AM 66-24

PROBLEMS IN DEPTH PERCEPTION

Equidistance Judgments in the Vicinity of a Binocular Illusion

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July 1966

FEDERAL AVIATION AGENCY
Office of Aviation Medicine

FOREWORD

This study was conducted by Frank L. Agee, Jr. (now at the Boeing Company, Aerospace Division, Seattle, Washington), under the direction of Walter C. Gogel (now at the Psychology Dept., University of California, Santa Barbara), and was submitted by Mr. Agee to the University of Oklahoma in partial fulfillment of the requirements for the MS degree.

The authors wish to thank James C. Hester for his assistance in collecting the data of this study.

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PROBLEMS IN DEPTH PERCEPTIONS:

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I. Introduction.

Research has clearly indicated that misleading size cues can alter the apparent depth orientation of an object in spite of the presence of veridical cues of binocular disparity.[1–8] For example, if an Ames trapezoidal window [1] is oriented with its smaller end closer to the observer (*O*), it will usually appear as though this end were the more distant. A situation of this type can be called a binocular illusion in depth since it is a distortion by other cues (in this case, the cue of relative size) of the perception that normally would occur from the cue of binocular disparity. It has been demonstrated [2] that the perceptual consequences of a binocular illusion in depth are not confined to the stereoscopic display used in producing the binocular illusion. More specifically, it has been asserted that the depth position of an extraneous object in the vicinity of the depth illusion will be more correctly judged with respect to portions of the illusion display with which it is directionally close than with respect to portions of the illusion display from which it is directionally displaced.[2, 3]

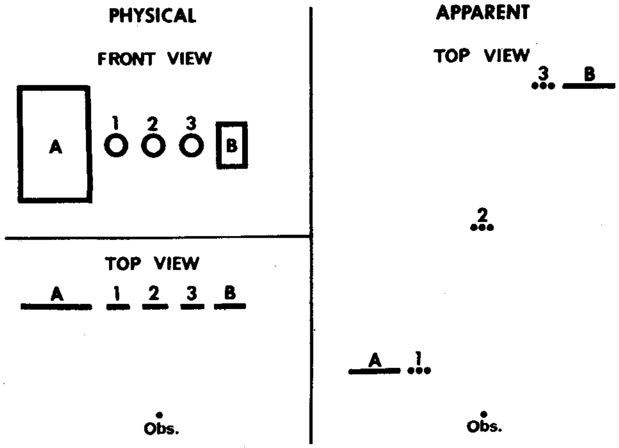

FIGURE 1. A schematic drawing illustrating the effect of a binocular illusion in depth upon the apparent depth location of other objects.

A demonstration of the effect of a binocular-depth illusion upon the perceived depth of extraneous objects is schematically illustrated in Figure 1. In Figure 1, two differently sized playing cards (A and B), and three disks (1, 2, and 3) are physically located at the same distance from *O* and, according to the stereoscopic (binocular-disparity) cue, should appear at the same distance. As a result of the misleading relative size cue between the two cards, however, Card A appears in front of (closer to *O* than) Card B. The difference between the physical and apparent distance positions of the card in Figure 1 represents a binocular illusion in depth. The disks in Figure 1 are the extraneous objects; i.e., they contain no misleading size cues. The apparent depth positions of these disks approximate the mean results obtained in an experiment[3] in which a single disk was alternately presented in each of the three lateral positions and judged as to its depth position with respect to each card. As is indicated in Figure 1, Disk 1 correctly appears at the distance of the left card, but it incorrectly appears in front of the right card. Similarly, Disk 3 is seen correctly in depth only with respect to the playing card (Card B) with which it is most nearly in line of sight. Disk 2, which is directionally midway between the two cards, is correctly perceived with respect to neither card but appears midway between them in depth.

