THE POGGENDORFF ILLUSION:
VARIANTS AND PERCEPTUAL GEOMETRY

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By

DARIUS CYRUS MACKAY, B.A., M.A.

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AUTHOR: Darius Cyrus MacKay, B.A. (Plymouth State College)
M.A. (University of New Brunswick)

SUPERVISOR: Professor P.L. Newbigging

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ABSTRACT

Nine experiments involving 147 subjects are described. Experiments 1 to 5 were designed to produce evidence relevant to the question "do the classic Poggendorff figure and its variants activate the same perceptual process(es) or are they distinct and give rise to different phenomena?" Experiments 6 to 8 constitute an attempt to determine the ways in which the perceptual geometry of the Poggendorff differs from its Euclidean geometry. The ninth and final experiment is addressed to the cause of the illusion.

Experiments 1 and 2 show that the classical Poggendorff figure and three of its variants all produce the same illusory effect and that, for all four figures, that effect is increased as the angle of interception of the oblique decreases and as the separation between the parallels increases. Experiment 3 shows that the differences in the magnitude of illusion produced by the variants is due to the particular component retained and not the total amount of the illusion figure present. Experiments 4 and 5 extended this analysis to study the effects of practice and the extent to which practice on the variants transfered to the classical figure. Decrements with practice were obtained for all figures and the figures were ordered, in terms of magnitude of illusion produced, precisely as they were for

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the initial two experiments. This result is noteworthy because it shows that the effects obtained are not dependent on either the details of the stimulus, psychophysical method, or mode of presentation. Also, equal or greater positive transfer to the classical figure is obtained from the variants as from the classical figure itself. The conclusion is reached that the classical figure and the variants arouse the same single perceptual process. Unfortunately, the data do not permit the identification of that process.

The results of Experiments 6 to 8 provide a model of what the visual system does when confronted with the classical Poggendorff figure: It was determined that the presence of a single transversal is all that is required to produce the full illusory effect (Experiment 7). The angle of interception of this transversal is perceptually enlarged (Experiment 8). This perceptual representation is then projected linearly across the space between the parallels (Experiment 6). An across-experiment test shows that the model fits the data reasonably well. Although the experiments were not designed to test any theory of the cause of the illusion, the resulting model has some features that are similar to angular distortion explanations. The ninth and final experiment was a direct test of Burns and Pritchard's (1971) proposal that lateral inhibition in the visual system is the basis for the distortion of cortical images and thus the Poggendorff illusion. The result was a significant reduction, but not the elimination, of the illusory effect.

In the final chapter it is noted that while lateral inhibition seems to figure causatively in the classical figure, certain configurations, particularly those that do not include acute angles, present some difficulty. Suggestions for further research which will explicate the phenomenon are also noted.

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CHAPTER I

ILLUSIONS IN PSYCHOLOGY

An illusion exists where there is a consistent disparity between a physical stimulus and its perceptual representation. Several different kinds of illusions appear in all sensory modalities.

Visual illusions have been known for a long time and a considerable amount of experimental and theoretical work has been published. In fact, in terms of publications, more have been devoted to illusions than to any other single phenomenon in visual perception (Zusne, 1970). The problem of why our senses should be misled in certain situations is one of genuine scientific interest, for illusions are not random deviations of our nervous system but are systematic errors (Gregory & Gombrich, 1973). The problem of the accuracy of our sensory experience ~~in~~ reflecting the real world was also an early and major concern of philosophers (Johannsen, 1971). Luckiesh (1922) offers the following summary:

> Illusions are so numerous and varied that they have long challenged the interest of the scientist. They may be so useful or even disasteous that they have been utilized or counteracted by the skilled artist or artisan. The architect and painter have used or avoided them. The stage artist employs them ... The magician has employed them ... and the camoufleur used them ... They

> are vastly entertaining, useful, deceiving, or disastrous , depending upon the viewpoint. (Pp. 2-3)

Historically, the study of illusions, especially the "geometric optical illusions", a term coined by Oppel in 1854, can be seen as reflecting certain dominant trends within pyschology. A recurring theme in the analysis of illusions is that they served primarily as "test cases" for various theories of perception (Robinson, 1972). Much of the early impetus for studying illusions was the hope that the explanation of illusions would illuminate the basis of all perception.

Although not named individually and as a class until the 19th century, the geometric optical illusions have a long history extending back at least as far as the ancient Greeks. That the Greeks knew about optical illusions is evidenced by the fact that their architects inclined the end columns of their temples and buildings and gave a slight curvature to the architrave in order to combat the optical illusion which causes the vertical columns to diverge upwards and the long horizontal lines to bend toward the sky. It is an interesting problem as to why more illusions, given that most occur in nature, were not noted until relatively late. Possible factors which militated against the rise of illusions to prominence until the 19th century was the degree of sophistication of both scientific concepts and instruments, and the general standard of life within society. These factors can be seen as reflecting Kuhn's (1962) first criterion for scientific discovery: the awareness of an anomaly. According to Kuhn the isolation of an anomaly, the failure to conform to expectation, requires the presence of a certain intellectual milieu. Further, once recognized there followed an extended period of additional observation and experimentation during which many investigators tried to make illusions lawlike, the second of Kuhn's three criteria. The final characteristic, that of adjustment, adaptation, and assimilation of anomaly into the existing pattern of thought, can be seen in the various (and unsuccessful) attempts to find a general law which could account for both perception in general and illusions in particular.

By the 19th century interest in sensation and perception had grown substantially. The ideas of Newton and Locke were modified and extended, along with other empiricists's notions. Notions relating to the idea of association in particular abounded. Within perception itself, ideas concerning the perception of objects revolved around notions of the identity of real world objects with their retinal counterparts. The veridicality of perception was recognized and thus in order to account for illusory perception visual image modifying mechanisms had to be postulated.

