THE POGGENDORFF ILLUSION, AN EXPLANATION BASED ON NEUROPHYSIOLOGICAL MECHANISMS

A Thesis

Presented to

the Faculty of the Department of Psychology

University of Houston

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

by

Robert Lee Houck

January, 1970

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ABSTRACT

A review of the literature concerning the Poggendorff illusion implicated four basic components effecting its magnitude: (1) the size of the angle formed by the intersection of the interrupted oblique line segments with the parallel distractor lines, (2) the orientation (vertical, horizontal, or oblique) of the interrupted illusory segment in space, (3) the amount of experienced _O_ has had with the illusion, and (4) the nature of _O_'s eye movements as he views the illusion. Earlier investigations from our own laboratory suggested a fifth factor, this being the possibility of alternate perceptual organizations of the component parts of the illusory figure. Possible explanatory mechanisms to account for these various components are suggested. These suggestions are based on recent neurophysiological findings concerning the functional nature of the visual system. Hypotheses derived from these suggestions are tested by the psychophysical method of adjustment using 15 _Os_ practiced in reporting their perceptual experiences.

The conclusion reached was that the illusion involves the interaction of multiple factors. These factors, for the most part, can be accounted for on the basis of the known neurophysiological structure and its function in the visual-perceptual system. Modifications of the illusion based on hypotheses regarding these neurophysiological mechanisms resulted in predictable phenomenal alterations with respect to the magnitude of the illusion.

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CHAPTER I

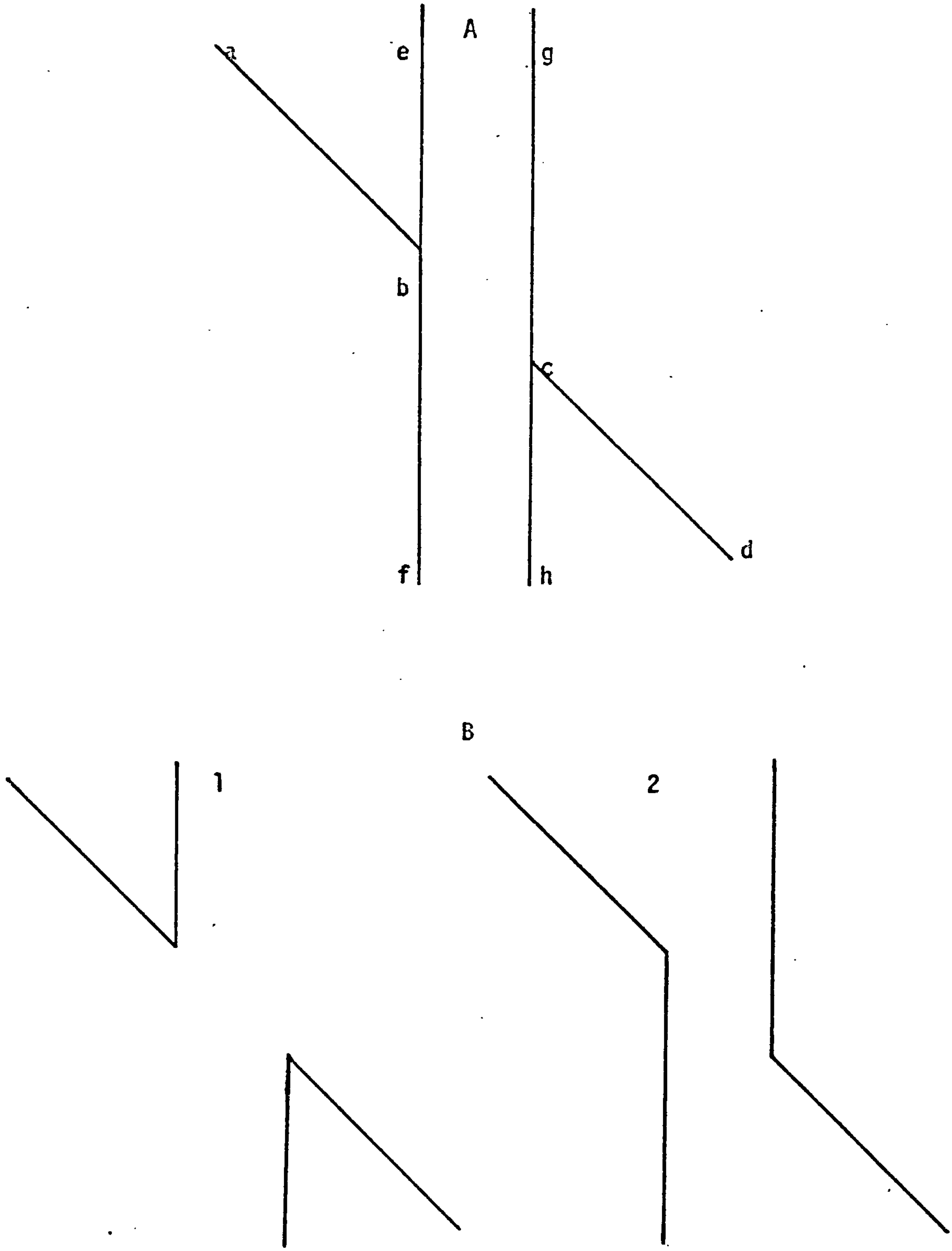
PROBLEM INTRODUCTION

Over a century ago many of the leading physicists of the day became avidly interested in visual illusions as examples of perceptual inaccuracies. Many of these scientists are remembered today chiefly because of an illusory effect they discovered. One of these investigators was Johann C. Poggendorff, a German physicist, who more than a century ago first reported the illusion under consideration here. The Poggendorff illusion (Fig. 1A) represents one of those relatively rare cases in which veridicality and perceptual experience are at variance. Such a situation provides an opportunity to investigate basic mechanisms of the perceptual system. The classical stimulus (Fig. 1A) consists of two parallel lines of approximately equal length that are intersected at a 45° angle by an oblique line, the central section of which is deleted, i.e., that portion between the parallels. The two segments of the oblique line do not appear to lie along the same line. Instead, they appear to be parallel and distinctly separate line segments with the upper segment (ab) appearing to be above the lower segment (cd).

Since its discovery, several investigators have attempted to explain the phenomenon. Green and Hoyle (1964) in a detailed review of earlier research attributed the first investigation of the illusion to Herring (1861), who "dealt with it in terms of the misjudgment of angles." Judd (1899) made a very detailed examination of the angle hypothesis and produced convincing evidence contradicting this as the explanation. He proposed instead that the illusion resulted from a rather complicated

FIGURE 1

The Poggendorff Illusion and Its Simplified Forms



interaction between eye movements and the misestimation of linear distances. He theorized that the eye tends "to follow lines rather than to plot its own course through space." When confronted with the necessity to diverge from this habit, the eye tends to deflect in the direction of the line it would normally be following. For example, referring to Fig. 1A, the eye begins at a, proceeds to b, and in attempting to cross to c actually deflects toward f. At the same time that the eye is deflected, the lengths of line segments bf and cg are overestimated. It was Judd's contention that both phenomena combine to account for the illusion. However, due to the extremely small number of Ss he used in the supporting experiments (N = 3), Judd's conclusions are not persuasive.

Pierce (1901) investigated the role of perspective in the Poggendorff illusion, but could not explain it in these terms. He concluded that the illusion is caused by an interaction between several factors. He also found, contrary to Judd's assertion, that the illusion does not vanish entirely when the oblique is rotated to a horizontal or vertical position, although it did diminish appreciably.

Cameron and Steele (1905) were the next investigators to consider the illusion. They found that with repeated exposures, the illusion gradually diminished. This is in agreement with Judd's (1902) account of the practice effect with the Muller-Lyer and the Zollner stimuli (Judd, 1905). Cameron and Steele (1905) were also among the first to report that as the acute angle (Fig. 1A, Labe) at which the tranverse line intersects the parallel lines was increased (i.e., approached a right angle) the illusory effect decreased. They photographed the eye movements associated with the illusion and found that the eyes exhibited many pauses, deflections, and re-adjustments at the intersection of the oblique and the parallel lines. One O, tested after the illusion had entirely disappeared, did not have these deflections, pauses, and re-adjustments. They concluded that eye movements cannot be ruled out as a contributing factor in the illusion.

Carr (1935) published a comprehensive review of the earlier research on the illusion. With respect to the eye movement theory, he concluded that there were four possible interpretations of the published data:

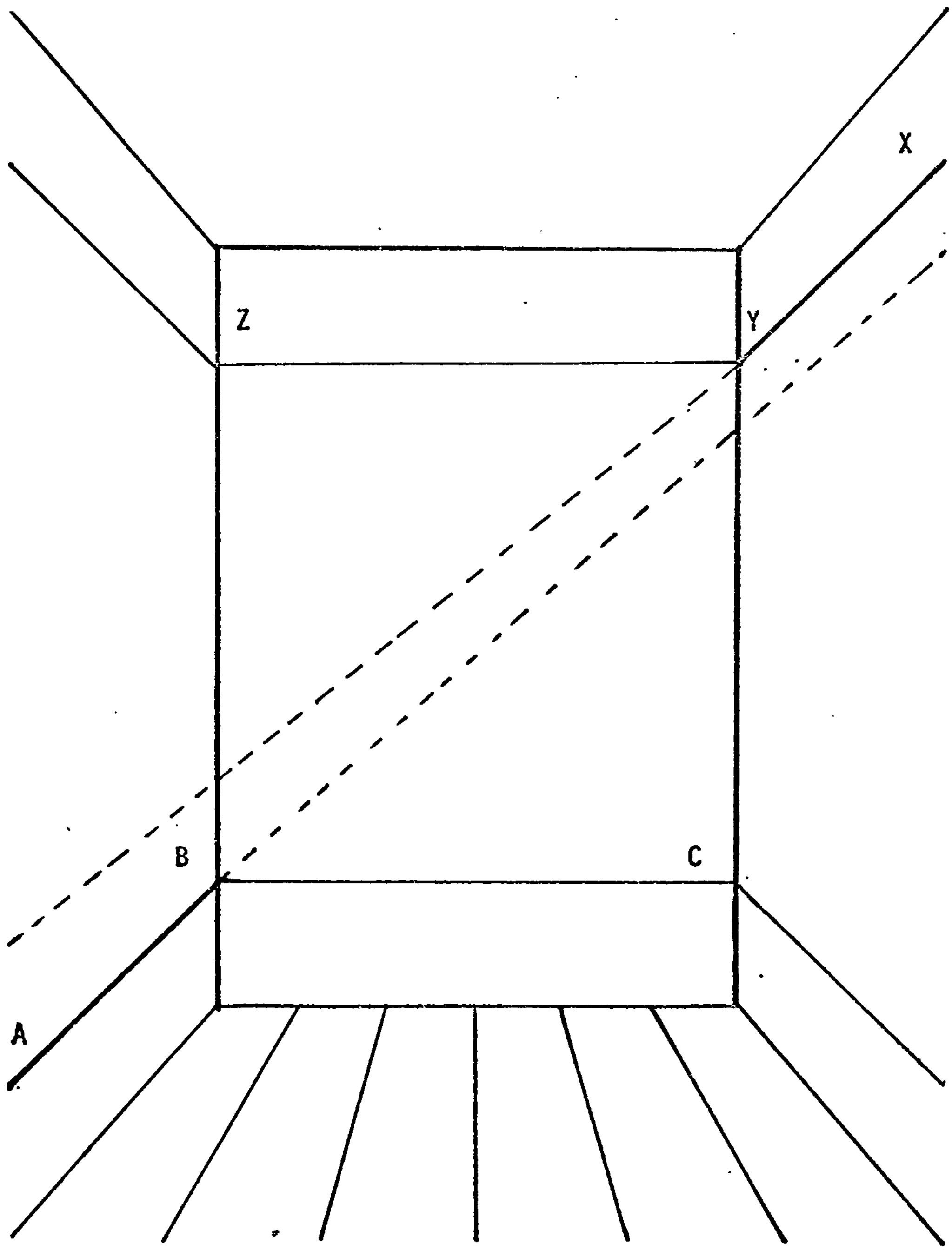
> "(1) The mode of perceiving these figures is a function of the character of the eye movements. This seems to be the interpretation adopted by Judd. (2) As critics have pointed out, it is equally possible that the character of eye movements is determined by the way we perceive the figure. (3) The two factors may causally interact upon each other. Each is in part a cause and in part an effect. (4) Finally, both terms of the correlation may have a common cause. In practice, we learn to ignore the accessory lines, and as a consequence they no longer affect either the eye movements or the perceptual judgments."

