm. The rod was 95.3×2.4 cm, centered within the frame, which was viewed at a distance of 150 cm. In Figure 2, the black regions represent the visible portions of the electroluminescent panels, while the white region represents the subjective frame. The curved pattern in Figure 2c had a radius of 9.5 cm, while the outside edge of the luminous corner in Condition 2c was 19 cm. The panels were hung on the full frame so that the corners and subjective contours overlapped the corresponding aspects of the objective frame. The subtense at the eye of one side of each subjective or objective frame was 40.8 deg.

Procedure. Settings to the apparent vertical were made as previously described in Experiment 1, with the exception that the line starting positions were 25 deg cw and ccw of the vertical. The frame tilt in Experiment 2 was 22 deg ccw, and the control measure of apparent upright were taken with the frame display completely absent. All subjects were exposed both to the full frame and to one of the partial-frame conditions, in counterbalanced order. Prior to the line settings, the subjects were shown samples of subjective contours from Kanizsa (1976). After all judgments of the vertical were completed, the subjects rated the quality or salience of the subjective contours on a scale of 0 to 5, with 0 representing no

Figure 2. Full-frame (a) and subjective-frame displays (b and c) used in Experiment 2.

subjective contour and 5 indicating a quality comparable with that seen in the Kanizsa figures.

Design. Twenty-eight subjects divided into two groups were exposed alternately either to displays 2a and 2b (the curve group) or to displays 2a and 2c (the corner group). Seven subjects in each group received the full-frame condition first, while the remaining seven first were exposed to the partial-frame display. In all cases, the frame-absent condition preceded the tilted frame measurements. There were four female and three male subjects within each subgroup of seven.

Results

As in the case of Experiment 1, whether the full frame preceded or followed the partial frame produced no significant sequence or order effects. Performance on the full and partial frames, pooled over sequence, is represented in Table 2. Within the curve group, the full frame yielded a significantly greater RFE than did the partial frame [$F(1,12) = 36.68$, $p < .01$]. The difference between the full and corner displays, however, was not significant [$F(1,12) = .941$, $p > .05$].

Since, as Table 2 shows, the groups differed widely on the full-frame condition, performance on the two partial frames was compared in analysis of covariance using the full frame as covariate. The results showed a highly significant difference in favor of the corner display [$F(1,25) = 19.88$, $p < .01$].

Subjective contour ratings did not differ significantly between the two groups, although there was some tendency toward higher ratings in the curve group. Thus there were six ratings of 0 in the corner group but only two in the curve condition, and the median rating was .5 in the former case, 2.0 in the latter.

Discussion

Although subjective contours were present in all but two subjects exposed to the curve display, the corresponding full-frame condition produced a RFE approximately 3.5 times as large. It is clear, therefore, that the presence of a subjective frame is not sufficient to produce the same level of RFE as the full frame itself. In fact, the curve display yielded about the same relative effect with respect to the full frame as that shown by the ratio of subjective *surface* to full frame in Experiment 1 (i.e., 3.49:1). Thus the subjective frame added no advantage to the subjective surface of Experiment 1.

The corner condition produced a surprisingly strong

RFE in Experiment 2 that was roughly equivalent to the full-frame condition. This cannot be due to the presence of subjective contours, since, at best, ratings were not higher than those of the curve condition. One explanation for the enhanced effect of the corner display relative to the full frame over the corresponding closure condition of the first experiment derives from the change in overall dimensions of the partial-relative to the full-frame counterparts. In Experiment 1, both displays had the same overall length. However, in Experiment 2, the size equivalence was maintained between the full frame and the *potential* subjective frame. It was necessary to construct the latter as though one actually were placing a frame over four square surfaces, one at each corner, thereby occluding a small portion of each. The net effect was to produce a somewhat larger overall pattern than the full frame itself. In Experiment 2, the result was a length, measured between the outer corners, of 121.9 cm, which produced a visual angle of 46.6 deg in comparison with 40.8 deg for the full frame. Since retinal size has been shown to be an effective determinant of the RFE (Ebenholtz, 1977), it is likely that this difference in relative angular size served to enhance the RFE in the corner display of Experiment 2. The extra corners and small square elements also may have contributed to the effect.

