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EFFECT OF DEPTH SEPARATION ON THE PONZO ILLUSION.(U)
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Effect of Depth Separation
on the Ponzo Illusion,

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positions of the triangle and the line segments. That hypothesis arose from prior research which indicated that the destructive interaction among spatially adjacent contours present in such phenomena as visual masking and lateral interference depended strongly on the relative depth positions of the interacting contours. The Ponzo illusion provided a stimulus configuration for determining if the effect of depth position applied to interactions that are not destructive. To provide facile manipulation of depth position the Ponzo stimuli were generated as stereoscopic contours formed from dynamic random-element stereograms. This approach permitted depth position and other parameters to be readily manipulated without introducing potentially confounding changes in proximal stimulation and in the apparent size of the stimulus elements. Estimates of illusion magnitude were obtained under a series of depth positions in which the test lines appeared in depth in the same plane as the triangle and either in front of, or behind the plane of the triangle. The main results were: (a) the magnitude of the illusion was strongly influenced by the depth position of the stimuli; (b) illusion magnitude declined when the test lines were in a depth plane in front of the triangle while illusion magnitude was enhanced when the test lines were in a depth plane behind the triangle. These results indicated that depth position plays a significant role in determining the magnitude of the spatial distortion typified by the Ponzo illusion. Further, the asymmetrical nature of the effect of depth position, which has been observed in other investigations, suggested that this asymmetry may be a general property of interactions in three-dimensional space.

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Effect of Depth Separation on the Ponzo Illusion

The perceived length of contours can be altered by their placement within the arms of an acute angle, as illustrated in Figure 1. Both of the enclosed parallel white lines are physically equal in length yet the one closer to the apex of the angle appears longer than its partner. As Figure 1 suggests, this apparent change in length can occur in many natural situations as, for example, on an aircraft runway, or in general, whenever linear perspective cues are present. When this change, or distortion, in length is studied in the laboratory, it is often referred to as the Ponzo illusion and regarded as one of a large class of two-dimensional visual geometric illusions that have interested psychologists for many years.

For the research described in this report the Ponzo illusion serves as a convenient stimulus configuration that can be used to explore the following experimental question: Would the magnitude of the illusion be altered if the arms of the acute angle were in a depth plane different from that of the parallel lines? The answer is sought by the general research program of which this report is a part. The objective is to determine if apparent depth plays an important role in governing the various kinds of interactions among spatially adjacent contours that occur when they occupy the same depth plane. In an earlier investigation of the threshold elevating (i.e., destructive) interaction between test and mask stimuli found in metacontrast masking, depth position proved to be a very significant factor. Whereas masking diminished (i.e., test is more detectable) when the test form appeared in a depth plane in front of the mask, a reversal of depth positions augmented masking; this relationship has been termed the "front effect" (Fox & Lehmkuhle, 1978;

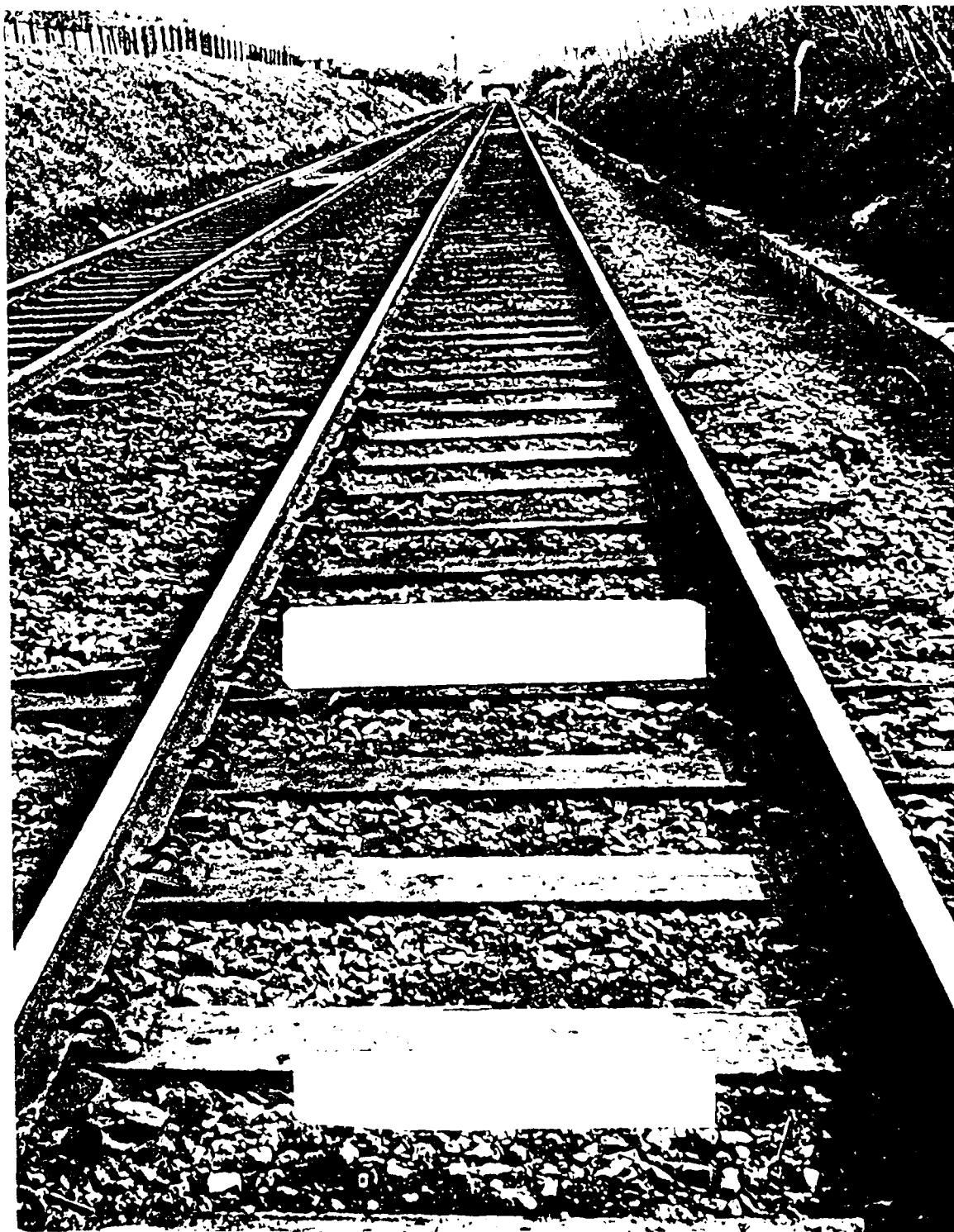


Figure 1. The Ponzo configuration embedded within a context of enhanced linear perspective.