Of all the early expressions of interest in illusions those stated by Helmholtz (1866) appear to be the most important. Helmholtz himsel was an empiricist and an associationist. The rationale he espoused, and which was subsequently echoed by Baldwin (1890), was that the key to understanding perception in general lay in a knowledge of "abnormal", i.e., illusory perception. Boring (1942) stated it thusly: "A knowledge of the principles governing the abnormal perception of extent would certainly help, it was thought, with the understanding of the normal cases" (p. 239). A contemporary version of this view can be seen in the following statement by Gregory and Gombrich (1973):

> Illusions are also tools for discovering processess of perception. In medicine, in engineering, and very frequently in biology, the abnormal and the surprising lead to key ideas and facts for understanding the normal. So here we may expect abnormal perception (deviations from truth) to give insights and data for understanding normal (correct) perception. (P. 7)

In the latter half of the 19th century two important trends in thought were developing which were to exert a profound effect on all of science, psychology included. These were evolutionary theory and certain holistic conceptions. Studies that arose directly out of evolutionary theory include the study of illusions in animals, e.g., Warden and Boar's (1929) demonstration of the Müller-Lyer illusion in ring doves; and Rivers's (1905) anthropological studies in which he found, in comparison to English subjects that Todas subjects exhibited a lesser sensitivity to the Müller-Lyer and a greater sensitivity to the Vertical-Horizontal illusion. Rivers thought that such comparative measures provided clues to the nature of an illusion stating that:

> If an illusion is proved to be more marked to the savage, this would suggest that the illusion has a physiological basis or at any rate that it depends on primitive and innate conditions the effect of which is marked by the results of experience in the more civilized. If, on the other hand, the illusion is less marked, the fact would suggest that the nature of the illusion is more complex and more dependent on the working of experience. (P. 363)

Rivers also noted "some degree of correlation between general intellectual development and certain simple mental properties" (p. 363). The second trend, holistic conceptions, culminated in Gestalt Psychology.

The psychological literature just before and just after the beginning of the 20th century abounded with publications on geometrical optical illusions. Most scholars of the time had something to offer about these phenomena. In fact, Boring (1929) has termed the period from 1890 to 1900 the "decade of the optical illusion" (p. 630).

Theories proliferated and were characterized by ambitious attempts to explain all illusions in terms of one simple theory. We have, for example, Brentano's (1892, cited by Blix, 1902) formulation of the overestimation of acute angles and the underestimation of obtuse angles, Thiery's (1896) suggestion of perspective perception, Wundt's (1898) account in terms of feedback from eye movements, and Einthoven's (1898) blurring of the retinal image. In a review of the literature of this period Carter and Pollack (1968) noted several general characteristics. Illusions actuated a diversity of theoretical views which were, in general, mainly conjectural in nature and often lacked any quantitative data. Communication between investigators was also uncommon. Further, the use of the author as the only subject has its limitations. "Wundt carried this to the extreme, since he was limited to monocular vision, and the myopia in his 'good' eye was not completely correctable" (p. 706).

According to Zusne (1970) after the early 20th century the topic of illusions "receded into the background without having yielded" (pp. 150-151). There are a number of possible reasons for this and prominent among them is the fact that the early optimism and rationale surrounding the study of illusions, that by explaining them all other visual perceptual phenomena would also be explained, was not fulfilled. Also, the credibility of a number of explanations was questioned as a consequence of the advent of new instruments and the trend toward increasing quantification. However, Zusne (1968) states that no concomitant decline in the number of publications on the subject of illusions appeared.

The appearance in 1922 of Luckiesh's book _Visual illusions: Their causes characteristics and applications_ can be considered notable. In it Luckiesh not only brought together an enormous amount of scattered material, he also sought to demonstrate the importance and relevance of illusions to various problems in architecture, painting, camouflage and to difficulties encountered in the perception of "nature".

From about 1930 to 1950 the study of illusions was received with skepticism; illusions, it was claimed, were but "inconsequential perceptual curiosities" (Fisher & Lucas, 1969, p. 11). A fact which led Boring (1942) to remark: "Strictly speaking the concept of illusions has no place in psychology" (p. 238).

It was during this time that Gestalt psychology began to exert its influence. In a departure from previous ways of considering illusions, that they are exceptions to the rule, Gestalt psychologists incorporated them along with other visual perceptual phenomena and discussed them in a similar fashion, that is, in terms of the organizational characteristics of the visual field (Zusne, 1970). In fact, illusions were cited as evidence for various Gestalt laws of perceptual organization, i.e., the law of Pragnanz is illustrated by the Müller-Lyer illusion. Here the outward pointing arrowheads can be seen as a diamond and as a consequence of bringing the obliques together to complete the diamond shape, the apparent length of the shaft is decreased.

It has only been within the last two decades that illusions have been seen as intrinsically interesting phenomena, worthy of investigation by themselves and not solely as "tools" or "test cases". Illusions will, of course, have to be included in any comprehensive theory of perception, for, as Murch (1973) says "they represent a fundamental aspect of the process by which the perceiving organism extracts information from the environment" (p. 228).

Today the literature on illusions is growing rapidly; old theories are being reappraised and new explanations are being advanced. An important impetus behind some of this work is the recognition that illusions are not "irrelevant to space perception in concrete conditions of real life" (Fisher & Lucas, 1969, p. 20). Aside from the obvious practical significance of compensation in operator-control situations, the trend toward quantification, and refinements in statistical and physiological techniques have also had their impact.

Several themes or trends can be detected in much of the contemporary work. For example, there is the interest in regularities and explanatory principles; the formulations of Ganz (1966) on lateral inhibition and Gregory (1963, 1966, 1968) on constancy would be examples. Another theme concerns individual differences and an interest in perceptual styles in general as exemplified by the work of Gardner (1961) and Pressey (1967).

The majority of contemporary work on illusions falls into fairly specific theoretical context, in that much work is theory oriented and here can be leveled a fairly sharp criticism. As Over's (1968) review showed less theory and more data, particularly in regard to parametric manipulations, is required.

Let us now turn our attention from these considerations of illusions in general and discuss a specific illusion, one which, while both familiar and frequently studied, remains unexplained and which is the object of study in this thesis.

CHAPTER II

THE POGGENDORFF ILLUSION

The Poggendorff illusion is observed when two physically collinear segments of an oblique line interrupted by two parallel lines are perceived as non-collinear. The classical form of the illusion is shown in Figure 1. In this figure the upper right oblique is usually judged as being "too high" for collinearity with the lower left oblique.