GENERAL DISCUSSION

When only small disks constituted the corners of a square form, as in Figure 1d, the RFE virtually disappeared. When corners were added to the disks, as in Figure 1c, in order to produce subjective contours corresponding to a surface, Experiment 1 showed that there was a slight, but not significant, enhancement of the RFE relative to the pattern (or disk) condition, and Experiment 2 showed that a subjective frame was about as effective as a subjective surface relative to a full-frame condition. The corner conditions represented by Figures 1b and 2c were most effective producing RFE ratios of full to partial frames of 1.73:1 in Experiment 1 and 1.13:1 in Experiment 2. The latter case, in which the partial frame was not significantly different from the full frame probably was due to its greater overall size, as discussed above.

The pattern of results of both experiments suggests that organizational or global factors that usually govern form perception are not effective determinants of orientation perception. What appears to be critical to the RFE is the representation of luminance-difference contours in the retinal periphery that encode orientation information. Clearly, circular patterns lack this information while it is present in the corner patterns. When both corners and curves are present (Figures 1c and 2b), it would appear that the most retinally eccentric feature governs the outcome. Thus, it may be supposed that what is essential to the

Table 2
Mean RFE (in Degrees) and Standard Error (SE) for
Full and Partial Frames

Condition	Full Frame		Partial Frame		Means*
	Mean	SE	Mean	SE	
Corner	5.59	1.06	4.96	.97	6.23
Curve	10.18	1.42	2.91	.79	1.64

Note— $N = 14$ in both conditions.

*Means adjusted for full-frame correlation.

RFE is not the result of constancy or even of form processing, i.e., the output of neither a postconstancy stage nor a postorganization stage is implicated, but rather it is the output of some prior stage more closely related to retinal pattern input. Previous results demonstrating the importance of retinal as opposed to apparent size (Ebenholtz, 1977) and the present results showing the unequal effects of members of the same form class³ both support such a "noncognitive" interpretation.

These conclusions support the further inference that the RFE occurs at a locus other than at primary visual projection sites. This possibility is consistent with the identification of the RFE as an instance of the control of posture and orientation by visual stimulation in the retinal periphery (e.g., Dichgans & Brandt, 1978; Leibowitz, Rodemer, & Dichgans, 1979), while such other functions as recognition and form perception are associated with foveal or parafoveal stimulus representations. The present studies support the distinctions engendered by the two visual systems theory (Held, 1968; Ingle, 1973; Schneider, 1969; Trevarthen, 1968) by demonstrating the insufficiency of form perception for the orientational control function.

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NOTES

1. Cross (1973) used a similar "corner" display to examine sensitivity to rod tilt. However, his measures derived from a signal detection procedure, and are not directly comparable with those of the present study. Nevertheless, if increased sensitivity can be identified with a decrease in the RFE, then the present results found with the full and closure patterns are consistent with Cross' sensitivity data for comparable frame patterns.
2. The low effect in the subjective condition is noteworthy in that it represents one of the few instances in which a subjective contour was relatively ineffective in comparison with its luminance-difference contour surrogate (e.g., Meyer & Garges, 1979; Smith & Over, 1979).
3. One reviewer suggested that, "In order to tease out the influence of the different stimulus determinants, each display would need to be specified in terms of its Fourier components". While it is true that a spatial frequency analysis would show certain commonalities such as a preponderance of high spatial frequencies associated with displays containing corners and may even suggest reasons for sensing each form as square, this approach could not explain why such equivalent *global* features should yield extremely different RFEs. The Fourier approach may be equally inappropriate to account for the effectiveness of retinal size, even though retinal angle is encoded by spatial frequency. The problem is that retinal *eccentricity* rather than size may be the critical variable.

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