Lehmkuhle & Fox, 1980). To determine if this effect of apparent depth was confined to the transient, threshold level stimuli attendant to visual masking, Fox and Patterson (1980) examined the effect of depth position on lateral interference, the nature of which involves an impairment in visibility of closely spaced, suprathreshold contours. They found that depth position had the same effect on lateral interference as it had on visual masking.

The purpose of the present study was to determine if depth position also influenced suprathreshold interactions that are not destructive, but rather act on some other stimulus dimension such as the change in apparent length integral to the Ponzo illusion. Before turning directly to the description of that study, however, consideration should be given to several previous studies that have examined the effect of depth position on the Ponzo illusion.

Green, Lawson, and Godek (1972) presented the illusion as a stereogram consisting of discrete contours. The authors found that illusion magnitude diminished when the test lines, with crossed disparity, appeared in depth planes in front of the inducing triangle, yet increased with uncrossed disparity that placed the lines in a depth plane behind the triangle. They attributed this asymmetrical effect of depth position on illusion magnitude to changes in the apparent size of the test lines induced by size constancy. According to this explanation, when the lines were presented in crossed disparity they appeared smaller, thereby increasing the apparent spacing between them and the edges of the triangle. Conversely, when the lines were presented in uncrossed disparity they appeared larger, thereby decreasing the apparent spacing between them and the edges of the triangle.

The asymmetrical effect of depth position found by Green, Lawson and Godek is not consistent with the adjacency principle developed by Gogel (e.g., Gogel, 1978), which would posit a symmetrical decrease in illusion

magnitude as the difference in depth position between interacting elements increases. This departure from the adjacency principle led Gogel to examine the effect of depth position on the Ponzo illusion under several conditions in which depth was manipulated by combining absolute distance cues with stereoscopic depth cues (Gogel, 1975). In one condition, in which a single triangle was used, the effect of depth position on illusion magnitude was similar to the relationship observed by Green et al. (1972). That is, illusion magnitude declined when the test lines were in a depth plane in front of the triangle, but it did not decline when the test lines were in a depth plane behind that of the triangle. In a second condition, two inducing triangles were located at different depth planes with their apexes oriented in opposite directions. This yielded a more complex pattern of results which Gogel interpreted as being consistent with the adjacency principle. No ready explanation, however, was available for the failure of the results to conform to the adjacency principle when a single triangle was used. Gogel suggested several possibilities, including differential effects of attention, changes in apparent size of the figures induced by size constancy, and conflicting information about depth induced by the interaction of absolute and relative depth cues.

In a brief report, Hennessey and Leibowitz (1972) used a method of physical separation (lines on a glass sheet) to locate the test lines of the Ponzo illusion at a depth position in front of the triangle. The authors found that illusion magnitude decreased under conditions of depth separation relative to the case where the test lines and triangle were positioned in the same depth plane.

In his book, which summarizes research with random-element

stereograms, Julesz (1971) presents a static random-element stereogram of the Ponzo illusion in which the triangle and test line are separated in depth. He makes the anecdotal observation that the depth separation appears to change illusion magnitude. But, a more rigorous check on this observation, made in this laboratory, did not yield general agreement. Ten observers were required to make forced-choice judgments as to direction of illusion magnitude--five reported an increase, while the remainder reported a decrease, in magnitude.

Taken together, it is clear that the results of these studies are rather equivocal. A major factor responsible for the disagreements is the difficulty encountered in manipulating the apparent depth of stimuli without at the same time introducing confounding changes in proximal stimulation. Typically, only a limited range of depth positions can be varied, and it is very difficult to compensate for changes in apparent size that covary with changes in apparent depth. These restrictions on experimental manipulation have, in general, impeded research concerning the effect of depth position on stimulus interaction.

To overcome these difficulties this research program has capitalized upon recent advances in the techniques available for the generation of dynamic random-element stereograms. Random-element stereograms, developed by Julesz (1960), are matrices of random dots in which the retinal disparity that gives rise to stereoscopic forms is camouflaged within the dot structure. When viewed monocularly, these stereograms appear to be random collections of dots without identifiable shapes. But when viewed under stereoscopic conditions, clearcut stereoscopic forms with distinct edges can be seen. In a functional sense, the forms bypass or skip more peripheral stages in the visual system and

arrive at the central stage responsible for stereopsis. Even though the stereoscopic forms do not exist as physical luminance gradients impinging on the retina, they can induce illusions, aftereffects, and other perceptual phenomena similar to those induced by physical contours. The great advantage of such stereograms is that large changes in apparent depth can be made without introducing changes in proximal stimulation.

The utility of random-element stereograms has been greatly enhanced by recent technical developments that have made possible the dynamic generation of stereograms, wherein all parameters of the stereoscopic display can be changed instantaneously. With these dynamic stereograms, stereoscopic forms can be moved about in stereoscopic space in X-Y-Z coordinates, and the configuration of the forms can be quickly altered without introducing monocular cues. A system for generating dynamic random-element stereograms has been developed at Vanderbilt and used in a variety of research applications, including investigations of the effect of depth position on contour interaction (e.g., Fox & Lehmkuhle, 1978; Lehmkuhle & Fox, 1980; Fox & Patterson, 1980). The system was used in this experiment to generate the inducing triangle and test lines that comprise the Ponzo illusion.

Method

Observers

Twelve persons (1 male and 11 females) participated in the study. All 12 had no knowledge of the hypothesis under test, but possessed good stereopsis and had recent training in perceiving stereoscopic contours formed from dynamic random-element stereograms.