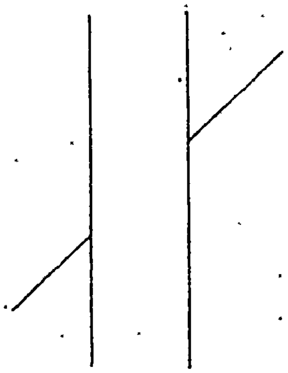


Figure 1. The classical Poggendorff illusion.

The illusion also occurs in a variety of figures containing rectilinear and curved lines (Carr, 1935; Croft, 1892; Lewis, 1892; Pierce, 1898; Robinson, 1972; Tolansky, 1964). For example, in discussing Figure 2 Lewis (1892) stressed the apparent offset of the two parts of the arch and admonished architects to be cognizant of this phenomenon,

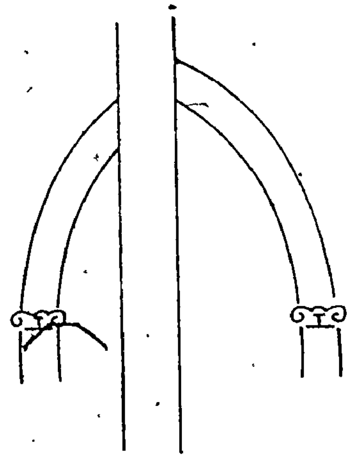


Figure 2. Lewis's (1892) Gothic Arch Illusion.

he also added that, to his knowledge, this was the first time that a figure like this has appeared in print. Croft (1892) also mentions the Gothic Arch illusion and noted that a similar effect occurs with the Norman semicircular arch as well, making it appear Moorish. Pierce (1898) appears to have been the first person to note this similarity between various architectural forms and the Poggendorff illusion stating that the Gothic Arch illusion "is manifestly but a variant of the more simple rectangular form" (p.820). Furthermore, according to Lucas and Fisher (1969), configurations which produce the Poggendorff effect are frequent in nature as well as in man made structures.. In their experiments Lucas and Fisher observed that not only does the characteristic displacement occur in nature, but it is of comparable magnitude as well.

The illusion was first mentioned by Zöllner in 1860 who credited Poggendorff with drawing his attention to it.

Apparently while editing a paper by Zöllner on the illusion which bears his name, Poggendorff noticed a further illusory effect in his figure. The two parts of the short oblique line which crossed a long vertical line did not appear continuous but rather perceptually displaced relative to one another (Figure 3). Zöllner termed this the "nonius effect" and evidently left the matter there (Johannsen, 1971). According to Jastrow (1891-92), Poggendorff's observation of this second illusion was regarded by Zöllner as unrelated to the illusory effect observed in his figure. Zöllner attributed the apparent displacement to astigmatism. It was not until 1896 that Burmester, in the introduction to an experimental study, named it for its discoverer.

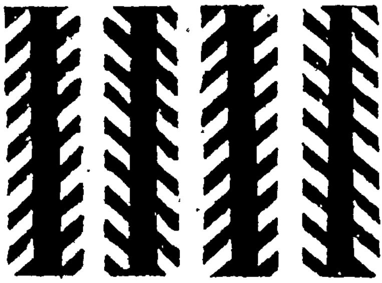


Figure 3. Zöllner's (1860) illusion.

Approximately 160 studies concerned with the Poggendorff illusion have been published since its discovery in 1860, with the most fertile periods being 1890-1899 (16 studies), 1960-1969 (41 studies), and 1970-1976 (59 studies). In fact, most of the important stimulus variables, variations on the classical display, and principal theoretical positions were put forward in the period from 1890 to 1905. Some of the major ideas to emerge include: the role of angle of interception and separation between the parallels in influencing the magnitude of displacement; the idea of reducing the illusion into its component parts inorder to analyze the causes of the effect; and explanations based on the perceptual enlargement of acute angles and perspective perception. For the most part recent studies on the Poggendorff illusion are concerned with variations on the classical figure or are extensions of earlier studies.

The first part of the literature review which follows will be ordered in terms of parametric studies, while the second part will be organized around theoretical issues.

STIMULUS VARIABLES

Changing various features of the Poggendorff figure has been shown to have reliable and often quite substantial effects on the magnitude of the illusion. In this section, experiments are reviewed which investigated the following: the size of the angle at which the obliques intercept the parallels; the distance between the parallels; the content of the space between the parallels; the length of the parallels; the orientation of the total pattern; the length of the obliques; variants of the complete pattern created by removing certain of the line segments or by drawing the pattern as a plane or perspective figure.

<u>Angle</u> Burmester (1896) appears to have been the

first to systematically study the effect of angle and in his extensive paper he reported that the magnitude of illusion was inversely related to the size of the angle of interception. That is, the illusion was found to be greater at small angles and to decrease monotonically as the angle approached 90°. This result has since been replicated many times (e.g., Anton, 1976; Caelli, Finlay, & Hall, 1975; Cameron & Steele, 1905; Houck & Mefferd, 1973; Novak, 1966; Tichý, 1912; Velinsky, 1925; Weintraub & Krantz, 1971).

Distance between the parallels Separation of the parallel lines is another obvious variable and again Burmester (1896) was one of the first to systematically investigate its effect. Burmester showed that the magnitude of illusion was directly related to the separation of the parallels, the illusion increasing regularly with increasing separation. This effect has also been repeatedly confirmed (e.g., Caelli, Finlay, & Hall, 1975; Cameron & Steele, 1905; Hasserodt, 1913; Hotopf & Ollerearnshaw, 1972b; Pressey & Sweeney, 1972b; Thiery, 1896; Tichý, 1912; Tong & Weintraub, 1974; Velinsky, 1925; Weintraub & Krantz, 1971).

It should be pointed out that a major part of Burmester's (1896) research was concerned with the nature of the relation between angle of interception and separation of the parallels. That is, with the angle by separation interaction. Within the range of values used, Burmester derived a formula for expressing the magnitude of illusion observed: I=KW cotangent θ, where I= illusion magnitude, K= an individual constant, W= separation between the parallels, and θ= angle of interception. This multiplicative relationship between angle of interception and separation of the parallels has recently been verified by Weintraub and Krantz (1971) and by Caelli, Finlay, and Hall (1975).