The next step in the search for an explanation of the illusion did not occur until Tausch's (1954) attempt to apply the transactionalist concept of misapplied constancy scaling. Green and Hoyle (1964) presented a very detailed review of Tausch's investigation of the illusion. The explanation proposed by Tausch is based on the phenomenon known as the Rausch effect. In explaining this, Green and Hoyle (1964) used as an example the shape constancy seen in the perception of a table top as rectangular while the retinal image is trapezoidal. Tausch hypothesized that the visual system applies a process of counter-distortion based on past experience to reduce the discrepancy between the retinal image and what is known about the source of stimulation, a process he termed "phenomenal regression to the real object." This process makes the acute retinal angles appear more obtuse and the obtuse retinal angles seem more acute. Green and Hoyle (1964) dismiss Tausch's explanation of the illusion for three reasons. First, the Rausch effect is very stimulus-specific (viz., if the angle of regard of the table top is diagonal rather than from one end, constancy remains, even though the acute and obtuse angles are now reversed). Second, the hypothesis does not explain why the illusion should be reduced when the interrupted oblique is rotated to a vertical or horizontal position. Third, they found that the illusion disappeared when an incomplete stimulus was used (Fig. 1B, stimulus 1), while Tausch would have predicted that the acute angles would appear more obtuse than they in fact are, and, therefore, that the illusion would not disappear.

Green and Hoyle (1964) modified Tausch's hypothesis to accomodate these exceptions. They referred the Poggendorff stimulus to a room rather than to a table--to "room geometry." They suggested that the parallel lines of Fig. 2 (CY and BZ) are viewed as the corners of a room with the upper transverse line (XY) being a picture rail near the ceiling, while the lower line (AB) represents the baseboard. The misapplication of size and shape constancy to the flat drawing results in the tendency to continue XY to Z rather than to AB and similarly to continue AB to C rather than to XY. The authors point out that in

FIGURE 2

The Room Analogy Proposed by Green and Hoyle (1964)

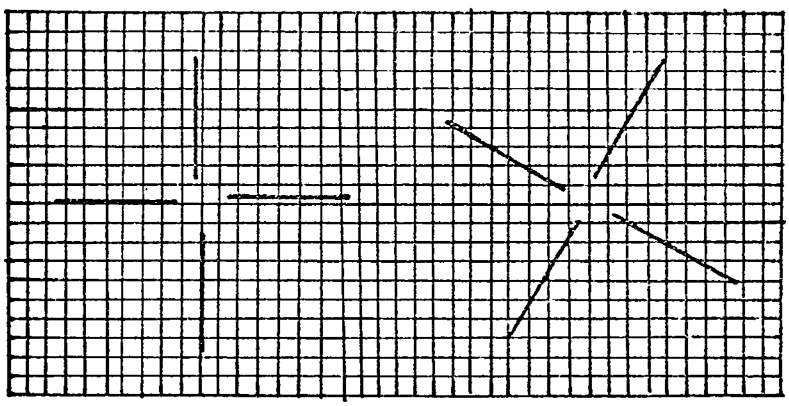


common with Tausch's hypothesis, this suggestion fails to account for the illusion's reduction when the interrupted oblique line is placed in the horizontal or vertical position. To correct for this, they proposed that the vertical and horizontal planes enjoy a special property based on the existence of some "fine grained grid" (Fig. 3), against which visual stimuli are compared. One result of this property is that as straight lines approach the vertical or horizontal position, Os ability to discriminate small differences in position improves and the illusion is reduced. Green and Hoyle (1964) concluded that the illusion results from a summation of all the incoming information about the stimulus. For example, the final percept would result from an interaction between the degree to which the constancy mechanism is misapplied due to the interpretation of the figure as a room, the effect of the degree of coincidence with the vertical-horizontal grid, and the amount of past experience with the illusion.

Green and Hoyle (1964) actually did little to improve Tausch's hypothesis. Tausch used the table top example only to illustrate what he considered to be a basic underlying mechanism, i.e., that acute angles are overestimated while obtuse angles are underestimated. No such underlying concept is to be found in Green's and Hoyle's use of the room analogy. Rather, they used a very particular situation and attempted to construct around it a case for the formation of a constancy mechanism via some vague adaptive process. Assuming that such a specific constancy mechanism could result from such a specific "room" experience, they hypothesized that its misapplication in the drawing was based not

FIGURE 3

The Concept of the Vertical-Horizontal Reference Grid in the Visual System (Green & Hoyle, 1964)



on some general principle, but rather on the minimal similarity of the illusion to the original situation. When this hypothesized mechanism failed to explain all the facets of the illusion, they advanced the additional concept of the vertical-horizontal grid, an intriguing concept which they failed to test. Piaget and Lambercier (1956) presented data suggesting a similar situation, but they explained this as resulting from something that altered selective fixation of one end of a line. This provocative suggestion deserves testing, but it must be concluded that, as with earlier efforts, this one also failed to provide a definitive explanation of the illusion.

Gregory (1963; 1967) proposed the existence of a size-constancy scaling mechanism in a sophisticated transactionalistic approach as "the explanation" of geometric illusions. Unlike the adaptation view of Green and Hoyle (1964), misapplied constancy for Gregory refers to a specific mechanism. He suggests that there is a perceptual mechanism that maintains size constancy in three dimensional figures and that when this is misapplied in two dimensional drawings due to stimulus properties suggestive of depth, the illusory spatial distortions appear. Arguments that this mechanism be limited to illusions involving depth have been presented earlier (Houck, Mefferd, & Wieland, 1969). These same investigators demonstrated that the constancy scaling mechanism though sufficient to explain the illusory effect in the more popular perceptual organization of the Ponzo illusion, was inadequate to explain all the perceptual fluctuations.

A more recent investigation of the Poggendorff illusion (Novak, 1966) returned to the idea that eye movement is a prime determinant of the illusion. Using the complete stimulus, three conditions were examined: (1) free regard, (2) free regard but with a small fixation cross placed at the midpoint of the interrupted oblique line, (Os were instructed not to fixate the cross), and (3) regard while fixating the small cross. Novak (1966) found no differences between the first two conditions, but fixation of the cross resulted in a significant reduction in the illusion. The somewhat surprising conclusion the author drew from these results was that "gross eye movements cannot be said to have contributed even in part as a causal mechanism in the production of the illusion." Novak's (1966) data actually suggest the opposite conclusion. However, that eye movement clearly fails to account for the illusion can be seen in the persistence of the illusion when Pritchard (1958) using the technique of a stabilized retinal image projected the Poggendorff stimulus on O's retina.

Little agreement exists in the literature either with respect to the data reported or in the conclusions their authors derived from this data. Four basic phenomena are implicated however: (1) the effect on the illusion of the size of the angle formed by the intersection of the transverse line with the parallel distractor lines, (2) the diminution or disappearance of the illusion when the interrupted transverse line is rotated to the vertical or horizontal positions, (3) the disappearance of the illusion with repeated exposures, and (4) the effect of restricted eye movement or fixation.

CHAPTER II

PROBLEM DEVELOPMENT

The general purpose of this investigation is to amalgamate these basic phenomena in a comprehensive theory. The first of the phenomena is concerned with the influence exerted by size differences in the angle formed by the intersection of the transverse and the parallel lines. There is general agreement (Cameron & Steele, 1905; Carr, 1935; Novak, 1966) that as the angle of inclination (Labe, Fig. 1) increases toward 90°, the illusion decreases. That these transverse angles are misjudged was the basis of the earliest theory (Herring, 1861) attempting to account for the illusion. A later investigator, Tausch (1954), theorized that the acute angles are overestimated while the obtuse angles are underestimated due to the misapplication of a size constancy scaling mechanism, and he "explained" the illusion in transactional terms. Green and Hoyle (1964) found when the stimulus was divided into its component parts (Fig. 1B), the illusion disappeared in _1_, but persisted in _2_. The question thus remains open with respect to the illusory effect created by mere changes in angle size.

The second phenomenon involves the effect on the illusion of the orientation of the stimulus in the frontoparallel plane. Judd (1899) reported that the illusion disappeared when the interrupted oblique line lay in either the vertical or horizontal plane. However, Pierce (1901) found that although the illusion was seriously diminished in these positions, it did not disappear completely. Recently, Green and Hoyle (1964) confirmed that there was a significant reduction in the illusion when the transverse line was in a horizontal position but that complete negation of the illusion did not occur. They provided no data on the effect of a vertical presentation of the line. Two explanations discussed earlier have been advanced to account for the vertical-horizontal effect. The first involved eye movements (Judd, 1899), while the second proposed the existence of a "fine lined vertical-horizontal grid" within the visual system against which incoming signals are compared (Green & Hoyle, 1964).

The effect of prolonged or repeated regard of the stimulus on the strength of the illusion is the third phenomenon to be considered. Several investigators have reported that the illusion disappears with repeated exposure, and Judd (1902) suggested that this resulted from the development of systematic eye movements across the illusion. Cameron and Steele (1905) photographed the eye movements of observers (Os) as they viewed the stimulus and obtained results that led them to concur with Judd's suggestion. Carr (1935) also noted the effect, and Green and Hoyle (1964) speculated that the gradual disappearance of the illusion was due to an adaptive process within the visual system resulting from the increased experience of O in the illusory situation.

The fourth phenomenon, superficially related to the third, has to do with the effect on the illusion of fixation (i.e., of the restriction of eye movements). Although early studies (Judd, 1899; Cameron & Steele, 1905) seemed to implicate eye movement, Novak (1966) recently concluded that eye movement is not the cause of the illusion. However, his data are amenable to interpretations other than the one he offers. Though eye movements may well exert some influence on the illusion, Pritchard has conclusively demonstrated that this cannot be the principle cause.

The fifth and final phenomenon to be considered involves the recently demonstrated operation of a basic perceptual mechanism establishing the organization in a percept of elements within the visual field--the one object-multiple object mechanism (Mefferd, 1968). Houck, Mefferd, and Wieland (1969) demonstrated that variations in the Ponzo illusion could be most effectively accounted for by examining changes in the perceptual organization of the stimulus. Other theorists, however, have not considered the possibility that changes (e.g., a diminution) in various illusions, including the Poggendorff, may be due to such basic changes in the organization of the percept. Relative to the transverse line, two primarily different organizations of the Poggendorff stimulus (and especially with the partial figure) are readily apparent to the experienced _O_--(1) two independent angles not pointing at each other, and (2) two segments of a continuous, single transverse line intersecting segments of two parallel lines, the parallel lines being more indistinct and "fuzzy."

To date no single theory has been advanced to account for all of these phenomena. Further, the earlier attempts each "explained" only one facet of the illusion with the result that there is little agreement among the concepts. On the other hand, by regarding all of these phenomena to be the result of a variation in a single or at least a few basic perceptual mechanism(s), a general theory about the illusion may become possible.