Apparatus

The dynamic stereograms employed in this study are similar conceptually to the static stereograms developed by Julesz (1971). As shown in Figure 2, each monocular view of a static random-element stereogram consists of a random-dot matrix of about 10,000 dots. The scheme employed with these stereograms for producing the retinal disparity essential for the induction of stereopsis is depicted in Figure 3. A subset of dots within a center square area of one dot matrix is displaced, or shifted, horizontally by one column relative to corresponding dots in the other matrix. It is this lateral displacement which results in the production of retinal disparity between those elements in the shifted submatrix and corresponding elements in the other matrix.

Because the laterally shifted submatrix is camouflaged by a large number of surrounding elements, it cannot be seen under nonstereoscopic viewing conditions. But under appropriate viewing conditions, in which each random dot matrix stimulates a separate eye, the binocular visual system, in a sense, detects the presence of retinal disparity. For example, under these conditions the form depicted in Figure 3 would appear as a solid textured square standing out in depth.

There is, however, one important limitation with regard to the method of producing retinal disparity outlined above. With respect to the static stereograms, the common practice has been to fill the gap which has been created on one side of the displaced matrix with non-disparate elements (cells labeled X & Y in Figure 3) originating from the other side of the matrix, i.e., those which had just been covered by the displaced matrix. But as Bridgman (1964) and Gulick and Lawson



Figure 2. The two monocular patterns of a typical static random-element stereogram. When each pattern stimulates a separate eye, a stereoscopic form can be perceived (after Julesz, 1971).

1	0	1	0	1	0	0	1	0	1
1	0	0	1	0	1	0	1	0	0
0	0	1	1	0	1	1	0	1	0
0	1	0	Y	A	A	B	B	0	1
1	1	1	X	B	A	B	A	0	1
0	0	1	X	A	A	B	A	1	0
1	1	1	Y	B	B	A	B	0	1
1	0	0	1	1	0	1	1	0	1
1	1	0	0	1	1	0	1	1	1
0	1	0	0	0	1	1	1	1	0

1	0	1	0	1	0	0	1	0	1
1	0	0	1	0	1	0	1	0	0
0	0	1	1	0	1	1	0	1	0
0	1	0	A	A	B	B	X	0	1
1	1	1	B	A	B	A	Y	0	1
0	0	1	A	A	B	A	Y	1	0
1	1	1	B	B	A	B	X	0	1
1	0	0	1	1	0	1	1	0	1
1	1	0	0	1	1	0	1	1	1
0	1	0	0	0	1	1	1	1	0

Figure 3. The displacement process for the generation of static random-element stereograms (after Julesz, 1971).

(1976) point out, this technique produces columns of elements in one dot matrix unpaired with those in the other dot matrix. Consequently, these columns are seen as part of the background rather than as part of the figure, an outcome which results in a decrease in size of the figure as disparity is increased. This reduction in size, moreover, is not due to any apparent reduction owing to size constancy, but rather a result of the physical characteristics of the static method of stereogram generation. This problem of correlation between size and disparity found in the static method of generation is avoided in the present method of dynamic generation; the size and shape of the stereoscopic figures are independent of their disparity.

Only a brief overview of the dynamic random-element stereogram system developed at Vanderbilt will be presented here. More complete descriptions of this system are given in Fox and Lehmkuhle (1978), Lehmkuhle and Fox (1980), and Shetty, Brodersen, and Fox (1979). The system used in the present investigation is composed of three components: the display device, the electronic generation unit, and the optical programming device. The interrelationship of these three units is shown in Figure 4; their description is given below.

The display device is a color television receiver so modified that the red and green guns can be electronically controlled at the level of the video amplifiers; the blue gun is disabled. The red and green guns are modulated in raster-scan mode at standard video frequencies, and produce random-dot matrices composed of red and green dots. Dot patterns are produced by turning the guns on and off as they sweep the raster.

Stereogram construction is accomplished via the second unit, the electronic generation system. This system is composed of four subsystems,