It can be inferred from this and similar displays that if the disks had been adjusted to appear equidistant from *O*, Disk 2 would have had to be moved physically nearer to *O* than Disk 1, etc.[2] It is possible, however, that in adjusting the disks to apparent equidistance with each other, *O* would be able to ignore the playing cards and consequently the effect of the binocular illusion upon the equidistance judgment would be reduced or eliminated. Also, as is indicated in Figure 1, the effect of the binocular-depth illusion extends beyond the immediate vicinity of the illusion-producing objects (playing cards). It is possible, therefore, that the magnitude of the distorting effect of the binocular illusion upon the apparent depth positions of the extraneous objects might vary as the extraneous objects are directionally displaced from the display producing the binocular illusion. Previous studies [2, 3] have employed stimulus displays in which the depth illusion has been oriented horizontally with the extraneous object separated laterally within (or nearly within) the right-left extent of the illusion. There is little reason not to expect similar results, however, when the binocular illusion is vertically oriented with a vertical separation between the extraneous objects and when the extraneous objects are located outside the horizontal or vertical extent of the illusion. These conditions were investigated in the present study.

II. Apparatus.

A. *The Binocular Illusion.* The binocular illusion in depth was produced by an Ames trapezoidal window (Portable Model, Catalog No. RTW_1), 33.8 cm long, which was illuminated by a projector invisible to *O*. The average luminance of the light gray portions of the window was 0.35 ft-L. Both horizontal and vertical orientations of the long axis of the window were used. The window was slanted in depth 45° with respect to *O*'s objective frontal plane when presented horizontally, but it was parallel to *O*'s objective frontal plane when presented vertically. The window presentations were such as to result in the following four experimental conditions:

1. A horizontal orientation of the window in which the large end of the window was on *O*'s left and was physically more distant than the small end.
2. A horizontal orientation of the window in which the large end of the window was on *O*'s right and was physically more distant than the small end.
3. A vertical orientation of the window in which the large end of the window was higher in *O*'s field of view than the small end, with the two ends physically equidistant from *O*.
4. A vertical orientation of the window in which the large end of the window was lower in *O*'s field of view than the small end, with the two ends physically equidistant from *O*.

In all experimental conditions, the large end of the window was 304 cm from the eyes of *O*. Any effect of aniseikonia upon the overall experimental results for the horizontal orientations of the window was eliminated by orienting the window at equal but opposite directions of physical slant (Conditions 1 and 2). Any tendency to induce cyclorotation of the eyes when the window was verticaly positioned was avoided by always placing the vertical window in a plane parallel to the objective frontal plane of *O* (Conditions 3 and 4).

B. *The Extraneous Objects.* The extraneous objects that were adjusted by *O* to be at the same apparent distance (from himself) in the presence of the binocular illusion were two circular spots (disks) of light with diameters of ¼ inch. The disks were slightly orange in color and were produced by plexiglass surfaces transilluminated by incandescent lamps. By means of spur and rack gear arrangements, the experimenter (*E*), while invisible to *O*, could adjust the disks through approximately 60 cm of depth. The luminance of the disks was 0.35 ft-L.

One disk of the pair being judged remained stationary with its center always physically separated 4 cm from the large end of the window and at the distance of that end (304 cm from *O*). The path of depth movement of the adjustable disk was always perpendicular to the objective frontal plane of *O*, and for Conditions 1 and 2 was displaced laterally either 4 or 14 cm from the small end of the window. The disks in Conditions 1 and 2 were at the height of *O*'s eyes (slightly below the midline of the window) and were laterally separated from each other by either 31.9 or 41.9 cm. For Conditions 3 and 4, only one vertical separation of the disks was used. The center of each disk was vertically separated 4 cm from the end of the window most adjacent to it. Thus, a constant vertical separation of 41.8 cm occurred between the disks when the window was oriented vertically.

The *O*'s binocularly viewed the window and disks from a darkened observation position that contained a chin cup and a pair of eyepieces whose separation could be adjusted for different interpupillary distances. Apertures, invisible to *O*, which were located between *O* and the window, eliminated extraneous light so that only the window and disks were visible.