Space between the parallels Another phenomenon is that the magnitude of the Poggendorff effect has been found to vary with the nature of the filling between the parallels. Pierce (1901) was the first to undertake an investigation of this and he found that filling the space between the parallels decreased the illusory effect. This suggested to Pierce that the false estimation of the distance between the parallels is involved. Later studies have also found that filling the space between the parallels decreases the illusory effect (Cameron & Steele, 1905; Tong & Weintraub, 1974).

Length of the parallels Hasserodt (1913), who appears to have done the only study of the effect of the length of the parallels, found that the illusion was greater with long parallels as contrasted with short parallels.

Orientation of the figure Many investigators have found that the orientation of the figure has a great influence on the magnitude of the illusion. The magnitude of displacement has been found to be approximately the same and in the same direction when the parallels are horizontal or vertical (Anton, 1976; Burmester, 1896; Jastrow, 1891-92; Obonai, 1931, cited by Oyama, 1960; Sanford, 1901; Thiery, 1896; Tichý, 1912; Weintraub & Krantz, 1971). However, when the two horizontal parallels are omitted and the space filled with a series of short vertical lines, a negative illusion is observed (Blix, 1902, Jastrow, 1891-92; Sanford, 1901; Thiery, 1986). Thiery (1896) observed that when the figure was rotated so that the obliques were either horizontal or vertical the illusion disappeared. Judd (1899) also noted that the illusion was eliminated under these conditions. Other investigators, however, have found that rotating the obliques substantially reduces but does not eliminate the illusion. Pierce (1901) was the first to note this and since then numerous studies have confirmed his conclusion (e.g., Anton, 1976; Green & Hoyle, 1964; Houck & Mefferd, 1973; Leibowitz & Toffey, 1966; Obonai, 1931, cited by Oyama, 1960; Weintraub & Krantz, 1971). Here it should be noted that performance has been found to be superior for a number of perceptual tasks when stimuli are oriented vertically or horizontally as contrasted with oblique orientations (Appelle, 1972).

<u>Length of the obliques</u> Another variable on which the magnitude of illusion has been found to depend is the length of the oblique lines. Long obliques are found to decrease, while short obliques increase, the illusory effects. Helmholtz (1866) was the first person to note this

phenomenon although the first systematic investigation of this variable was undertaken by Burmester (1896). While later studies have supported this conclusion (e.g., Blix, 1902; Hasserodt, 1913; Hotopf & Robertson, 1975; Pierce, 1901; Robinson, 1968; Sanford, 1901; Thiery, 1896) a recent study by Wilson and Pressey (1976) reported an inverted U shaped function. While often cited as critical, most of the above mentioned studies only causally observed the effect, using two or three widely differing values and noting that in one instance (long obliques) the magnitude of illusion was depressed relative to the other (short obliques). Systematic studies have yet to be done.

Poggendorff variants A large and often conflicting literature exists concerned with variations of the classical Poggendorff figure. The first mention of modifications to the illusion figure were those by Kundt in 1863 (cited by Blix, 1902) and Delboeuf in 1865 (cited by von Kries, 1910). However, it was not until around the turn of the century that anything specific was done. In his study of geometrical illusions, Judd (1899) stated that the Poggendorff has many variants and that the illusory effect decreased whenever any line segments of the classical figure were removed. Pierce (1901) referred to variants as "mutilated" Poggendorffs and questioned their relevance. He stated that "we have wholly deserted the Poggendorff figure when we come to any such dissevered remnants of it, and consequently the alleged evidence (of variants) is hardly to the point" (p. 257). Sanford (1901), as well, expressed reservations concerning the use of variants. More recently, Walker (1973) has stated that such manipulations may "render the figure distinct from the Poggendorff figure" (p. 475).

Blix (1902), however, gave a different dimension to this work. In his lengthly paper Blix mentions that several investigators have recommended that the Poggendorff illusion be "reduced" into its various parts in order to analyze the causes of the effect and to assess their relative significance. While often recommended, Blix was the first to systematically take this approach and in his paper he presents and discusses several of the variants that have been the subject of recent experimental analysis and controversy. Further, Ladd and Woodworth (1911), in anticipation of much recent work, stated that "various degrees of (the Poggendorff) illusion are produced by dissecting the figure and presenting its parts separately" (p. 440). Figure 4 illustrates five major variants, each of which is now discussed in turn: obtuse angle, acute angle, oblique only, perspective, and cognitive contour.

Several investigators have modified the classical Poggendorff figure such that the obtuse angles are the only angles present (Figure 4A). Under these conditions a significant positive illusory effect has been observed (Day, 1973b; Green & Hoyle, 1964; Houck & Mefferd, 1973; Imai,