The hypotheses to be explored here arose largely from a logical application of certain recent neurophysiological advances. The work of Talbot and Marshall (1941) and Hubel and Wiesel (1959; 1960; 1961; 1962; 1963a; 1963b; 1965) indicate that the visual system at the level of the cortex is organized to detect straight lines and edges in a finite number of orientations in the visual field. Three types of functional visual cells--simple, complex, and hyper-complex--have been identified in the visual cortex. The simple cells predominate in area 17, the striate cortex (Hubel & Wiesel, 1959), and these respond optimally to a straight line with a given orientation and a specific position in the visual field. Complex and hyper-complex cells are more prevalent in areas 18 and 19, the non-striate visual areas (Hubel & Wiesel, 1962; 1965). The complex cells also respond optimally to a straight line at a particular orientation as do simple cells; however, the receptive fields (i.e., the area on the retina which when stimulated results in changes in the firing rate of a given cortical cell) of these cells are considerably larger than those of the simple cells. Thus, the exact position of the stimulus in the visual field is less specific for the complex than the simple cells:

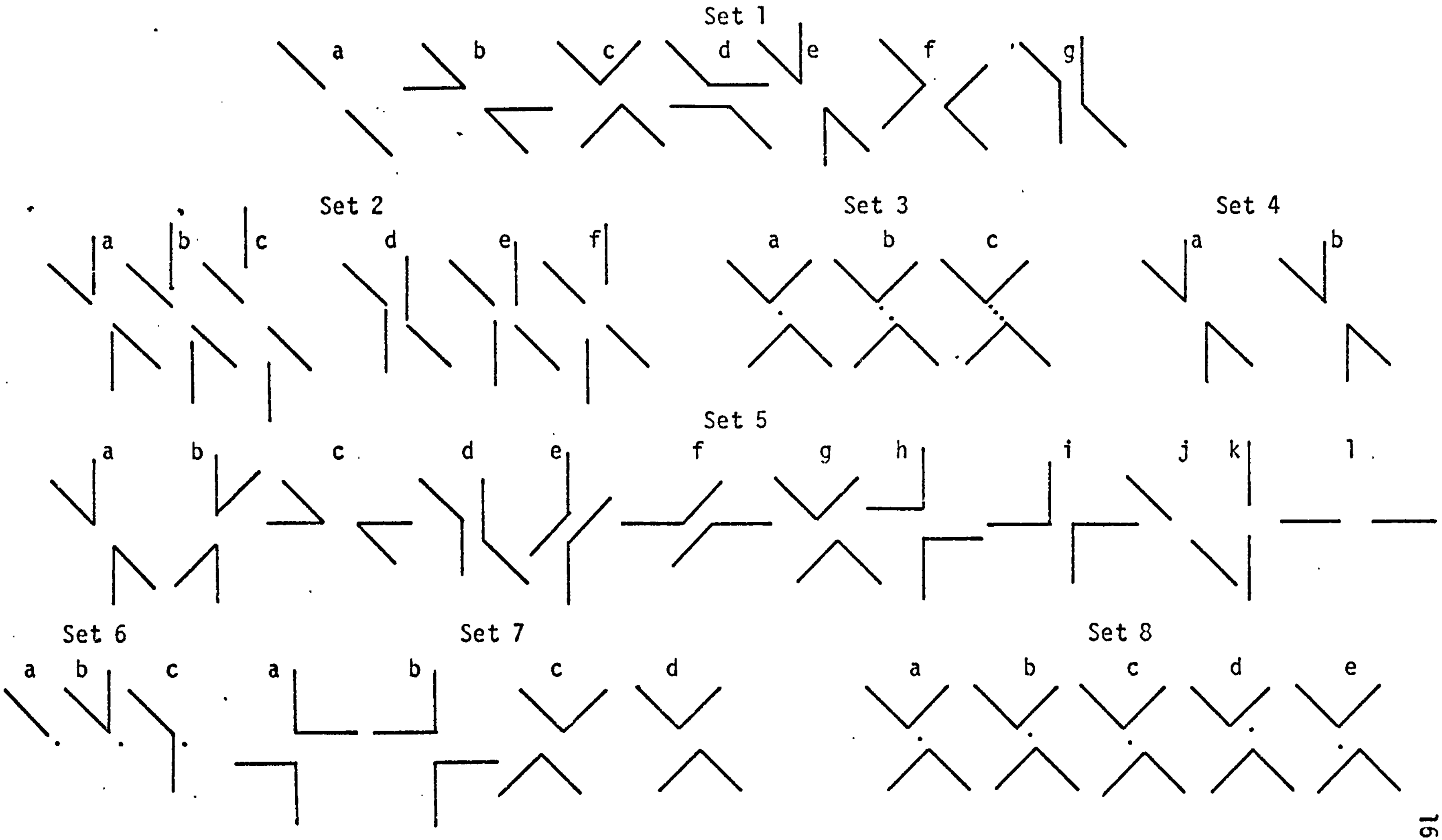
> "These complex cells behave as though they receive projections from a large number of simple cortical cells all having the same receptive field arrangement and orientation, but differing in the exact positions of these fields." (Hubel & Wiesel, 1965).

Finally, the hyper-complex cells respond optimally to edges or bars oriented in a particular direction. Some of these cells have been found to respond best to a stimulus having a 90° angle, while for others, the greatest response is elicited by a straight edge (Hubel & Wiesel, 1965). Each hyper-complex cell seems to receive projections from a number of complex cells. With all three types of cells any stimulus orientation that differs from the preferred one for a given cell results in a decreased response.

These results suggest a number of testable hypotheses involving the Poggendorff illusion. It is logical to expect changes to occur in the overall firing rate of the different types of cells of the visual cortex as a function of changes in properties of the stimulus (e.g., as the size of the transverse angle is increased--Fig. 1B). Eventually, these changes will be reflected in the operation of the hyper-complex cells. As _O_ views in sequence the stimuli in Set 1 of Fig. 4, those hyper-complex cells that respond optimally to a 90° angle of this orientation should respond at a low rate with _b_, at the maximal rate with _c_, and again at a reduced rate with _d_. Conversely, hyper-complex cells that are most responsive to a straight edge of this orientation should respond at an increasing rate as the line becomes both straight and longer in _d_, than they would with _c_. Hubel and Wiesel (1965) found that of the several hundred cells they tested, more of the hyper-complex cells were edge detectors (180° cells) than blocked end (90° angle) detectors. If this generally is true, the overall activity in the visual cortex should increase as the angle becomes increasingly obtuse, as in the Set 1 stimuli of Fig. 4. A possible explanation for the angle phenomenon discussed above thus presents itself, viz., that the increased excitation pushes the apparent position of the interrupted oblique in the direction of the point of the angle of which it forms a part. The first

FIGURE 4

Organization of the Stimulus Patterns Into Sets to Test the Hypothesis Under Consideration



specific hypothesis to be tested is that as the angle is increased in the partial figures (Fig. 4, Set 1), an increase in the illusory effect should be observed. This hypothesis is compatible with the reports cited above that as the angle of the intersecting line of the classical stimulus (Labe, Fig. 1A) is increased, the illusion is decreased. Since in this stimulus there are conflicting angles exerting opposing forces, the more nearly equal the angles, the more nearly equal the forces, and therefore, the less the illusory effect.

Related to the second phenomenon under consideration (i.e., the vertical and horizontal effect) are other recent neurological findings. Several investigators have suggested that there is some mechanism that provides a vertical-horizontal reference grid (e.g., Piaget & Lambercier, 1956; Green & Hoyle, 1964). That this mechanism might be supplied by the vestibular system is suggested by Witkin's (1950) demonstration of dramatic individual differences involved in the separation of conflicting visual and vestibular inputs. Pressey (1967) demonstrated that individuals categorized as field dependent by Witkin's tests showed greater illusory effects on the Poggendorff.

Recently, Jung (1961) implicated the vestibular system as an important source of input to the visual cortex:

> "Most neurons of the visual cortex were found to receive convergent impulses from specific retino-geniculate, non-specific reticulo-thalamic and vestibular afferents."

A logical explanation for this double sensory input to the visual cortex is that the two inputs interact to provide a vertical-horizontal frame of reference--the "fine lined vertical-horizontal grid" suggested by Green and Hoyle (1964). In addition to this consideration, an important structural factor must also be taken into account regarding this second phenomenon. If a straight horizontal line is fixated about the center, the visual system projects the right half to the left occipital lobe and the left half to the right occipital lobe. With a vertical presentation, however, its full extent is projected to both hemispheres. A condition very similar to this exists with respect to the horizontal and vertical presentation of the interrupted oblique segments of the Poggendorff, if the assumption that the largest part of O's viewing time will be spent casting his eyes about the center of the illusion can be made. This assumption receives some support from the work of Cameron and Steele (1905) photographing eye movements across the illusion. A horizontal presentation of the two segments of the interrupted line would thus result in the projection of each to opposite hemispheres, while a vertical presentation would project both segments to both hemispheres. Returning to the question of what elements of the stimulus become organized as the perceptual unit(s) it seems highly probable that in the horizontal case the angles will be predominant, therefore the force exerted on the illusion by the angle would be maximized. In the case of the vertical presentation of the interrupted segments the probability of them being organized as the perceptual unit, as opposed to the angles, is increased and the distorting effect of the angles becomes less.

The vestibular system and this structural system likely exert opposing forces in the horizontal situation. The vestibular system providing a mechanism to facilitate the alignment of the separated segments while the structural system encourages the organization of angles and their accompanying illusory effect. In the vertical situation however, both systems act in unison inhibiting the illusory effect of the angles.

The second hypothesis states that the illusion will be maximal when the interrupted oblique segments are not aligned with O's head, and therefore the vestibular signals. The illusion will be reduced if the interrupted obliques are rotated to O's horizontal direction, but it will nevertheless persist. Finally, the illusion will be minimal when the interrupted obliques are aligned in O's vertical direction. The tilting of O's head accompanied with parallel shifting of the illusion should produce identical results. Individual differences in terms of Witkin's field dependence and field independence must of course be expected when the individual's vestibular and visual mechanisms are at variance.

This hypothesis is in agreement with the studies cited above that showed a reduction of the illusion when the oblique line is rotated to either the horizontal or vertical position relative to O. If the vestibular system is in fact involved in the illusion, it should also be possible to manipulate the extent of the illusion by appropriate tilts of O's head to align or dis-align the vestibular system and the transverse line just as occurs when the stimulus itself is tilted.

With respect to the commonly noted effect of repeated viewing of the stimulus on the illusion a somewhat more transactionalist position will be taken. It seems probable that two systems are involved in the illusion. The first system, operating on the current input from the stimulus, is referred to here as the perceptual system. The second system is the analytic or cognitive system conceptualized as being involved with reconciliation of this current input with stored information from past experiences. The third hypothesis states that the illusion is maximal during the first few seconds of viewing and that it gradually disappears with viewing time. Thus, rapid judgments should reflect a greater illusion than do slow, considered judgments. This is in line with the reported disappearance of the illusion with repeated exposure since it can be assumed that with increased viewing the stored information about the stimulus should increase sufficiently to influence the probability of a veridical organization of its parts. However, even with extensive viewing the illusory effect should remain as long as judgments are rapid enough to exclude intervention of the analytic system.

Many authors have speculated that there is a relationship between eye movement and the illusion. The presence of the illusion with a stabilized retinal image of the stimulus (Pritchard, 1958) showed that the illusion per se does not have its origin in eye movements. In a recent study, Novak (1966) had _Os_ fixate a small cross in the center of the interrupted space between the parallel lines, and found that this resulted in a significant reduction in the magnitude of the illusion. When _Os_ were instructed not to fixate the cross, however, there was no such diminution. Although Novak interpreted this in terms of eye movement, his data may be interpreted in other terms. For example, the cross would activate additional visual cells. Since the signals from many simple cells converge upon a single hyper-complex cell, the effect of the activation of even a few retinal cells would be magnified greatly. With the cross located in the locus of the transverse line mid-way between the parallel lines, this additional activity should tend to "close" the gap between the interior ends of the transverse line. This "closure" would increase the probability that the line segments would be organized as a single line (i.e., to reduce the illusion). This probability should increase either as additional dots are placed in the locus of the line across the gap, or as the parallel lines are brought closer together, as was noted by Carr (1935). Fixation of the dot(s) would bring both the dot and the critical images of the ends of the transverse line within the dense foveal retina, increasing the probability of closure due to the overall greater neural activity evoked along the locus of the line. However, even without fixation of the dot, the probability of closure should be increased by the mere presence of the appropriately located dot-stimulus.