C. *Slant-Measurement Apparatus.* The occurrence of a binocular illusion in depth was a requirement of this study. Hence, in order to be certain that the illusion was present, the perceived slant of the window was measured. For this purpose, after every equidistance judgment made by *O*, a pair of lights was turned on in an area on *O*'s immediate left. This area contained a black rotatable indicator rod (¼×½×12 inches) and a gray reference board (to provide a physically fronto-parallel plane) mounted on a light-gray surface. The task of *O* was to adjust the indicator until it seemed to be slanted with respect to the reference board by the same amount that the window had appeared slanted with respect to his frontal plane. The indicator was horizontal or vertical as required by the horizontal or vertical orientation of the window. A scale, not seen by *O*, enabled *E* to record *O*'s slant adjustments in degrees.

III. Procedure.

The *O*'s were 16 men with a stereoacuity of at least 25.25 seconds of arc as determined by the Diagnostic Series for Macular Stereopsis of the Keystone Orthoscope. All *O*'s made four consecutive equidistance judgments for each disk pair in each experimental condition. The sequence of stimulus presentations was systematically varied between *O*'s.

For each adjustment, *O* used a small switch near the viewing position to signal *E* to move the adjustable disk in a particular depth direction until the movable disk appeared to be at the distance of (equidistant with) the stationary disk. After completing each disk adjustment, *O* was instructed to note the apparent orientation of the window, to face toward the area to his left, which contained the slant apparatus, and to indicate the amount by which the window appeared slanted.

IV. Results.

A summary of both the physical depth distance between the two disks judged to be equidistant and the apparent slant of the trapezoidal window as measured by *O*'s adjustments of the rotatable indicator is given in Table 1. The values of apparent slant for the horizontal orientation of the window are averages of 32 scores, two from each *O*, where each score is an average of the four slant adjustments made with a particular orientation of the window and a particular lateral separation of the disks. The values of apparent slant for the vertical orientation of the window are averages of 16 scores, one from each *O*, where each score is the average of the four slant adjustments. A positive angle (slant) in the "*Apparent slant*" column of Table 1 indicates that the small end of the window was perceptually more distant than the large end. A positive angle (slant) in the "*Physical Slant*" column of Table 1 would indicate that the small end of the window was physically more distant than the large end. Since the small end of the window was perceptually behind the large end for all orientations of the window, all values in the "*Apparent slant*" columns are positive. Since the small end of the window was physically in front of the large end for the horizontal orientations of the window, the "*Physical slant*" values

TABLE 1. Average Measurements of Apparent Slant of Window and Physical Positions at which Disks Appeared Equidistant.

A. Horizontal orientation of window

Direction position of small end	*Adjusted depth between disks (cm)*		*Apparent slant (deg)*	*Physical slant (deg)*	*Amount of window illusion (deg)*
	Small lat. Separation	Large lat. Separation			
Small end left	−25.8	−23.3	+45.6	−45.0	+90.6
Small end right	−26.9	−25.7	+40.6	−45.0	+85.6

B. Vertical orientation of window

Small end top	−4.1	+51.7	0	+51.7
Small end bottom	+0.1	+35.0	0	+35.0

are negative or zero, respectively. The magnitude of the binocular illusion in depth is found by subtracting the physical from the apparent slant.

The average physical depth between the two disks when they appeared to be equidistant for the different conditions of the experiment also is shown in Table 1. It will be recalled that the movable disk was always directionally most adjacent to the small end of the window. A negative value in the adjusted depth between the disks indicates that, when the two disks appeared equidistant, the movable disk was physically closer to *O* than the stationary disk. In each horizontal condition, the disk pair, in order to appear equidistant, had to be physically separated in depth by amounts significantly different from zero beyond the 0.01 level of confidence with t values of 20.20, 11.12, 20.67, and 13.14 (with df's of 15) for the values of -25.8, -23.3, -26.9, and -25.7, respectively, of Table 1. Clearly, when the orientation of the window and the separation of the disks were horizontal, a large error occurred in adjusting the disks to apparent equidistance with each other. This error in adjustment was much less, however, when the orientation of the window and the separation of the disks were vertical. With the vertical condition, only the 4.1-cm difference in depth adjustment was significant ($P < 0.01$, $t = 3.46$, $\mathrm{df} = 15$). The amount of distortion of the equidistance adjustments of the disks with the horizontal orientation of the window was only slightly different between the 31.9- and 41.9-cm separations, with neither of these differences significant at the 0.05 level ($t = 1.96$ and 0.87, df's of 15, respectively).