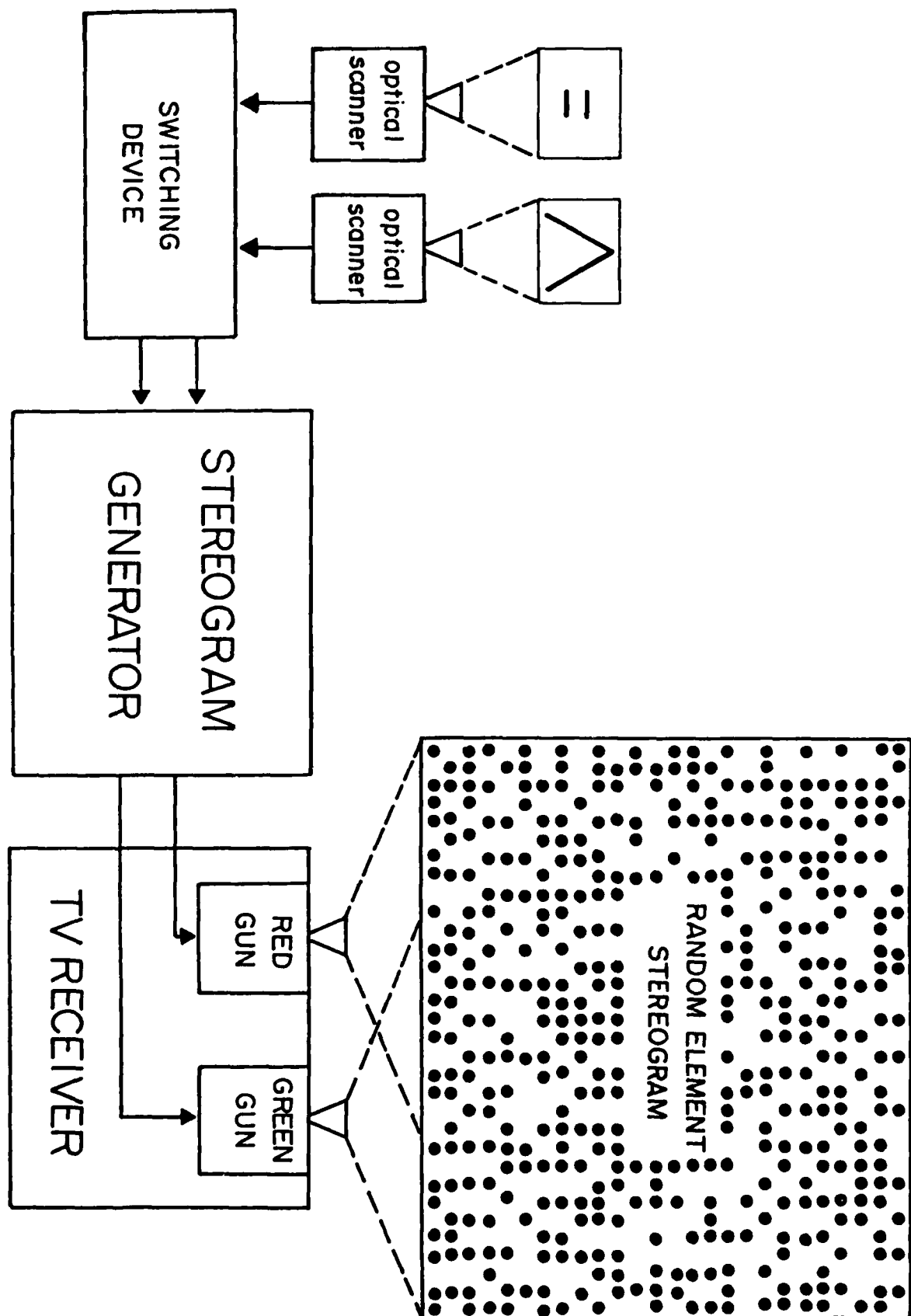


Figure 4. Display, programming, and logic units of the stereogram generation system.

each of which constructs some portion of the stereogram. As the final output all portions are presented simultaneously. The functions of these four subsystems are: (a) The undelayed dot generation system generates random matrices of red and green dots without disparity; (b) the size/shape system specifies the X/Y coordinates of the stereoscopic form to be displayed by blanking the appropriate dots generated by the undelayed dot generation system; (c) the dot delay system produces a slight delay in the output of one or the other of the electronic guns, which results in a difference in spatial position between red and green dots. This spatial displacement produces the retinal disparity essential for stereopsis. Dichoptic stimulation is achieved by use of the well-known anaglyph technique, in which appropriately matched red and green filters are worn by the observers. Note that since the dots that are delayed are those which will fill the area specified by the size/shape system, the disparity is produced between only these delayed dots and the undelayed dots from the other gun that also fill the same area; (d) the gap filling system provides dots without disparity which precisely fill the gap produced by the delay. The output of these subsystems are combined by ANDing logic operations, and when simultaneously displayed on the television screen, the stereoscopic form can be seen without the presence of monocular cues.

In this dynamic method of generation, all dots are replaced in both matrices at either the field rate of 60 times per second, or the frame rate of 30 times per second of the video receiver. Replacement of dots in this fashion permits the configuration of the stereoscopic form to be continuously manipulated in X, Y, and Z positions without the introduction of monocular cues. Dot replacement in this way also produces

apparent motion of the dots, not unlike the static seen on an untuned TV channel. This apparent motion, however, does not impair the visibility of the stereoscopic form.

The electronic generation unit also provides controls for instantaneously changing the magnitude and direction of disparity. But this unit by itself allows only for the generation of rectilinear stereoscopic forms.

The third unit of this system, the optical programming device, makes it possible to present virtually any stimulus configuration as a stereoscopic form. The principle of the programming system is similar to that of a flying spot scanner. The scan of a modified black and white video camera is synchronized with the sweep of the video receiver. The camera controls the size/shape system by specifying the area that is to receive the delayed dots. This is accomplished by having the analog voltage emitted by the camera vary as it sweeps over contours varying in luminance. Thus, any black and white two-dimensional configuration scanned by the camera can be converted into its corresponding stereoscopic counterpart. The number of cameras employed with this system determines the number of stimulus configurations that can be displayed simultaneously, with the parameters of the stereoscopic configuration encoded by one camera manipulated independently of those encoded by another camera. In the present study, two video cameras were employed.

The stimuli employed in the present study consisted of two horizontal lines of equal physical length (e.g., the test stimuli) and a triangle; these stimuli were achromatic two-dimensional pictures mounted on a wall. Of the two modified video cameras used in this study, one scanned the image of the test lines while the other scanned the image of the triangle (see Figure 5). Note that the cameras only provide