Evidence to support this view is available from both perceptual and neurophysiological work. Piaget (1956) demonstrated that the magnitude of a fixated or "centrated" point appears larger than surrounding points. Anatomically, the receptors of the fovea not only are more densely packed, but the ratio of the number of receptors contributing to each bipolar cell is smaller than in the periphery. This lower ratio means that a given stimulus will evoke greater neural activity when its image is cast upon the fovea than when it strikes the periphery. Based on these considerations, the fourth hypothesis states that as the number of elements in the interrupted space of the transverse line is increased, a decrease in the illusion should be observed. Furthermore, as the dot(s) is moved away from the locus of the transverse line, but still between the parallel lines, the illusion should increase.

The final hypothesis is general and subsumes all the others. Simply stated, anything that serves to change the probability that the interrupted transverse line will be organized perceptually as a single unit (i.e., as a continuous line) will also opperate to shift the magnitude of the illusion in the appropriate direction.

CHAPTER III

METHODS

The observers were 16 laboratory personnel (8 males and 8 females) who were experienced in reporting perceptual phenomena. A criterion for accuracy was demanded of each _O_. This criterion was an adjustment of stimulus Set 1a (Fig. 4) to within two degrees of zero error in each of three successive judgments. Failure to meet this criterion resulted in _O_'s elimination from the study. It was necessary on this basis to eliminate only one female _O_ from the pool described above.

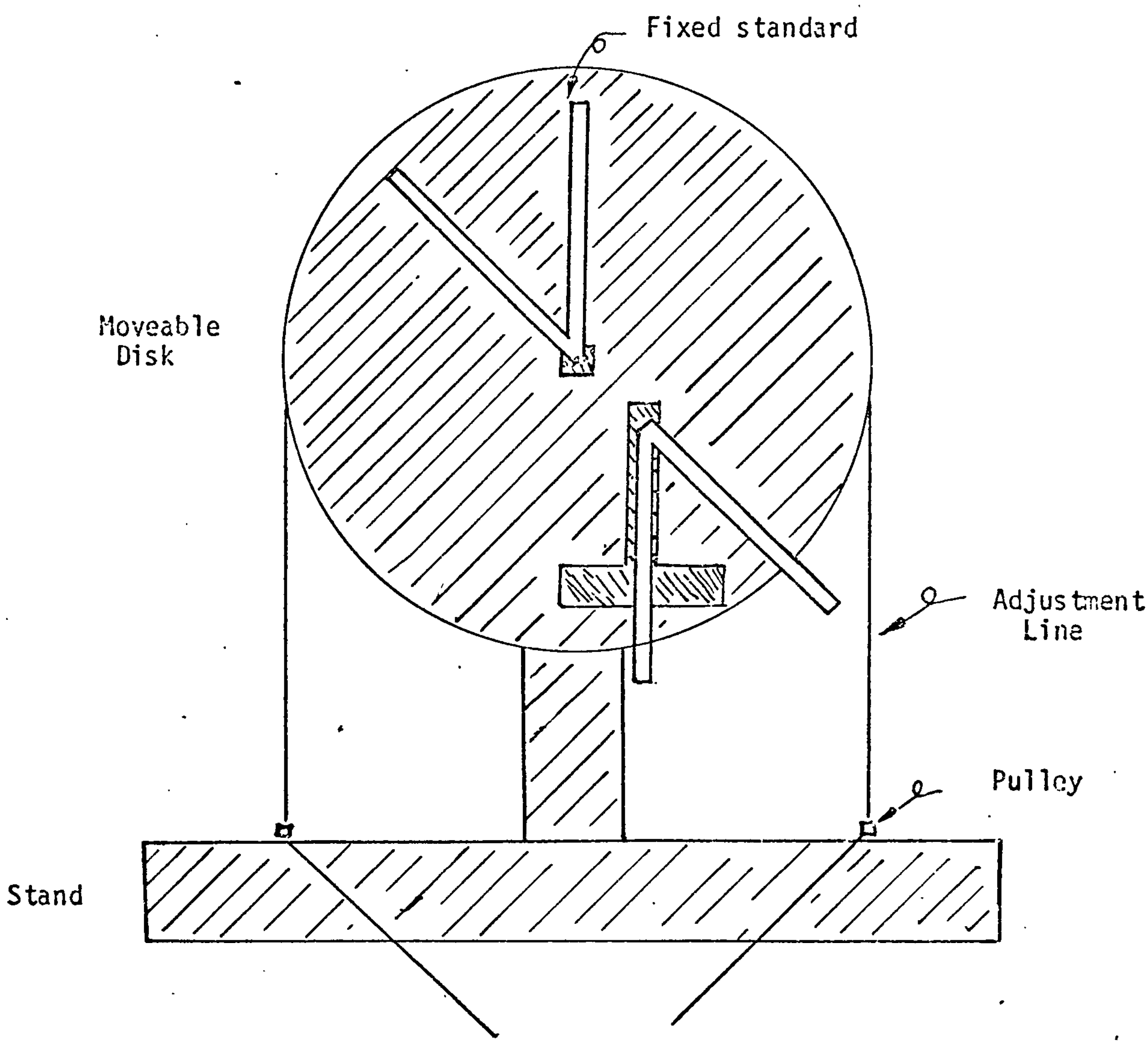
The stimuli were presented under conditions of extreme perceptual reduction 5 M in front of and at eye level to the seated _O_. Regard was monocular, with _O_ closing his eye after each judgment as _E_ changed the stimulus. During this interval, a light was directed toward _O_ to limit the extent of dark adaptation he underwent.

The testing session lasted approximately one hour. After all _O_s were tested an error in one of the stimulus patterns of Set 7 (Fig. 4) was discovered. Judgments on this entire set were discarded and each _O_ was retested on this set at a later date ranging from two to three weeks after the original session. This second session lasted approximately 15-minutes.

All stimulus patterns are modifications of the simplified forms of the illusion (Fig. 1B, _1_ and _2_). The stimuli were bars 1 cm. wide and 25 cm. long and dots 1 cm. in diameter (Fig. 4) cut from heavy pasteboard and painted with green fluorescent paint. When presented under ultraviolet light all stimuli appeared sharp and clear. The stimuli were attached to an apparatus (Fig. 5) that maintained a constant orientation and distance (viz., 18 cm.) between the two line segments to be adjusted. The apparatus consisted of a circular disk 45 cm. in diameter attached to a stand so that the disk rotated about its center. O made his judgments by pulling cords attached to the disk. Pulling the right hand cord turned the disk clockwise while pulling the left hand cord turned the disk in the opposite direction. The upper part of each stimulus was attached in a fixed position at the center of the disk but independent of it. The lower part of the stimulus, the part adjusted, was placed in a holder attached to the disk 18 cm. from its center. The holder was counterbalanced so that as the disk rotated the lower part of the stimulus remained in the same orientation as the fixed upper part. The adjustable portion of the stimulus was always started from a position 15° or more counterclockwise to the position necessary for a perfect (zero degrees error) adjustment. This system of presentation had the advantage of keeping constant the distance (18 cm.) between the vertices of the two angles and keeping the lines being adjusted in a parallel position. The entire apparatus was painted black and illuminated uniformly with two ultraviolet lights, thus only the green fluorescent stimuli were visible to O. Attached to the back of the circular disk was a protractor permitting E to record the number of degrees the comparison line had been moved above or below the position necessary to line the

FIGURE 5

Schematic of the Adjustable Apparatus



two segments up perfectly. An error score for each of O's judgments was recorded in this manner.

Os task was to rapidly adjust, by means of the pulley arrangement, one of the bars or the dot so that it appeared to lie in the same locus as a fixed bar. If O took longer than 10-sec. on any judgment the stimulus was removed and retested later in the experimental session. O received no feedback with respect to his judgments.

The stimuli were divided into four general classes on the basis of the size of the angle formed by the intersection of the interrupted segment with the distracting lines: 45°, 90°, 135°, or 180° (i.e., a straight bar). All the stimuli of one class were presented in a block with the order of presentations of blocks confounded by Ss; stimuli within a block were randomized. This procedure assured the elimination of an order effect and served to shorten the experimental session by requiring less complicated stimulus changes after each trial.

After collection the data were arranged into the eight sets shown in Fig. 4 to test the hypotheses under consideration (the order in which the stimulus sets appear in the figure does not correspond to the order in which the hypotheses were tested). Although, several of the stimuli appear in several of the sets, each was presented to O for only one judgment under each condition (e.g., the stimulus in Sets 1a and 5j is the same, hence judged only once, while the same stimulus in Sets 3a and 8a was judged twice since it appeared under different conditions).

The stimuli of Set 1 were designed to investigate the effect of angle size on the magnitude of the illusion. _Os_ adjusted the oblique segments while the angle at which the parallel distractor lines intersected these segments was varied. Set 6 was also related to this phenomenon but included a test of the displacement effect of the angles, e.g., is the illusory effect reduced when only one angle is presented? _O_ adjusted the dot until it appeared to lie on the locus of points of the oblique line segment. Sets 2 and 3 served a dual purpose; first, to determine whether it is possible to manipulate the degree of the perceptual organization by either separating the components of the angle are placing dots across the interrupted space, and second, if such an influence does exist, what effect does it exert on the magnitude of the illusion. In Set 4, _Os_ made three consecutive rapid judgments of stimulus _a_, _O_ was then instructed to take all the time he desired and made three slow considered judgments of stimulus _b_. One half of the _Ss_ received the reverse order. These stimuli were used to test the hypothesis regarding the effect of increased viewing time on the illusion. Set 5 investigates the vertical-horizontal phenomenon noted in the introduction, the three angle sizes were tested under three different orientations of the illusory line segments. Stimuli j, k, and l of Set 5 served as control figures for these orientations since they were not sub-tended by angles. The viewing condition for Set 7 was with _O_'s head tilted at a 45° angle to his right. Comparison of this group of stimuli with _O_'s adjustments of stimuli Set 1c, Set 1f, Set 5h, and Set 5i, respectively presented a direct test of the second hypothesis regarding the interaction of the vestibular and visual inputs in determining the vertical-horizontal effect. All eight of these stimuli were tested in the second session referred to earlier. The proximal stimulus of each pair were identical, the only variable changed was O's head position. For example, when Set 1c was viewed with O's head vertical the retinal image was identical to that produced by viewing 7a with O's head tilted. In the remaining stimuli (Set 8), O was required to fixate the dot positioned in the space between the two parallel line segments and on the locus of points bisecting the distance between the ends of the interrupted oblique line segments. In Stimulus a of this set, the dot was mid-way on the locus of the interrupted oblique segments. In Stimulus b, the dot was positioned 4.5 cm. above the locus of the interrupted oblique on the perpendicular bisector of this locus. In Stimulus c, the dot was positioned the same distance below the locus. The distance was increased to 9 cm. above or below the locus of the interrupted oblique for Stimuli d and e, respectively. Organization of the data into these various sets facilitated testing the hypothesis under consideration.

CHAPTER IV

RESULTS

Due to the method used in recording O's judgments a positive error for one stimulus might mean a judgment in the direction of the illusion while for other stimuli it would indicate a judgment opposite the direction of the illusion. The signs on those stimuli in the latter class were changed so that a positive error always indicates a judgment in the direction of the illusion. All data were separated into the groups indicated in the two preceding sections. Continuous reference to Fig. 4 will aid the reader in the following discussion.

Comparison of O's judgments of the same stimulus presented at two different times (Fig. 4, Set 1e and Set 4a) during the first experimental session provided an examination of test-retest reliability of the measurement technique. The reliability was found to be satisfactorily high (Pearson $r = .86$). A test-retest reliability between the two sessions (Set 1c tested in both sessions with O's head vertical) also proved satisfactory (Pearson $r = .78$).