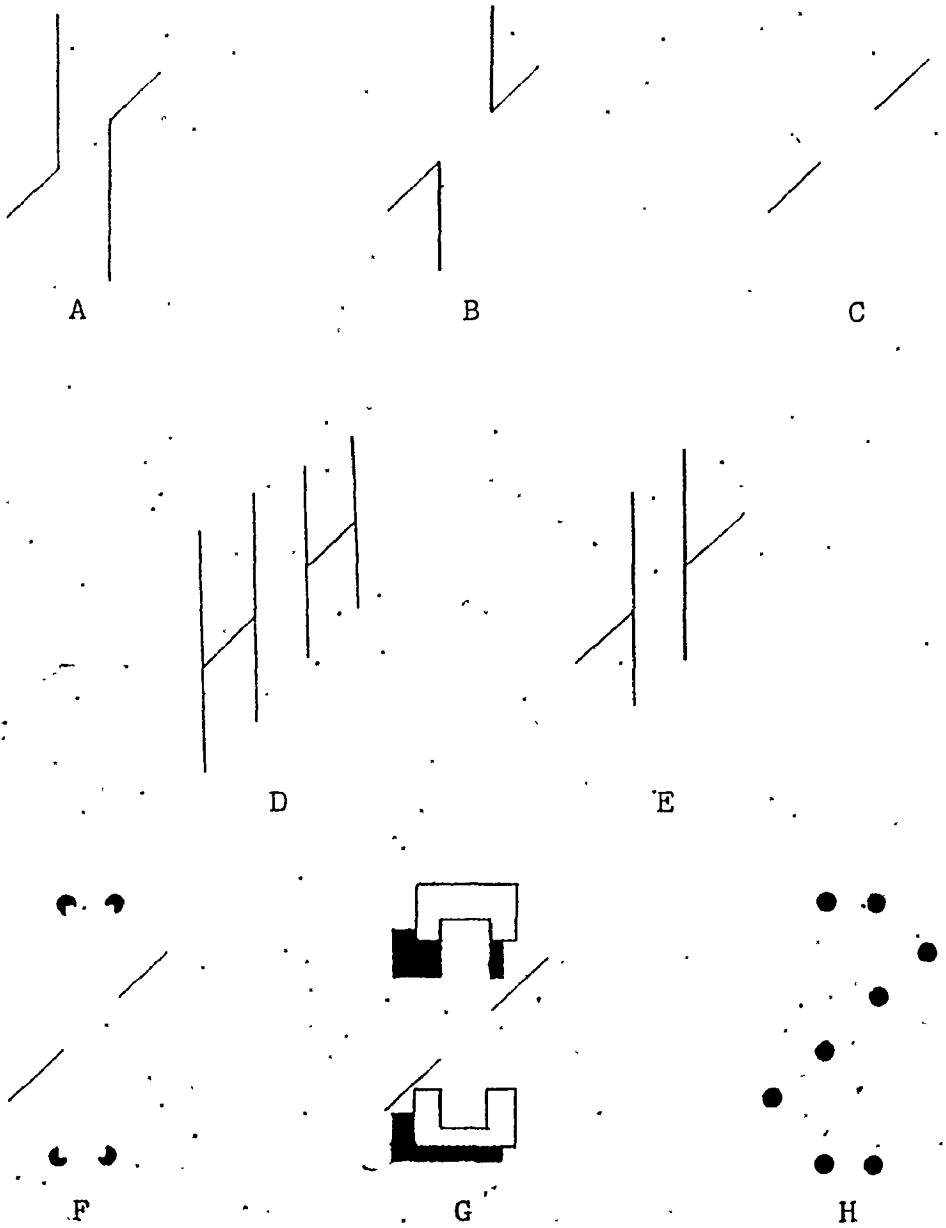


Figure 4. Variants of the classical Poggendorff Illusion. (A) Obtuse angle figure, (B) Acute angle figure, (C) Oblique only figure, (D) Vanishing point figure, (E) Plane figure, (F) Sectored disk figure, (G) Virtual contour figure, (H) Dot figure.

1973, cited by Day, 1973b; Krantz & Weintraub, 1973; Restle, 1969; Weintraub & Krantz, 1971). In addition, the magnitude of this effect is essentially the same as that of the classical figure. Other investigators have merely mentioned that a positive illusion will occur (e.g., Gillam, 1971; Pressey & den Heyer, 1968) or offer indirect evidence, for example, Jastrow (1891-92) remarked on the "quite marked" displacement which occurred when line segments forming obtuse angles are present. Still others state that a larger illusory effect is obtained than with the classical figure (e.g., Blix, 1902; Judd, 1899). Further, in an experiment varying reflectance contrast, Weintraub and Krantz (1971) found that as the line segment forming the obtuse angle was faded out the illusion reduced to zero. These data have led some investigators to conclude that the most critical feature of the Poggendorff figure is that portion forming the obtuse angle.

Where the obtuse angle variant showed agreement among investigators, research on the acute angle variant (Figure 4B) has produced discrepant results. Restle (1969) found that the acute angle figure showed the same amount of displacement as the classical and obtuse angle figures, but in the opposite direction, that is the acute angle figure gave a reversed or negative illusion. Restle's findings are supported by both earlier and more recent observations (e.g., Blix, 1902; Green & Hoyle, 1964; Houck & Mefferd, 1973;

Pierce, 1901). Other investigators, however, report only the absence of an illusion not a reversal (Judd, 1899; Krantz & Weintraub, 1973; Weintraub & Krantz, 1971). Furthermore, a reduced but nevertheless significant positive illusion has been found by Day (1973b), Imai (1973, cited by Day, 1973b), and Pressey and Sweeney (1972a).

The effect of angle of interception has also been investigated, although not systematically, in both the obtuse angle and acute angle figures. Here again the results are inconclusive. Day (1973b) found a larger illusion at 45° than at 30° for both figures, the opposite of the effect usually obtained for the classical figure. However, Day kept the collinear distance constant (i.e., the distance between the inner ends of the obliques) and thus varied the separation between the parallels, being 3cm for the 45° angle and 1.4 cm for the 30° angle. In addition, Ogasawara (1956, cited by Oyama, 1960) using a form of the acute angle figure consisting of an acute angle and an aligned dot, reported that the illusion varied as a function of angle, reaching a maximum at 25°-30° and decreasing to zero at 90°.

An oblique only Poggendorff figure (Figure 4C) reflects much the same pattern of findings as does the acute angled figure, with discrepancies existing not only between various investigators but also within a single laboratory. A slight positive displacement between two 45° oblique lines was recently reported by Goldstein and Weintraub (1972) as well as a negative illusion for two obliques at 30°. In an earlier paper Weintraub and Krantz (1971) obtained a substanial negative illusion for two obliques at an angle of 31° and a small, but positive, illusion with a 16.7° oblique figure. Earlier, Burmester (1896) observed that when the parallel lines were removed apparent displacement existed only for small angles, but in the opposite direction. Perceptual continuity or insignificant deviation has been found by others (e.g., Blix, 1902; Green & Hoyle, 1964; Houck & Mefferd, 1973; Jastrow, 1891-92; Restle, 1969). Jastrow stating that "when viewing two lines separated by a space, we are able to connect the two mentally and determine whether they are or are not continuations of one another" (p. 382). Finally, a positive, although small illusion compared to that associated with the classical figure has been reported by several investigators (e.g., Curthoys, Wenderoth, & Harris, 1975; Day, 1973a,b; Kobayashi, 1956; Pressey & Dewar, 1968; Pressey & Sweeney, 1969, 1972a; Thiery, 1896; Wundt, 1874, cited by Blix, 1902). In addition, both Day (1973a) and Pressey and Sweeney (1969) have noted that, in comparison with the classical figure, the effect obtained with an oblique only figure is consistent (positive) and that the two figures are significantly correlated in terms of misalignments.