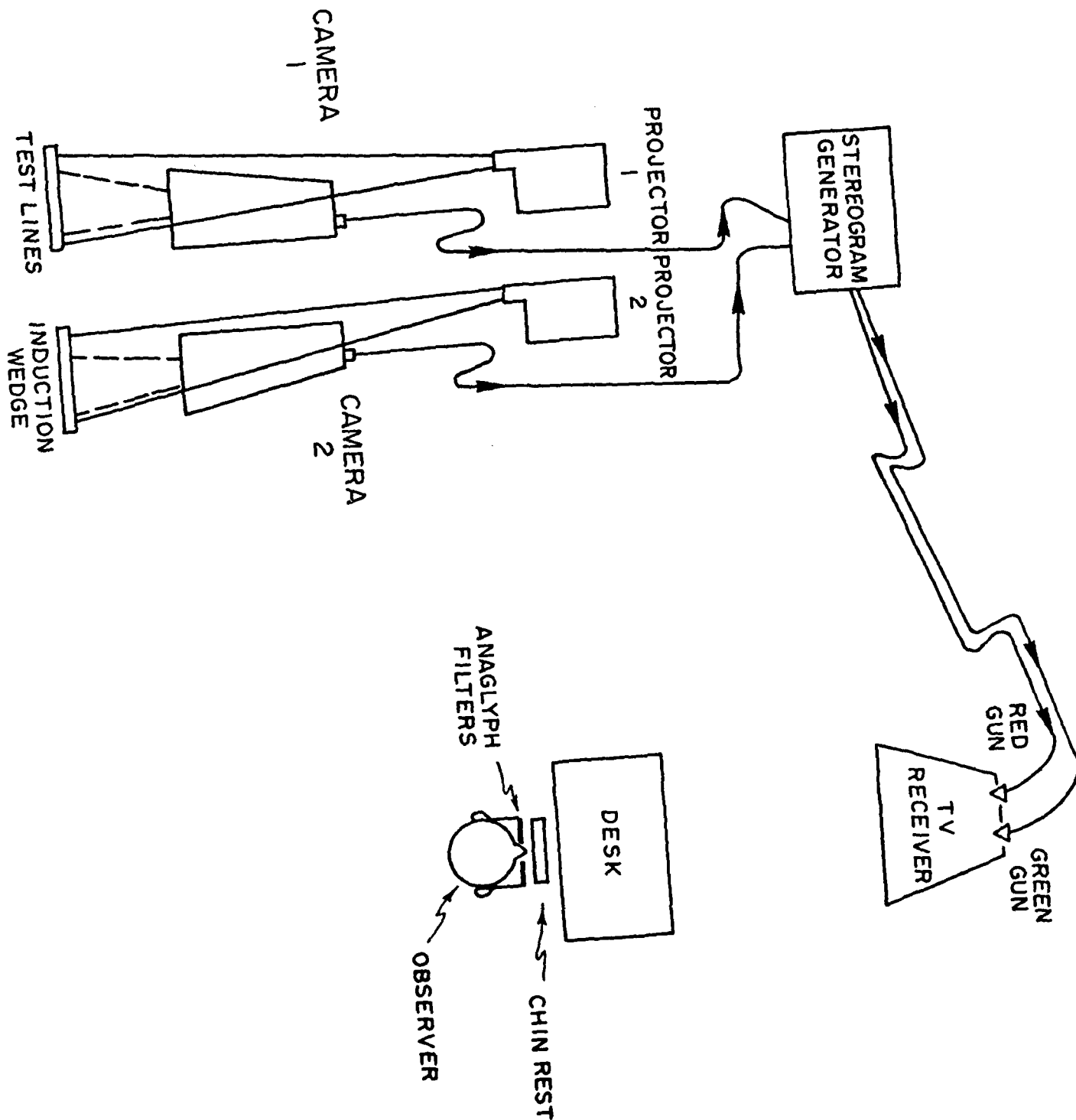


Figure 5. The stereogram generation system as arranged in the experimental room.

information concerning the position of the figures along the X- and Y-axes of the display. The depth positions of the stereoscopic counterparts of the test lines and triangle are controlled by the stereogram generation unit. That unit, in turn, addresses the display, which is a color TV receiver of the table model variety.

Stimuli

The dimensions of the stimuli employed in this study, which were arranged in the well-known Ponzo configuration, are shown in Figure 6. Note that the two legs of the triangle formed an angle of 50 deg, with the apex pointing upwards; at no time did the triangle overlap any portion of the test stimuli.

The test lines under all conditions remained in the same depth plane, which corresponded to a crossed disparity of 22'0". The induction triangle was presented at one of five depth positions: at depth conditions +2 and +1 corresponding to disparities of 7'20" and 14'40" respectively, the triangle was positioned in depth behind the test stimuli (see Figure 7). At depth condition 0 corresponding to a disparity of 22'0", the triangle occupied a depth plane equal to that of the test stimuli. Finally, at depth conditions -1 and -2 corresponding to disparities of 29'20" and 36'40" respectively, the triangle was positioned in depth in front of the test stimuli (see Figure 8). These disparities were all crossed. In the control condition, the test stimuli were presented in isolation. Although the apparent size of the induction triangle could be adjusted so as to remain constant for all depth manipulations, this adjustment was found to be unnecessary. Forced-choice judgments which were obtained from the 12 observers revealed that the size of the induction triangle