Hypothesis 1. The illusory effect increases as the size of the angle is increased.

The stimuli of Set 1, Fig. 4, with the exception of the first stimulus (a), which as discussed previously was the criterion measure for selection of Os, were tested in an analysis of variance design as three angles (45°, 90°, and 135°) each judged under two conditions;

(1) the distracting lines (i.e., the parallel lines) not crossing an imaginary line drawn vertically through the space between the oblique line segments (Set 1e, f, and g), or (2) the distracting lines not crossing an imaginary horizontal line drawn through the space in the oblique line segments (Set 1b, c, and d). The mean judgments for each stimulus are presented graphically in Fig. 6. Both a main effect of angles and of direction of distraction proved to be significant, no interaction was detected (Table 1). As the angle increased from 45° to 135° the strength of the illusion increased (45° vs. 90°, $p<.01$; 90° vs. 135°, $p<.01$, critical difference test). The vertical position of the distractors resulted in a greater illusory effect than did the horizontal position.

Hypothesis 2. The illusory effect will be maximal when the interrupted segments fail to coincide with O's vertical-horizontal direction.

The stimuli of Set 5 and Set 7 present a test of this hypothesis. An analysis of variance applied to the data collected on Set 5 is summarized in Table 2. The entire variance was attributable to the main effect of the orientation of the interrupted oblique segments. The illusion was maximum when the comparison segments appeared in an oblique orientation, a reduction was noted with rotation to a horizontal orientation with minimum illusory effect in the vertical orientation (oblique vs. horizontal, $p<.01$; horizontal vs. vertical, $p<.05$). Rotation of the stimulus effectively cancelled the angle effect evident in the oblique orientation. The mean errors for each stimuli appear in Fig. 7.

FIGURE 6

The Effect of Angle Size and Distraction Position on the Magnitude of the Illusion

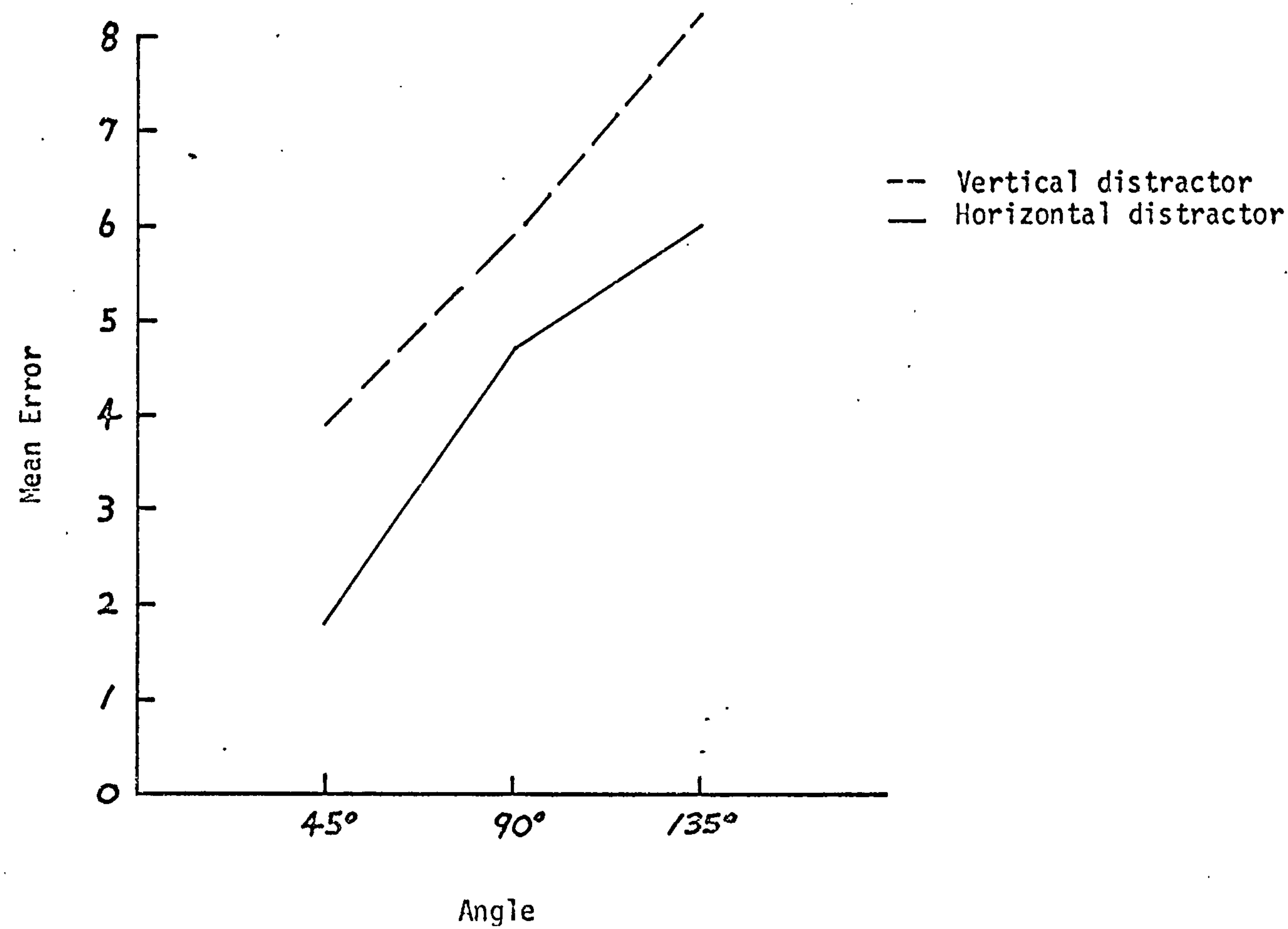


TABLE I

SUMMARY OF ANALYSIS OF VARIANCE FOR THE EFFECT OF ANGLE AND STIMULUS POSITION

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Figure position	1	79.33	79.33	7.382*
Subject x Position	14	150.45	10.74	
Angle size	2	272.63	136.31	13.145**
Subject x Angle	28	290.36	10.37	
Position x Angle	2	5.37	2.68	0.374
Subject x Position x Angle	28	200.96	7.17	

* $p<.05$

** $p<.01$

TABLE II

SUMMARY OF ANALYSIS OF VARIANCE FOR STIMULUS ORIENTATION--

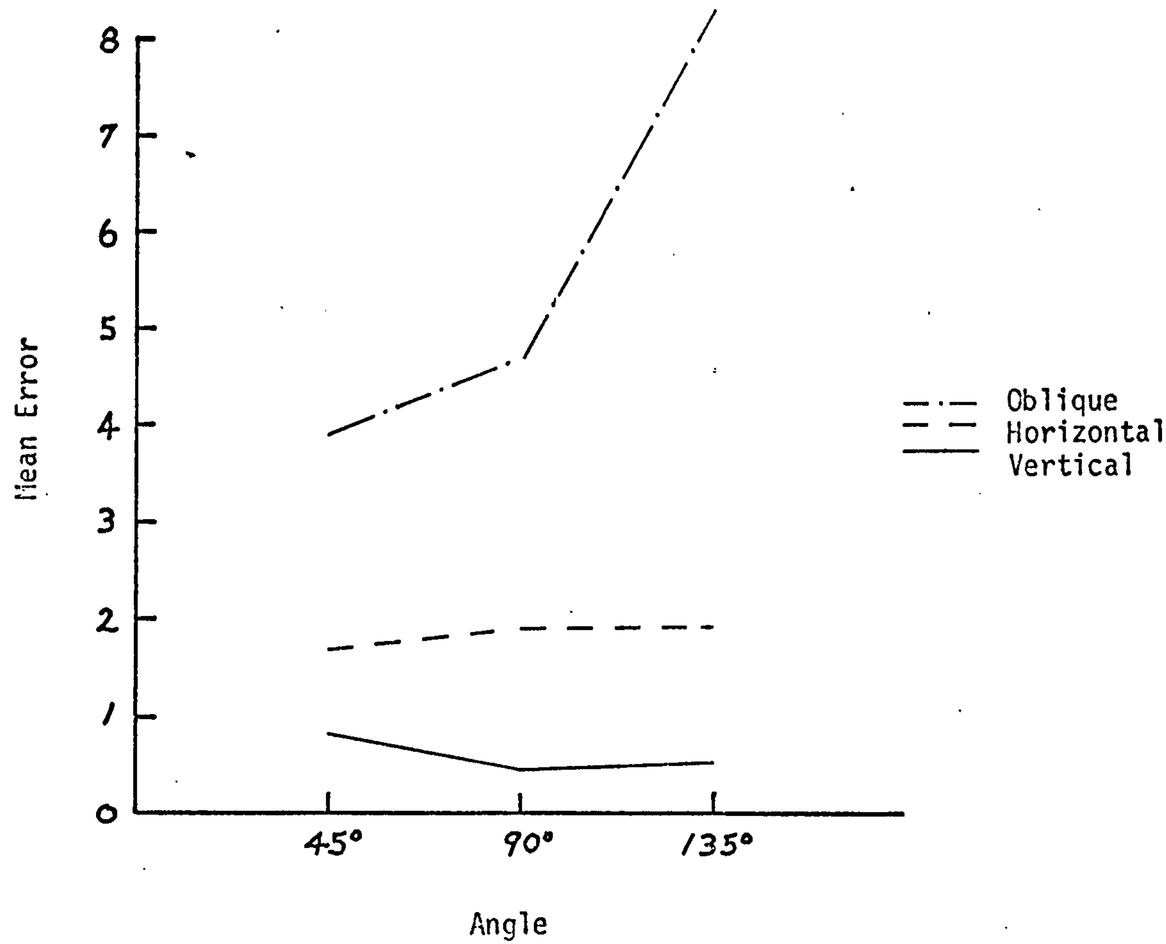
VERTICAL AND HORIZONTAL

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Ratio
Angle size	2	37.19	18.59	2.767
Subject x Angle	28	188.19	6.72	
Stimulus orientation	2	840.58	420.29	37.977*
Subject x Orientation	28	309.87	11.06	
Angle x Orientation	4	78.64	19.66	2.999
Subject x Angle x Orientation	56	367.03	6.55	

* p<.01

FIGURE 7

The Effect of Stimulus Orientation on the Magnitude of the Illusion



Rotation of the head as opposed to rotation of the stimulus was investigated by comparing the stimuli of Set 7 (a, b, c, and d) with the following stimuli respectively; Set 1c, Set 1f, Set 5h, and Set 5i. O's proximal stimulus of the four patterns in Set 7 when viewed with his head tilted 45° to his right are identical to those listed above when viewed with his head straight, e.g., stimulus Set 7a is identical to Stimulus Set 1c. The mean judgments made on each of these stimuli are presented in Fig. 8. There was a significant interaction between figure orientation and head position (Table 3) which must be taken into account when interpreting the two significant main effects. The two stimuli contributing variance to the interaction are the same two stimulus figures accounting for the main effect of head position (Fig. 8). The main effect can thereby be interpreted as an artifact produced by these two figures. This is not true for the main effect of figure orientation however. This main effect parallels the results of Set 5.

Hypothesis 3. Rapid judgments result in a larger illusory effect than slow considered judgments.

Comparing the means of the three judgments for each O on stimulus Set 4a with those on stimulus Set 4b permits an examination of this third hypothesis. Slow judgments resulted in a considerable reduction in the illusion ($t = 3.085$, $p<.01$). Figure 9 plots the means of the three fast judgments and the three slow judgments.