Day (1973a), in fact, systematically varied the angle of the obliques from 0° to 90° in 15° steps. The relationship obtained, however, was different from the inverse function found for the classical figure, in this instance it was asymmetrical about 45°. It should be noted, however, that Day kept the collinear distance constant and therefore the separation varied across the various angles. Earlier Kobayashi (1956) had subjects extend an oblique line to the point where it would intercept a horizontal line. He found that the judgments were effected by the angle of the oblique and the distance to the horizontal line. Some investigators, however, regard the oblique line illusion with skepticism. Sanford (1901) stating that: "It may be doubted whether the illusion in this case really belongs to the Poggendorff type" (pp. 228-229). Sanford found large individual differences with this figure, some subjects showing a slight negative and others a slight positive effect. More recently Goldstein and Weintraub (1972) concluded that the "paralleless Poggendorff ... (is) a Poggendorff of a different stripe" (p. 353).

While perspective perception has often been causally implicated in the Poggendorff illusion, few experiments have actually attempted a direct test. Although Green and Hoyle (1964) presented a figure resembling a vanishing point figure (Figure 4D) and found a significant positive illusion, it was Gillam (1971) who first studied this systematically. Gillam found that when perspective cues were added, such as in the vanishing point figure, where all the lines go to a common vanishing point, the illusory effects were reduced by "roughly half". In an extension of this work Young (1976) found that when the background was ambiguous as to whether or not the figure was in a two-dimensional setting, that is when it was an illuminated pattern in a dark room, a reduction of 50% occurred; however, when the background was not ambiguous, that is when the pattern was drawn on paper, a reduction of only 30% was found. A new perspective variant was also generated by Young, one in which the parallels receded in the same plane as the obliques (Figure 4E). A similar reduction to that obtained for the vanishing point figure was found here as well. In addition, Young manipulated the angle of interception and the separation between the parallels in these two perspective variants and found that they responded in a fashion similar to the classical figure, but less vigorously. That is, as the angle of interception increased, the magnitude of illusion decreased and as the separation of the parallels increased, the magnitude of illusion increased.

The Poggendorff effect can also be generated by cognitive contours and regions. For example, Gregory (1972) found that a Poggendorff figure in which the parallels were omitted and generated by four sectored disks (Figure 4F) produced significant displacement. Similar effects were obtained by Farne (1970) and Goldstein and Weintraub (1972) using a "virtual contour" figure (Figure 4G). In addition, Goldstein and Weintraub found that the illusory magnitude in such a figure increased when the angle of inclination increased from 45° to 51°, the reverse of the classical figure. Finally, Coren (1970) found that a dot figure (Figure 4H) containing no lines also produced a significant positive effect.

TASK VARIABLES

A number of studies have investigated the effect on the magnitude of the Poggendorff illusion of the conditions of presentation. Specifically, data are available on the effects of repeated observations or practice, of fixation verses free viewing, of sensory modality, and of stereoscopic presentation.

Practice The Poggendorff illusion has been found to diminish (or even disappear) with practice or prolonged visual inspection (Cameron & Steele, 1905; Coren & Girgus, 1972; Pressey & Sweeney, 1969). In the course of such an experiment the subject typically responds to repeated presentations of the figure with a very marked decrease in illusion. Cameron and Steele (1905) were the first to systematically study the effects of repeated trials on the magnitude of the illusion. Practice sessions occurred at approximately the same time every morning and evening for over a month with 50 trials per session. They found that the illusion gradually disappeared over the course of 3,200 trials. The decrement obtained was fairly uniform with some negative illusions occurring after the 1900th trial. The effects of practice were found to transfer, to a large extent, to other forms of the illusion as well. The effect also seemed to be relatively permanent in that one subject tested again after a year was found to have an illusion only one-fifth of his initial size. In addition, eye movements were photographically recorded before and after practice. Before practice the eyes exhibited pauses, deflections, and re-adjustments at the intersections with the parallels. After practice these pauses, deflections, and re-adjustments were absent.

A decrement of the illusion over successive trials has also been found for the oblique only variant by Pressey and Sweeney (1969). A few studies, however, have failed to demonstrate a decrement with practice. Pressey, Bayer, and Kelm (1969), for example, found an inverted U shaped curve for a sample of nurses and schizophrenics. Furthermore, children do not seem to be responsive to the effect of repeated trials (Mallenby, 1974; Pressey & Sweeney, 1970).

<u>Fixation</u> The effects of fixation are inconclusive. Central fixation has been found: not to affect the magnitude of the illusory effects (Helmholtz, 1866; Tichý, 1912); to decrease significantly but not abolish the illusory effects (Cameron & Steele, 1905; Houck & Mefferd, 1973; Judd, 1899;

Novak, 1966); and to completely abolish the illusory effects (Carr, 1935; Dresslar, 1893-95; Velinsky, 1925). Off-center fixation, on the other hand, is reported to enhance the illusory effect (Houck & Mefferd, 1973). In addition, according to Zajoc (1951) when different points on the figure are fixated some interesting things are said to occur. For example, fixating on a point below the right-hand oblique (obliques going left to right upwards), causes the obliques to appear inclined toward each other with their outer ends lowered. Fixating on a point above the left-hand oblique causes the obliques to appear inclined toward each other with their outer ends raised. When fixation is shifted from one point to the other, continuous movement of the inner or outer portions of the obliques is observed. Furthermore, the illusion has been found to persist undiminished when viewed as a negative afterimage (Blix, 1902; Helmholtz, 1866). More recently, Evans and Marsden (1966) used the flash method of stabilization to impress an image on the retina as an afterimage and found that the illusion persisted under these stablized retinal image conditions.