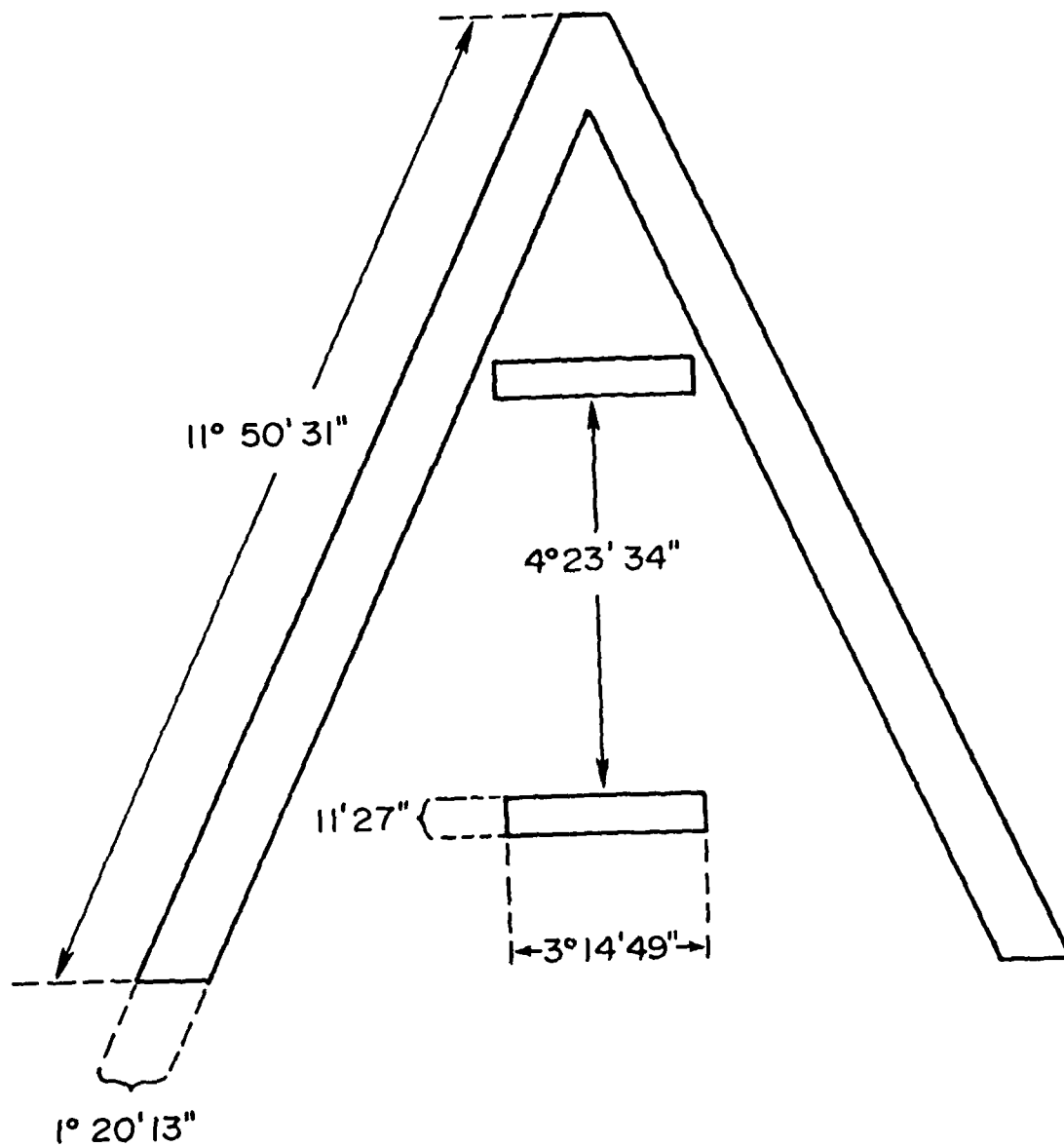


Figure 6. Dimensions of test lines and inducing triangle.

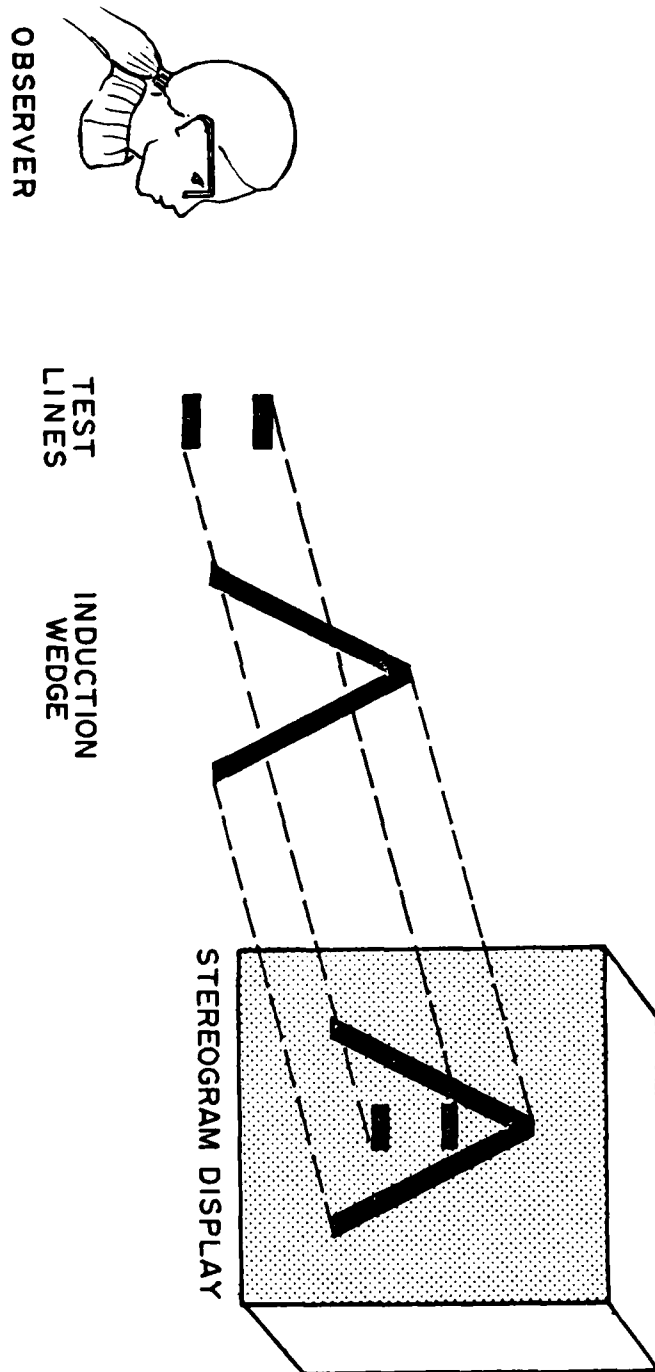


Figure 7. Stimulus arrangement showing relative depth of test lines (in front) and inducing triangle (Note that the term "inducing triangle" is synonymous with induction wedge in the figure).