FIGURE 8

The Effect of Head Position on the Magnitude of the Illusion

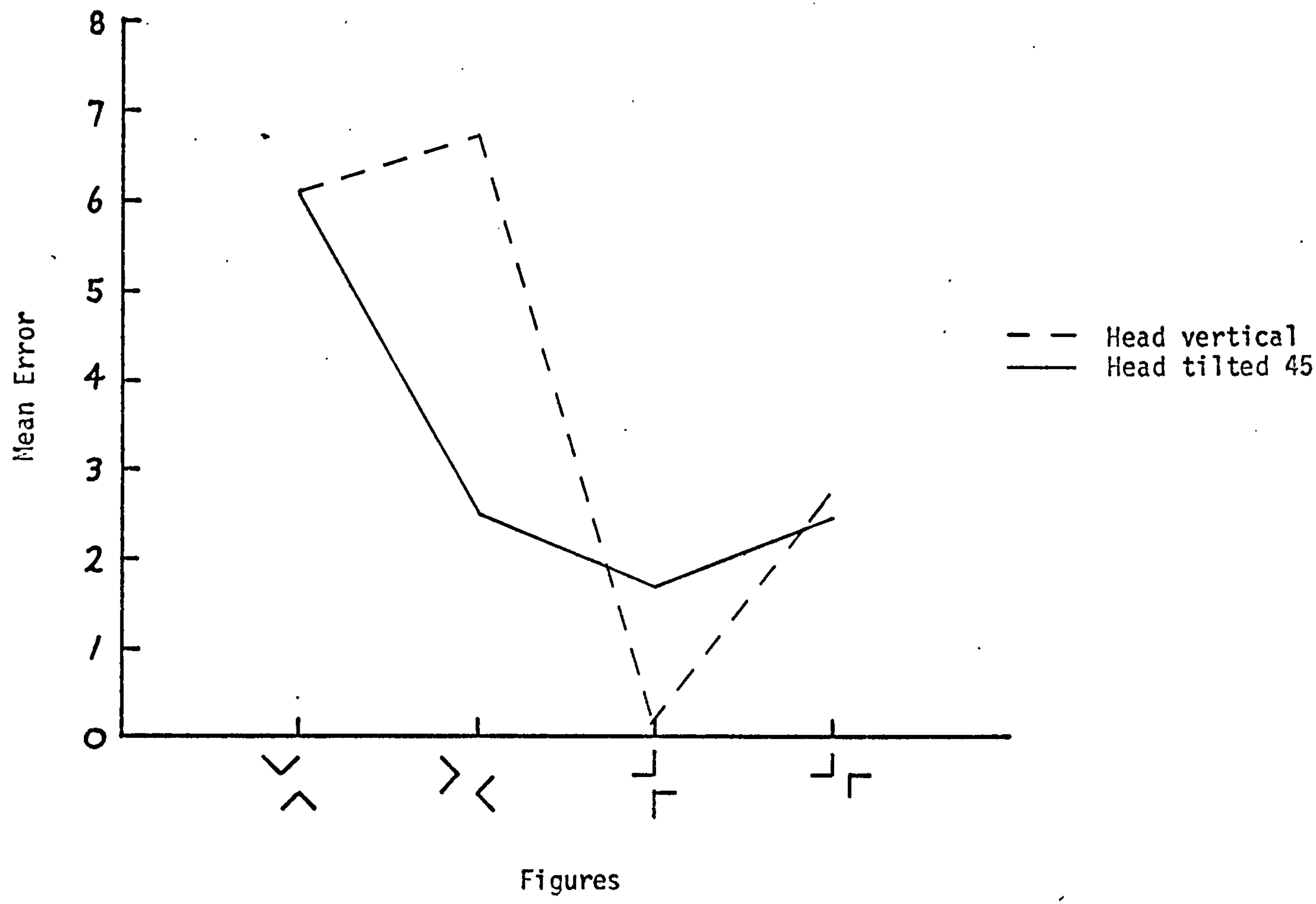


TABLE III

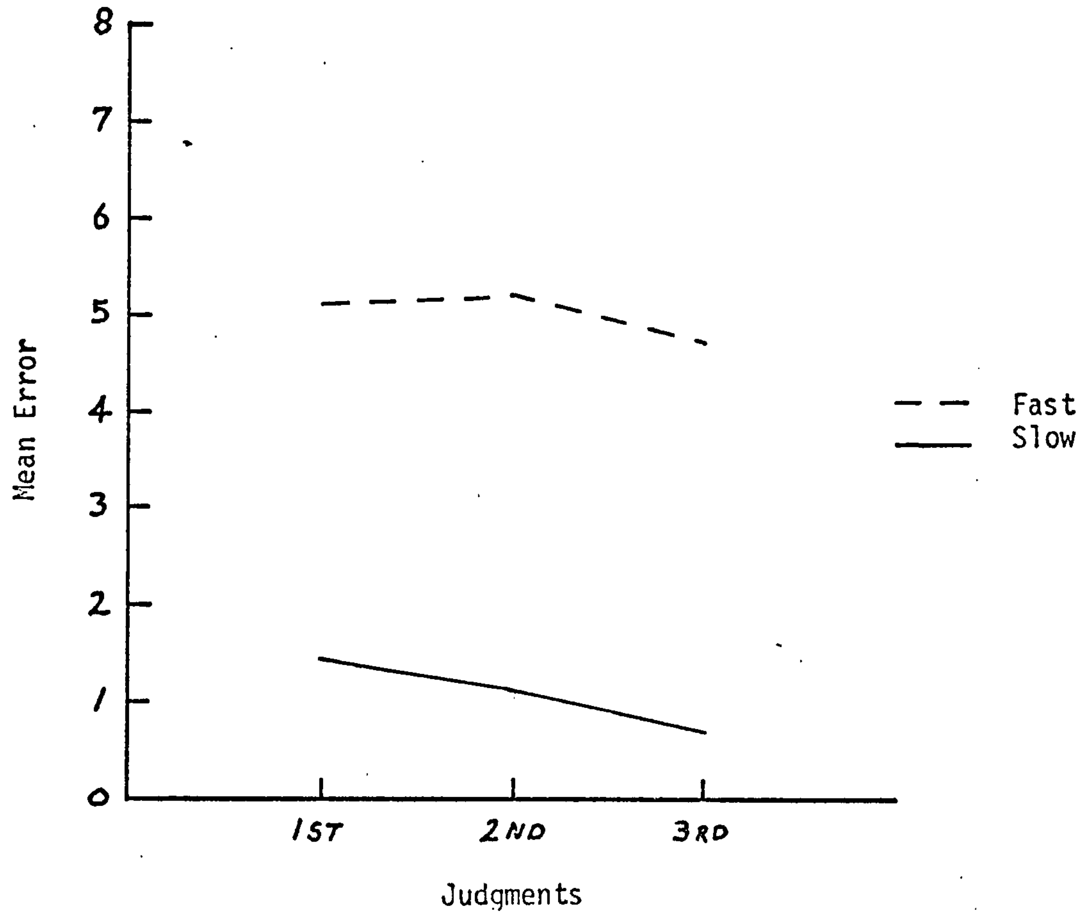
SUMMARY OF ANALYSIS OF VARIANCE FOR HEAD POSITION AND FIGURE ORIENTATION

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Head position	1	16.13	16.13	9.083*
Subject x Position	14	24.86	1.77	
Figure orientation	3	466.21	155.40	33.595*
Subject x Orientation	42	194.28	4.62	
Position x Orientation	3	123.68	41.22	9.207*
Subject x Position x Orientation	42	188.06	4.47	

* $p<.01$

FIGURE 9

The Effect of Speed of Judgment on the Magnitude of the Illusion



Hypothesis 4. The activation of additional visual units by placing a dot stimulus mid-way between the ends of the interrupted oblique segments should result in a diminution of the illusory effect. Fixation of this dot should produce an even greater reduction.

Two additional stimuli (Set 1c and Set 3a) were grouped with those of Set 8 to examine the effect of fixation. With the angle size and orientation held constant, regard was varied in the following ways: (1) free viewing without a fixation point present, (2) free viewing but with a dot present on the locus of points of the interrupted oblique segments mid-way between the two segments, (3) fixation of this dot, and (4) fixation of a dot systematically shifted both above and below the locus of the interrupted oblique. A simple analysis of variance showed that variation in regard did exert a significant effect on O's judgments (Table 4). Although errors made under free viewing conditions without a fixation point (Set 1c) were greater than those made with the fixation point present (still with free regard, Set 8a) the difference was not significant (critical difference test, $p<.30$). When the dot was fixated, the errors were significantly smaller than either free viewing condition ($p<.01$ for both). Fixating a point above the locus of the interrupted oblique lines (Set 8b and d) resulted in greater illusory effect than fixating a point below this locus (Set 8c and e). In all cases, fixation of a point off the locus of the interrupted oblique lines resulted in a smaller illusory effect than that observed under the free viewing condition without a fixation point, this difference was significant only in Set 8c ($p<.02$), and Set 8e ($p<.01$). The decreased

TABLE IV

SUMMARY OF ANALYSIS OF VARIANCE FOR EFFECT OF FIXATION

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Between figures	6	240.605	40.100	5.113*
Between subjects	13	100.194	7.707	0.982
Residual	78	611.735	7.842	
Total	97	952.534		

* $p<.01$

illusory effect was not as great as that observed when O was required to fixate a point on the locus of the interrupted oblique (Set 8a), however, significance was found in only one of these differences (Set 8d, $p<.01$). These results are graphically presented in Fig. 10.

Hypothesis 5. Changing the perceptual organization of the stimuli should result in changes in the magnitude of the illusion.

Judgments of stimuli of Sets 2 and 3 provide a test of the hypothesis concerning the effect on the illusion of the strength of the organization of the angles as the predominant percept. These stimuli were separated into three groups: (1) stimulus Set 1e was grouped with stimuli Set 2a, b, and c, (2) Set 1g was grouped with Set 2d, e, and f, and (3) stimulus Set 1c was added to the three stimuli of Set 3. The mean judgments for each of the stimuli in each of the three groups are presented in Figs. 11, 12, and 13, respectively. A simple analysis of variance was performed on each of the three groups and main effects tested using the method of critical difference (Table 5, 6, and 7). As the organization of the angles as the dominant percept was destroyed and the organization of the interrupted oblique enhanced the illusory effect decreased, this was true for all three methods of stimulus modification.

Figure 14 contrasts the mean judgments for stimuli containing two angles (Set 1a, e, and g) as opposed to those containing only one angle and a dot (Set 6). The illusion was found to be approximately twice as powerful when both angles were present than when only one angle and a dot were used (Table 8).