<u>Sensory modality</u> The Poggendorff illusion has, for the most part, been presented visually with few attempts to find out whether comparable effects occur in other sensory modalities. There is, however, some evidence which suggests that the Poggendorff illusion can be obtained when the pattern is presented haptically. The first investigation of

a haptic Poggendorff was conducted by Robertson (1902). Robertson found that the illusion was present but opposite in direction, that is a negative illusion was observed. Moreover, the illusory effect was greater than that found visually. In an oblique only version the illusion was found to be substantially reduced but positive. Further, placing the parallels in a horizontal position weakened but did not reverse the illusion. Robertson cited the amount of pressure exerted and the rapidity of movement as factors influencing the amount of displacement. Anecdotal evidence for the existence of a tactual Poggendorff in both blind and blindfolded subjects was presented by Beam (1938). These observations were corroborated and extended by Pasnak and Ahr (1970). Both blind and blindfolded subjects were found to show a small "tactual" Poggendorff illusion that was equivalent in amount. These data were taken to indicate that experience in a sensory modality and receptor sensitivity are not crucial. Further, working on the assumption that spatial information is analyzed according to the operation of a single, centrally organized, mechanism, Fisher (1966) considered the question of the occurrence of geometrical illusions in other modalities. His results showed that the Poggendorff illusion was apparent in both the visual and in the "tactile-kinaesthetic" conditions; also, there was no significant difference in illusion magnitude between the two conditions.

Stereoscopic presentation A number of investigators have presented the classical Poggendorff figure under stereoscopic conditions, presenting part of the figure to each eye such that no two spatially adjacent contours appear on the same retina. Ohwaki (1960) observed that both the frequency of occurrence and magnitude of illusion were less when the figure was presented stereoscopically. However, because there was a statistically significant reduction, he concluded that the illusion was destroyed. Similarly, Springbett (1961) reported the complete absence of illusion. Day (1961), however, questioned the interpretation and conclusions of both Ohwaki and Springbett. For example, Springbett's results could have arisen from the rivalry difficulties encountered and the absence of a normally viewed comparison figure. Consequently, Day repeated and extended Ohwaki's study. Day noted that the illusion persisted, although it was substantially reduced in magnitude. Rivalry difficulties were also reported by Day so Schiller and Weiner (1962) proposed another technique. They presented the illusion in a stereoscopic tachistoscope. With stereoscopic short exposure only a slight reduction was observed. However, a marked reduction in effect was observed with both stereoscopic successive and stereoscopic long exposure, with stereoscopic long exposure showing the greatest reduction. This problem was taken up further in a study by A.H. Gregory (1968) who found that in a 45° Poggendorff figure the illusion disappeared for mos' observers, while in a 30° figure the illusion maintained itself for most observers. In the main these studies have been in broad general agreement. The illusion is present, although greatly reduced in magnitude. In addition, Julesz (1971), using random dot stereograms, has demonstrated the existence of a cyclopean counterpart to the Poggendorff illusion which he states is quantitatively and qualititively the same.

SUBJECT VARIABLES

There has been relatively little experimental interest in the effects of characteristics of the subject on the magnitude of the Poggendorff illusion. Only age and intelligence have been directly and systematically studied.

Age Age has been found to have a marked effect on the magnitude of the Poggendorff illusion. In fact, the relationship of illusions to age appears to be of great interest (Wohlwill, 1960). Several investigators have even classified illusions into those which decrease and those which increase with age. In general, the Poggendorff illusion has been found to be greater in normal children than in adults, showing a systematic decrease as age increases (Hasserodt, 1913; Leibowitz & Gwozdecki, 1967; Letourneau, 1972; Pressey & Sweeney, 1970; Vurpillot, 1957). However, the limits of this decrement are unclear. For example, Leibowitz and Gwozdecki (1967) report a decrease in illusory magnitude from age 5 to 10, and to remain stable there after; Vurpillot (1957), on the other hand, found that the illusion increased from age 5 to 7 and then diminished. In addition, Pressey and Sweeney (1970) found the illusion to decrease through ages 8 to 15. This trend is quite pronounced; Leibowitz and Gwozdecki (1967) observed that the illusion after age 10 was half that found at age 5. This decrease with age has also been reproduced by hypnotic age regression techniques, although the effects are less robust (Parrish, Lundy, & Leibowitz, 1968). The validity of this technique for investigating developmental aspects of perception has, however, recently been questioned by Perry and Chisholm (1973) who failed completely to replicate any of Parrish et al's results. The meaningfulness of the figure was also manipulated by Vurpillot (1957) by suggesting a concrete scene while leaving the basic structure unaltered. When meaning was given to the figure varying degrees of displacement were observed. The illusory effects were smaller for adults and for children over 9 years, the opposite was found for children 5 years old, and no difference was observed for the 7 year olds. Further, girls were found to react more to meaning than boys. As noted earlier, Pressey and Sweeney (1970) also studied the effects of repeated trials in children and no decrement was found. Bayer (1972) has suggested that the developmental theory of Wapner and Werner provides an adequate perceptual model for an explanation of the differential effects of practice in children and in adults as well as the decrement in illusion over age. The discussion is in terms of information processing. Children are seen as perceiving more globally (or inarticulately) and this "globality implies rigid perceptual activity" (p.85).

Intelligence The effects of intelligence or intellectual factors on the Poggendorff illusion has also been investigated. Here the results are conflicting. Leibowitz and Gwozdecki (1967) tested a group of 57 institutionalized mental defectives and found that the magnitude of illusion was significantly higher than for normals of the same chronological age. Pressey (1965) confirmed this finding. Also, the illusion was found to decrease systematically, but nonsignificantly, as a function of mental age. Spitz, Goettler, and Dively (1970), on the other hand, failed to find any difference in illusion between adolescent retardates, fourth graders, and high school sophomores. As well, Hill (1971) found that both retardates and normals of the same chronological age had the same illusion. Further, there were no significant correlations with IQ. Recently, however, Letourneau (1972) found significant differences between retardates and adults and between retardates and normal adolescents of the same chronological age, the retardates showing a higher illusion. No differences were observed between the adults and normal adolescents.