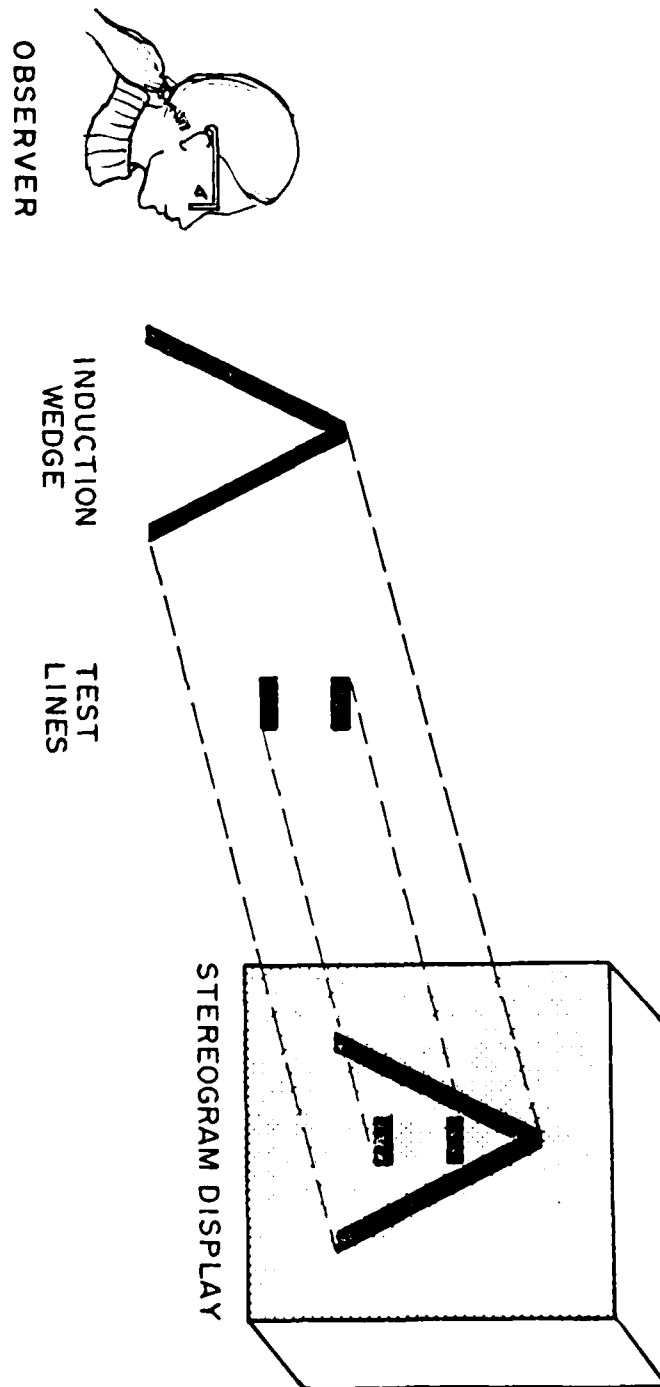


Figure 8. Stimulus arrangement showing relative depth of test lines (in back) and inducing triangle (note that the term "inducing triangle" is synonymous with induction wedge in the figure).

appeared equal under all depth conditions.

Procedure

The observers judged the length of one test line relative to that of the other in the following way: One half of the participants estimated the length of the lower line relative to that of the upper, with the upper test line assigned an arbitrary length of 10 units. The other half of the observers estimated the length of the upper line relative to that of the lower, with the lower test line assigned an arbitrary value of 10 units.

Both the test stimuli and triangle were continuously visible to the observers for the entire duration of each trial. The observers were allowed to use fractions or decimals in their estimations, taking as long as necessary to complete each trial. The one control and five depth conditions were randomly presented to the observers for five trials each, making a total of 30 trials. The display was viewed by the observers under constant conditions, such as fixed viewing distance and stable head position.

Results

Length estimations were converted to percent distortion for each observer in the following fashion: Average length estimations obtained under each of the five depth conditions were subtracted from the average estimations obtained under the control condition. Each absolute difference (disregarding the sign) was then divided by the control condition value and multiplied by 100.

Figure 9 shows the mean percent distortion for the one control and five depth conditions. Inspection of this figure shows distortion magnitude to be greater (i.e., greater length estimations for the upper

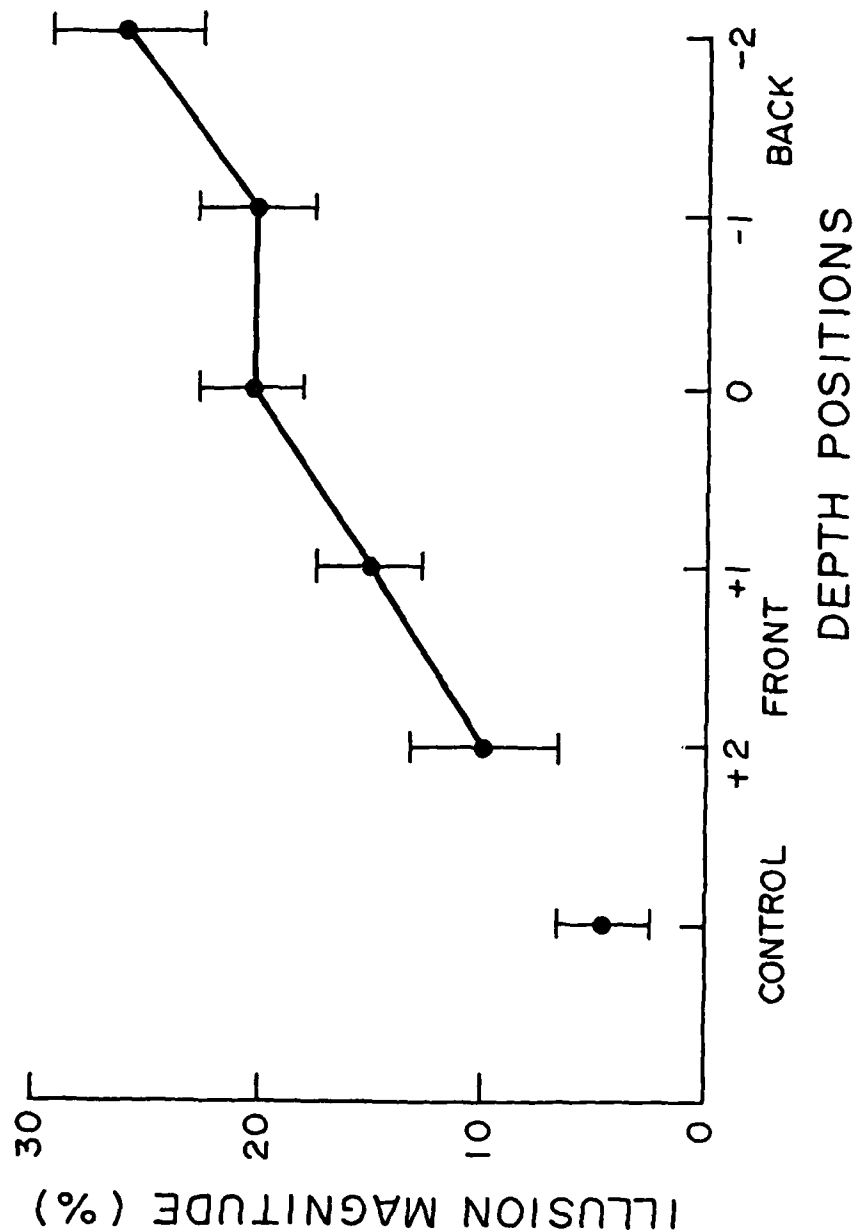


Figure 9. Illusion magnitude for the control condition, in which the test lines were presented without the inducing triangle, and for five depth conditions in which the test lines and inducing triangle were presented together (all stimuli were suprathreshold). For the two front depth conditions, the test lines were seen in depth in front of the inducing triangle, and for the two back depth conditions, the test lines appeared in depth behind the inducing triangle. For the zero depth condition the test lines and triangle occupied the same depth plane.