FIGURE 10

The Effect of Fixation on the Magnitude of the Illusion

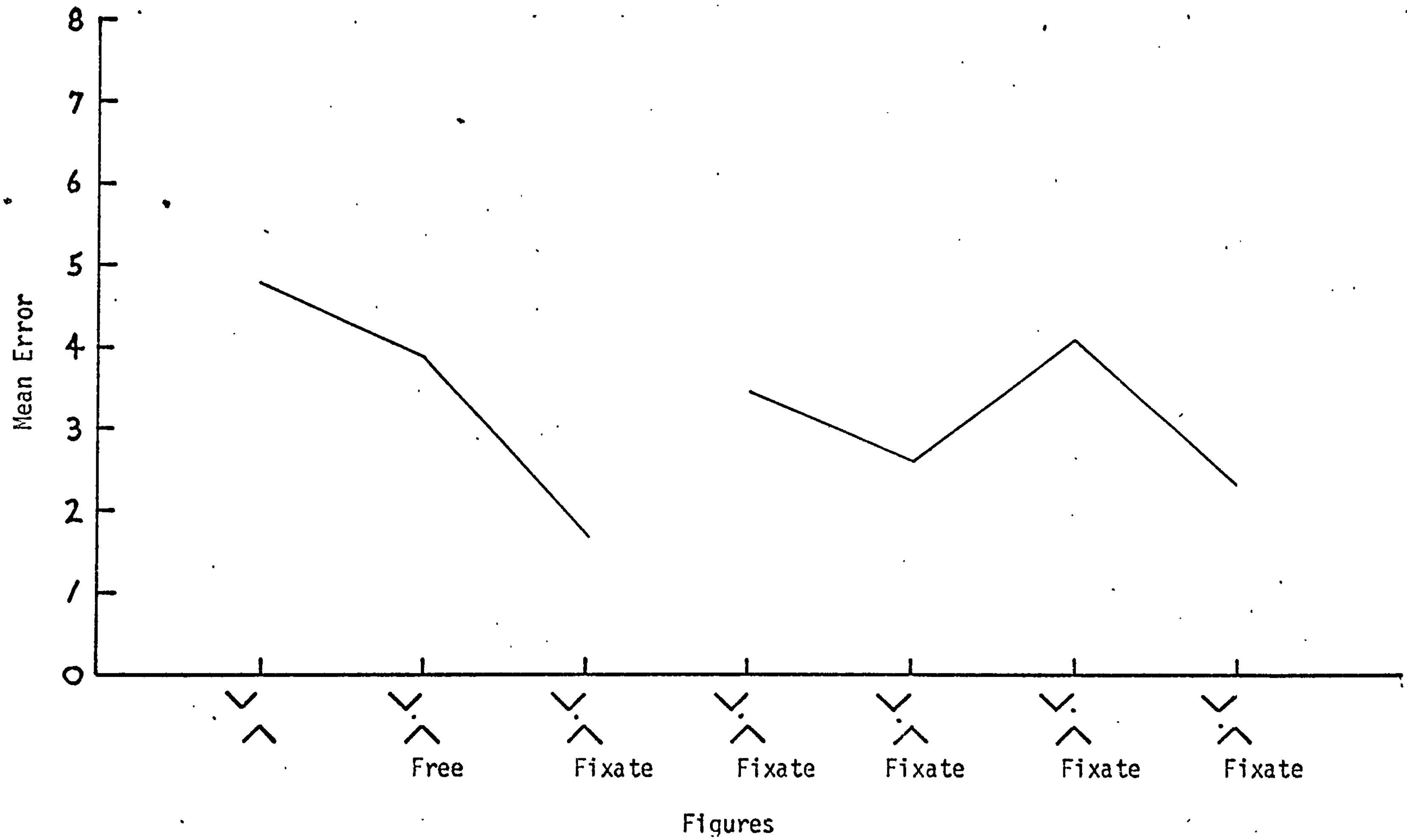


FIGURE 11

The Effect of Destroying the Organization of the Acute Angle on the Magnitude of the Illusion

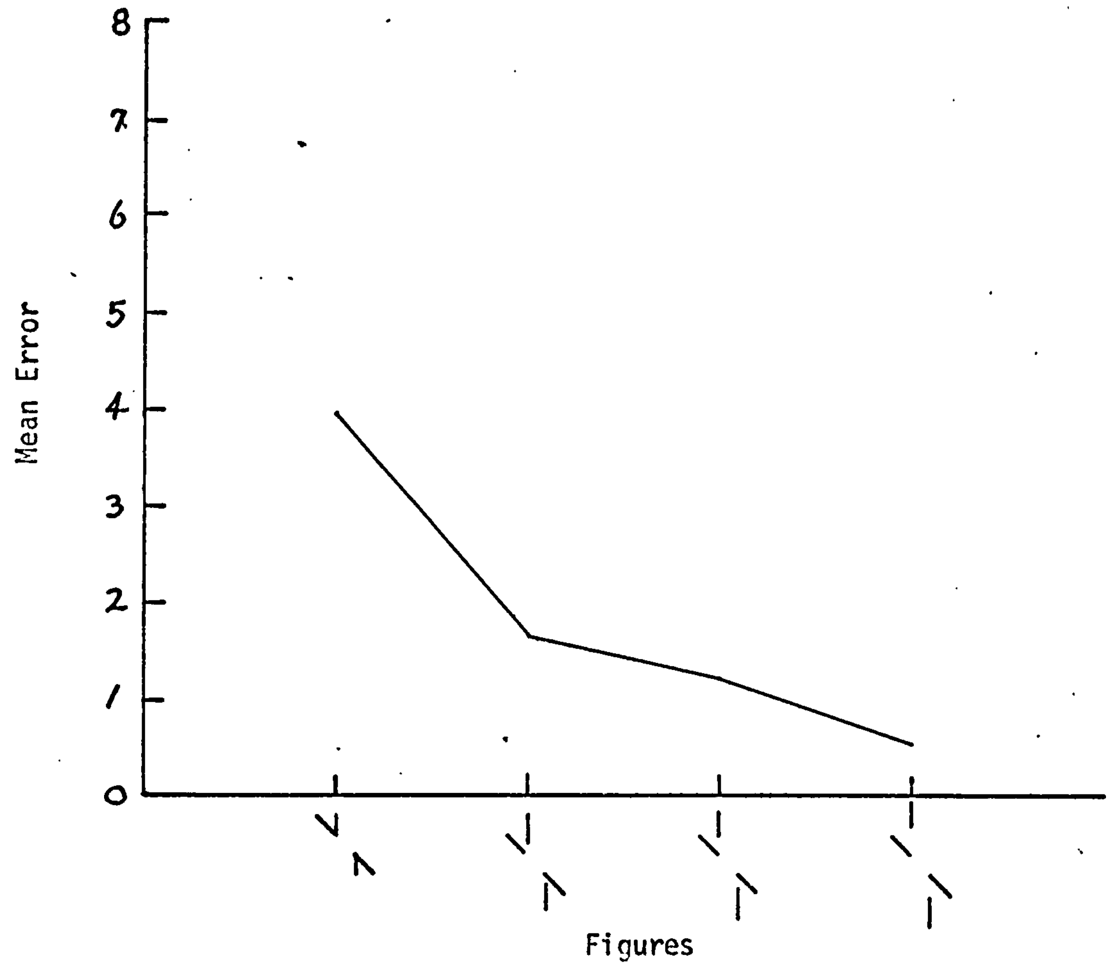


FIGURE 12

The Effect of Destroying the Organization of the Obtuse Angle

on the Magnitude of the Illusion

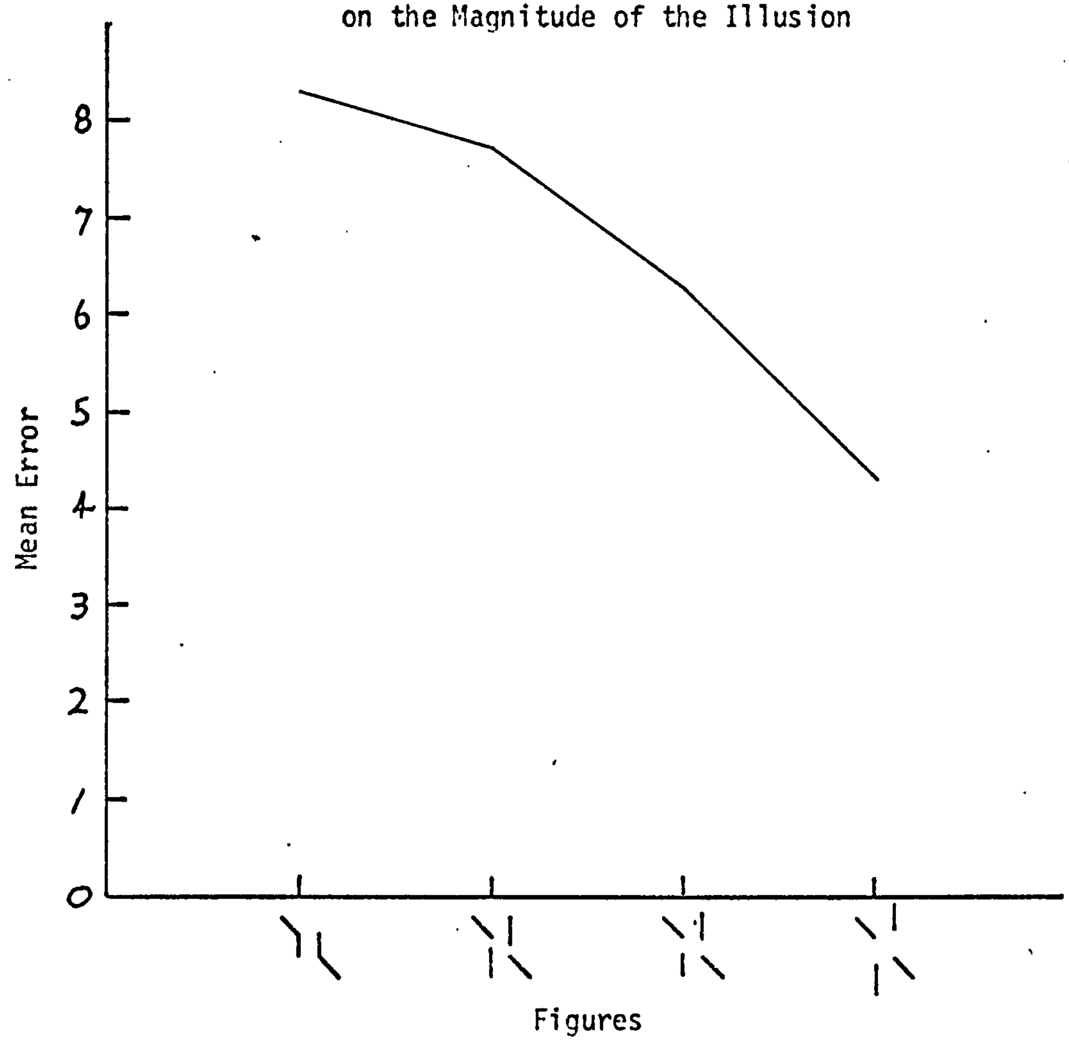


FIGURE 13

The Effect of Filling the Interrupted Space Between the Illusory Segments on the Magnitude of the Illusion

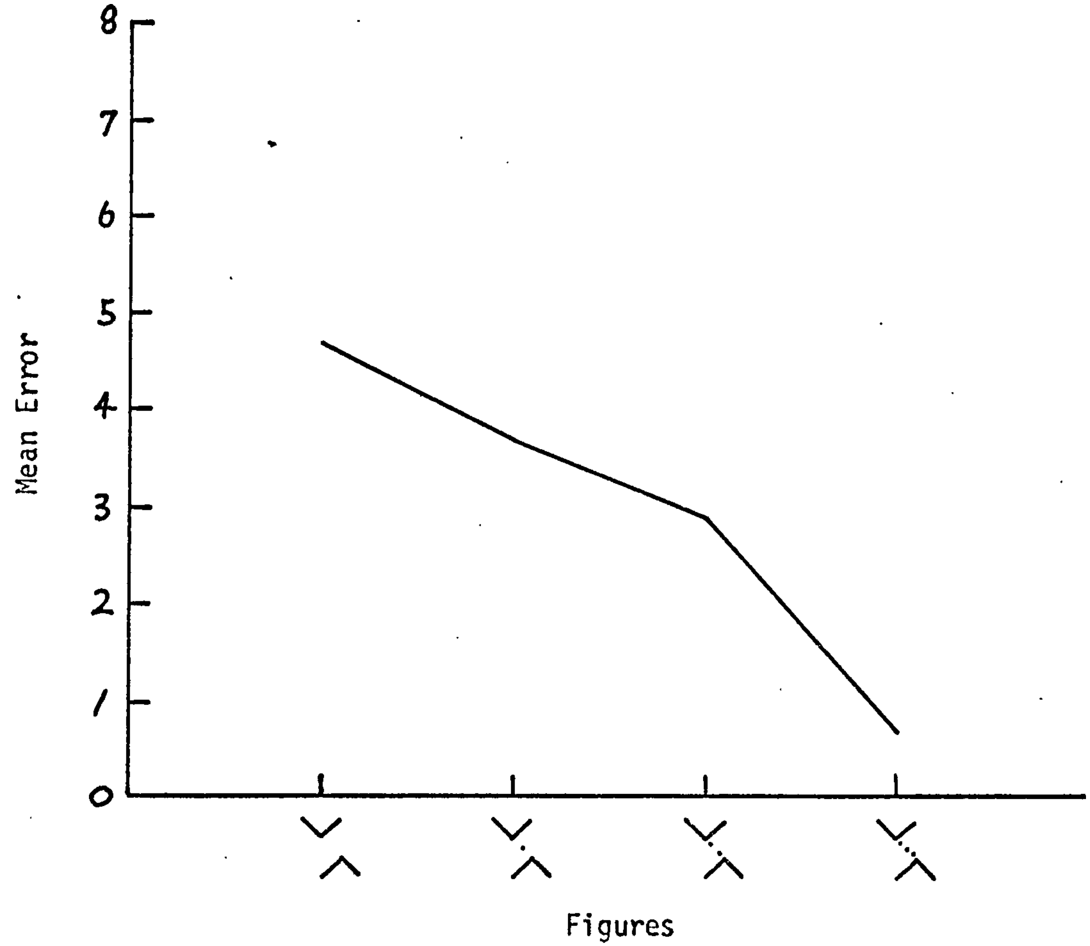


TABLE V

SUMMARY OF ANALYSIS OF VARIANCE FOR THE EFFECT OF ANGLE

ON THE MAGNITUDE OF THE ILLUSION (ACUTE ANGLE)