V. Discussion.

The results from the present study demonstrate that the presence of a binocular illusion in depth can affect the perceived depth between other objects even though these objects are extraneous to the illusion and even though no portion of the binocular-depth illusion (the window in this case) is directly involved in the task. It is as though the perceived space surrounding the (horizontal) window is distorted as a consequence of the binocular-window illusion. For example, the disk directionally near the physically closer, but apparently farther, small end of the window had to be adjusted closer to *O* than the other disk in order for the two disks to appear equidistant. It is as though the apparent depth between the disks was distorted in the same direction as that of the ends of the window, and, therefore, a depth adjustment opposite to this distortion had to be made in order for the disks to appear equidistant. The difference in the signs between the columns labeled "*Adjusted depth between disks*" and "*Amount of window illusion*" in Table 1 reflects this process.

Although the physical difference in depth between the apparently equidistant disks in Table 1 is large, there is reason to consider that this difference is not as large as would be expected from the magnitude of the depth distortion between the ends of the window. Physically the small end of the horizontal window was approximately 24 cm in front of the large end. The stationary disk was always at the distance of the large end of the window, and, according to Table 1, the disk directionally near the small end of the horizontal window had to be adjusted approximately 25 cm in front of the other disk in order for the two disks to appear equidistant. It follows that, when the two disks appeared equidistant, they were physically located in depth near the ends of the apparently slanted window. This result is in agreement in direction but not necessarily in magnitude with the simplified hypothesis[3] that the binocular disparity between each disk and its directionaly most adjacent end of the window will determine the apparent position of each disk.

There are several reasons why the slant illusion that occurred with the window might be expected to be greater than that between the two disks. First, the Ames trapezoidal window contains two (not one) binocular-depth illusions. One of these is produced by the trapezoidal shape of the window and is measured by the *O*'s adjustment of the apparent slant of the window. The second binocular illusion is produced by the shading at the large end of the window and is used to simulate thickness in the window. The directions of these two illusions are *opposite* in their effect upon the error occurring in the equidistance adjustments of the disks. The presence of the second illusion would act to reduce the magnitude of the error in apparent equidistance from that expected from the first illusion. Another explanation can be found in what is called the "adjacency principle".[9] As applied to the present experiment, this principle states that the apparent depth position of each disk would be most determined by the binocular disparity cue that occurred between it and adjacent parts of the window. If the adjacency is defined as perceptual rather than as retinal or physical,[10] the magnitude of the error in the equidistance judgments would be expected to be less than the magnitude of the depth illusion occurring with respect to the window. A third possible explanation involves the task set of *O*. It is possible[11] that, to some extent at least, the act of performing the apparent equidistance adjustment of the disks permitted *O* to ignore the window and, thus, to reduce somewhat its error-producing effects.

From Table 1, it is clear that the magnitude of the errors in the apparent equidistance judgments of the disks was less for the vertical than for the horizontal orientation of the window. This difference can also be explained by the opposing effects of the two illusions (size and shading) in the window. The magnitude of the first illusion clearly increases with an increase in the physical slant of the window (see Table 1) while the magnitude of the shading illusion does not. It follows that the capacity of the second illusion to offset the effect of the first upon the apparent equidistance adjustments of the disks should be much greater for the frontoparallel (vertical) rather than the 45° (horizontal) orientation of the window. It is likely that, with the vertical window, the resultant effect of the two depth illusions was small and that, therefore, the error found in the equidistance judgments also was small.

The increase in the horizontal separation of the disks (from 31.9 to 41.9 cm) with the window oriented horizontally did not produce a large change in the adjustment error (Table 1). The direction of this change, however, is such as to suggest that the effect (a) extends beyond the edges of the window, but (b) with slightly decreasing effectiveness. The last portion of this conclusion must be considered as very tentative pending the use of additional separations.

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