test line) under the condition where the induction triangle was presented along with the test stimuli in the same depth plane (depth condition 0), relative to the control condition in which the test stimuli were presented in isolation. Furthermore, relative to the equal depth condition (depth condition 0), the magnitude of distortion was found to be asymmetrical following depth manipulations of the induction triangle: Distortion was found to decrease under conditions in which the test stimuli appeared in depth in front of the induction triangle (depth conditions +2 and +1), whereas distortion was observed to increase in the situation where the test stimuli appeared in depth behind the induction triangle (depth condition -2). A one-way Analysis of Variance (ANOVA) for repeated measures revealed these differences to be significant, $F(4,44) = 6.47$, $p < .001$ (see Table 1).

A Newman-Keuls test for these means was also computed, and the results are presented in Table 2. With regard to the main comparisons, results from this test found that the difference in distortion magnitude between depth condition 0, in which both the induction triangle and test lines were presented in the same depth plane, and the control condition was significant. Furthermore, the decrement in distortion magnitude which occurred under depth condition +2, in which the test lines appeared in front of the triangle, relative to depth condition 0 was also significant. However, the increase in distortion magnitude which occurred for depth condition -2, in which the test lines appeared behind the triangle, relative to depth condition 0 was not significant.

Discussion

When both triangle and test lines occupy the same depth plane, the magnitude of illusion is greater relative to that observed when the test lines are presented without the triangle. This difference in illusion magnitude, which is about 15% and statistically significant, indicates that the presence of the triangle did induce a substantial change in the

TABLE 1
ONE-WAY ANALYSIS OF VARIANCE SUMMARY TABLE

Source	Sum of Squares	df	Mean Ratio	F-Ratio
Between Error	5131.27	11	466.479	
Depth Conditions	4106.44	5	821.288	8.575*
Within Error 1	5393.48	55	98.0633	
Total	14631.2	71	206.073	

*p < .001

TABLE 2
NEWMAN-KUELS TEST FOR TREATMENT MEANS OBTAINED UNDER ONE:
CONTROL AND FIVE DEPTH CONDITIONS

Depth Condition	Depth Condition					
	C	+2	+1	0	-1	-2
C	4.67	---	*	**	**	**
+2	12.92	---	---	*	*	*
+1	17.75	---	---	---	---	---
0	23.17	---	---	---	---	---
-1	23.83	---	---	---	---	---
-2	26.83	---	---	---	---	---

* $\bar{p}$.05
** $\bar{p}$.01

apparent length of the test lines. Further, the relative depth position of triangle and test lines had a substantial effect on illusion magnitude. For the situation in which the lines were in front of the triangle (i.e., depth condition +2), illusion magnitude is significantly reduced relative to the case where both triangle and lines have the same depth plane (depth condition 0). There is also a tendency for illusion magnitude to remain the same or to increase, albeit not statistically significant, for the situation where the test lines appear in a depth plane behind the triangle (depth conditions -1 and -2).

These results are similar to those that have been obtained in the earlier investigations of visual masking and lateral interference (Lehmkuhle & Fox, 1980; Fox & Patterson, 1980). These phenomena involve interactions among contours which can be characterized as destructive, or inhibitory, in the sense that the perceptibility of contours is impaired as indexed by elevations in threshold. The present results, however, indicate the the effect of depth position is not confined to destructive interactions among contours. Rather, it can be generalized to the kind of spatial modification, or distortion, intrinsic to the Ponzo illusion, and presumably to other similar kinds of interactions involving apparent modifications in the dimensions of stimuli. Similarly, the asymmetrical effect of depth position, which has been observed in previous work and termed the front effect, is also present in these data. Accordingly, it is suggested that the front effect is a general phenomenon not limited to the case of destructive interaction.

The presence of a front effect in this study can contribute to a clarification of the earlier investigations of the effect of depth position on the Ponzo illusion discussed in the introduction. Recall

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that both Green et al. and Gogel, in his single triangle condition, found an asymmetrical effect of depth position similar to the front effect. But several of the hypotheses advanced by these authors to account for the asymmetry are not applicable to the present data. An explanation based on a change in apparent size is not possible because such changes did not occur. A conflict between absolute and relative depth cues could not be a contributing factor since all depth cues were stereoscopic. An appeal to differential eye movements, or changes in convergence, is not possible because the observers fixated upon the test lines which remained at one position in depth. An hypothesis based upon differences between crossed and uncrossed disparity is not viable because for all depth positions crossed disparity was employed, i.e., contours always appeared in front of the display in the space between the display and the observer.

It has been suggested, however, (Gogel, 1975; Gogel, personal communication) that somehow attention might be a factor, with the closer depth position of the triangle acting to attract greater attention than the farther depth positions of the triangle. But this idea requires further theoretical development before it can be evaluated empirically. Further, it does not seem applicable to situations involving briefly presented, threshold level stimuli, such as in the case of visual masking (e.g., Lehmkuhle & Fox, 1980).

The ubiquity of the front effect suggests that it may reflect a natural bias of the perceptual system to give greater weight to stimuli that are closer in depth to the observer. Such a bias could be analogous to the dominance of figure over ground. While more

research is required to elucidate the mechanisms responsible for the front effect, it does seem clear that it is a robust phenomenon which plays a significant role in influencing the interactions of stimuli in three-dimensional space.

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