	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Between figure	3	96.494	32.161	11.614**
Between subject	14	237.368	16.954	6.125
Residual	42	116.332		

Critical Difference Between Means

Set 1e vs. Set 2a, b, and c**

Set 2a vs. Set 2b*

* p<.05

** p<.01

TABLE VI

SUMMARY OF ANALYSIS OF VARIANCE OF THE EFFECT FOR ANGLE ORGANIZATION ON THE MAGNITUDE OF THE ILLUSION (OBTUSE ANGLE)

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Between figure	3	608.558	202.852	28.777**
Between subject	14	148.612	10.615	1.505
Residual	42	296.076	7.049	

Critical Difference Between Means

Set 1g vs. Set 2e and f**

Set 2d vs. Set 2e*

Set 2d vs. Set 2f**

Set 2e vs. Set 2f**

* p<.05

** p<.01

TABLE VII

SUMMARY OF ANALYSIS OF VARIANCE FOR FILLING THE SPACE BETWEEN

THE TWO SEGMENTS OF THE INTERRUPTED OBLIQUE

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Between figure	3	227.433	75.811	20.119*
Between subject	14	138.460	9.860	2.616*
Residual	42	158.267	3.768	

Critical Difference Between Means

Set 1c vs. Set 3b and c *

Set 3a vs. Set 3c *

Set 3b vs. Set 3c *

* p<.01

FIGURE 14

The Effect of Contrasting Angles on the Magnitude

of the Illusion

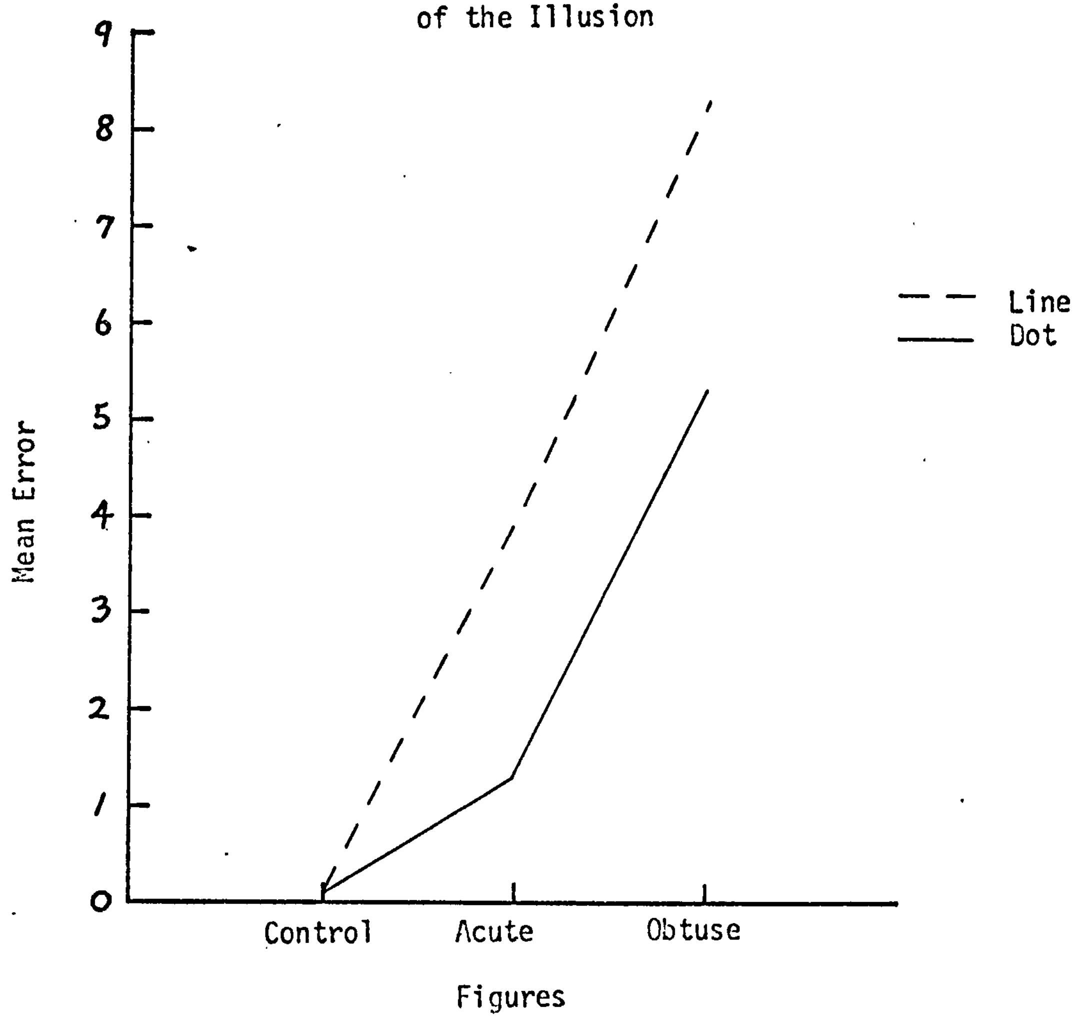


TABLE VIII

SUMMARY OF ANALYSIS FOR VARIANCE, DOUBLE ANGLE vs. SINGLE ANGLE

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio
Number of angles	1	87.02	87.02	10.463*
Subject x Number of angles	14	116.43	8.31	
Angle size	2	708.50	354.25	31.758*
Subject x Angle size	28	312.32	11.15	
Number x Size	2	31.85	15.92	2.730
Subject x Number x Size	28	163.31	5.83	

* p<.01

CHAPTER V

DISCUSSION

The earlier investigators of the Poggendorff illusion with the exception of Green and Hoyle (1964) searched primarily for a single factor "explanation" of the phenomenon. That the illusion cannot be attributed to a single factor is clearly demonstrated by the confirmation of all hypothesis put forward in this study. Although the results presented here are not contradictory to any of those reported by earlier investigators, the conclusions suggested are different. The confirmation of the first hypothesis supports the observations of both Herring (1861) and Tausch (1954) regarding the influence of the size of the transverse angle on the magnitude of the illusion. It has now been clearly demonstrated that under "certain conditions" as the size of this angle is increased the magnitude of the simplified illusion is also increased. That the interpretation of recent neurophysiological advances predicts these results is suggestive of an explanatory mechanism. As discussed in Chapter II, if increasing angle size does result in an increase in cortical activity (as predicted from the findings of Hubel and Wiesel) the effect of the angle would increase. No explanation has as yet been put forward to account for the fact that an angle (regardless of size) does exhibit an illusory effect. The concept of lateral inhibition recently demonstrated by von Bekesy (1960) suggests such an explanation. Following von Bekesy's concept, activity generated by the two component lines of the angle would produce greater inhibition on the interior of the angle as opposed to the surrounding area. The visual system in attempting to balance these two areas of inhibition may actually displace the apparent oblique segment in a direction external to the angle. In fact, the displacement of both components of the angle in opposite directions is most probably the case. However, by concentrating on the illusory segment the present study can provide no information concerning the effect of the angle size on the distractor components. The fact that the receptive field of each visual unit has associated with it both an excitatory area and an inhibitory area strongly supports the concept of lateral inhibition.

That the angle effect is but one of multiple factors combining to produce this complex illusory phenomenon is indicated by the confirmation of the second hypothesis. These results confirmed the findings of Judd (1879), Pierce (1901). and Green and Hoyle (1964) that the illusory effect is reduced when the illusion is rotated so that the interrupted line segments are positioned in O's horizontal or vertical dimension. The greatest reduction occurring when the illusory line is in the vertical dimension. The negation of the powerful angle effect discussed above suggests an inhibition of the mechanism responsible for the angle effect by a second mechanism. That this second mechanism could be the one-object multiple-object mechanism recently demonstrated by Mefferd (1968) was suggested in the development of this hypothesis in Chapter II. Rotating the illusory line segments to the vertical position results in their projection to both hemispheres due to the overlap of the projection fields in the immediate area of the fovea. With both segments projected to both hemispheres the probability of them being organized as the predominant perceptual unit (as opposed to the angle organization) should increase. Once this organization is achieved the angle effect could conceivable be inhibited since the focus of the organization of the percept has now shifted. In the horizontal orientation the illusion though significantly reduced remained minimally present. The structural bifurcation of the visual field in this situation projects each illusory line segment to separate hemispheres (Cameron & Steele [1905]demonstrated that Os choose to spend the majority of their viewing time observing the central section of the stimulus). The projection to opposite hemispheres of the illusory line segments should decrease the probability of them being organized as the predominant perceptual units. In fact the probability of the angles being the predominant organization is suggested and yet the illusion is diminished. The possibility of the vestibular system affecting the diminution was suggested earlier (see Chapter II), however, the nature of this interaction remains speculative (the "fine lined grid" suggested by Green & Hoyle, 1964).

Pritchard (1958) as summarized earlier, using the technique of stabilized retinal image has effectively demonstrated that the illusion cannot be attributed to eye movement. However, the results presented under hypothesis 4 showed that under free viewing conditions eye movements do exert a significant influence by contributing to the illusory effect. This result was also predicted from the known neurophysiological structure of the receptive fields of the retina.

Based on the diagraming by Hubel and Wiesel of the nature of the interconnection at all levels of the visual-perceptual system, predictions were made concerning the organization by this system of the perceptual field. For example, it was hypothesized that perceptual closure across the interrupted space in the illusory line segment would result in a diminution of the illusion. Increased closure was achieved by two methods: (1) filling the space with dots, or (2) destroying the strength of closure of the angles by separating the distractor lines from the illusory segments. Confirmation of this hypothesis points to the feasibility of this interpretation.

In the past, one methodology for the study of perception has been to explain perceptual phenomena on the basis of O's perceptual reporting behavior. These same judgments are then used as guides in the inference of physiological mechanisms which supposedly could account for the phenomenon. The technique applied in this study departs from this tradition by beginning with recently demonstrated neurophysiological mechanisms. Through the analysis of these mechanisms various hypotheses were put forward concerning perceptual phenomena. In light of the positive confirmation of all hypotheses resulting from this technique it has proved highly profitable.

All results point to the conclusion that known neurophysiological mechanism can account for the perceptual phenomenon present in at least this particular optico-geometric illusion. Furthermore, modification of the illusion based on these neurophysiological mechanisms result in predictable phenomenal alterations with respect to the magnitude of the illusion. The extent to which this finding can be generalized to other visual illusions as well as veridical visual perception clearly suggests future lines of research. As neurophysiological techniques continue to provide greater and greater insight into the structural mechanisms of the perceptual system, perceptual investigations guided by these discoveries should lead to improved understanding of their function.

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