MISCELLANEOUS STUDIES

A number of other results concerning the Poggendorff illusion, as well as many variables of incidental importance, have not been mentioned. In the interest of historical completeness some of these findings will be briefly considered.

Hasserodt (1913) noted that the illusion varied in size with the direction of the adjustment. Of interest in relation to this is the recent finding that inverting the display, from left to right upwards to left to right downwards, increased the magnitude of displacement (Tong & Weintraub, 1974; Weintraub & Virsu, 1971). Evidence that the illusion decreased with slow and considered judgments relative to rapid judgments was provided by Houck and Mefferd (1973). They argued that slow judgments function in much the same way as does central fixation. In a study on illusion susceptibility Tinker (1938) showed that the misalignment observed in the Poggendorff was specific and provided no indication of performance on other illusions, thus a common factor does not exist between the Poggendorff and other illusions. Learning or experience seems to be implicated in that, for example, upon recovery from early blindness Gregory (1974) observed that when tested with a Poggendorff figure, subject S.B. reported that the obliques were "all one line" (p.94). Also, evidence has been presented which suggests that the Poggendorff illusion is present in children and adults in other cultures, although problems with its determination were observed (Segall, Campbell, & Herskovits, 1966). In a study of individual differences Pressey and Koffman (1968) showed that susceptibility to figural aftereffects was inversely related to susceptibility to the Poggendorff illusion. Earlier Pressey (1967) found evidence that the Poggendorff illusion provides a measure of field dependence. In this study performance on the Rod-and-Frame Test and Embedded Figure Test were found to correlate significantly with performance on the Poggendorff illusion for men, while for women a significant relationship was found only between the Poggendorff and the Embedded Figure Test. Another population considered are schizophrenics, where the illusion obtained was found to be greater than that of normals (Pressey, Bayer, & Kelm, 1968). Further, Letourneau and Lavoie (1973) compared paranoid and simple schizophrenic inpatients on the Poggendorff illusion and found a smaller illusion among paranoids. Finally, both verbalization (Mallenby, 1974) and visual acuity (Anton, 1976) have been implicated in contributing to the Poggendorff effect. In the case of the former, Mallenby found that a group of subjects allowed to discuss their joint response to a Poggendorff figure showed significantly less displacement than groups not allowed this opportunity. As for the latter variable, Anton argues that data from parametric manipulation of the orientation of the obliques and parallels suggests that the visual acuity of the observer is important.

THEORY

The Poggendorff pattern is simple to construct and the illusion of misalignment that it generates is large and apparently universal. Despite these two facts, it has so far defied a generally accepted theoretical explanation. This has not been because of a lack of theoretical interest but rather because all of the ideas so far advanced fall short of encompassing some major features of the phenomenon. What follows is a critical examination of the major theoretical ideas that have been advanced, concluding with an attempt to summarize the current empirical and theoretical status that gave rise to the questions addressed in the experimental section of this thesis.

Gregory (1973) makes a useful distinction between two basic ways in which illusions may be generated that also provides categories into which the main theories may be placed. According to Gregory illusions may be generated by either errors due to the malfunction of mechanisms (physiological), or errors due to the inappropriateness of strategies (cognitive). Gregory argues that many illusions are caused by mechanical malfunction or disturbances of neural mechanisms. Illusions in this category may be due to either mechanism adaptation, mechanism inadequacy, or mechanism inappriateness. Examples include aftereffects, the autokinetic effect, and the phi phenomenon, respectively. Other illusions, however, may result even though the mechanisms are functioning perfectly. These are errors of strategy. The main idea here is that errors are generated by the misuse of data. An example of a purely cognitive illusion would be the size-weight illusion, where apparent weight changes as a function of the "assumed" mass of the object.

One way in which we can differentiate between these two types of illusions is by determining whether or not the illusion in question depends upon assumptions which can be either of the state of the organism or of the world. If assumptions are involved then it is a cognitive error; if they are not, it is an error of physiological mechanism. While this distinction holds for most illusory phenomena, Gregory points out that it is difficult to establish whether the errors observed in the classical distortion illusions (of which the Poggendorff is one) are due to mechanism or strategy. The theories are of a different kind, yet many of the predictions are the same.

This distinction between physiological mechanism and cognitive strategy is a useful one and will be maintained in the discussion which follows. For example, many theorists have stressed physiological factors at the retinal level (e.g., Chiang, 1968; Ganz, 1966; Robinson, 1968) or at the cortical level (e.g., Carpenter & Blakemore, 1973). Others, alternatively, have attributed the illusion to cognitive processing, stressing a variety of components such as processes occurring between the parallels (e.g., Pressey, 1971), or unconscious depth processing (e.g., Gillam, 1971).

Before describing various theoretical accounts, however, a slight digression from considerations of theory to a review of studies concerned with acute angle enlargement is in order. Many of the theoretical statements on the Poggendorff illusion refer either directly to, or imply, angular enlargement.

Angle processing An explanation of the Poggendorff illusion in terms of the overestimation of acute angles has been proposed by many (e.g., Blakemore, Carpenter, & Georgeson, 1970; Brentano, 1892, cited by Blix, 1902; Burmester, 1896; Burns & Pritchard, 1971; Carpenter & Blakemore, 1973; Delboeuf, 1865, cited by Blix, 1902; Eriksson, 1970; Ganz, 1966; Helmholtz, 1866; Hering, 1861, cited by Robinson, 1972; Hotopf & Ollerearnshaw, 1972a,b; Hotopf & Robertson, 1975; Kohler & Wallach, 1944; Kundt, 1863, cited by Blix, 1902; Robinson, 1968; Sanford, 1901; Tausch, 1954; Thiery, 1896; Titchener, 1901; Wundt, 1898). Next to Zollner's explanation in terms of astigmatism, it is the oldest with Hering (1861, cited by Robinson, 1972) as its original proponent. Indeed, as noted earlier, the magnitude of illusion varies systematically with changes in the angle of interception. It will be noted however, that little direct evidence has been produced for the view of acute angle overestimation (and obtuse angle underestimation) aside from illusions themselves. In fact, Pratt (1926) states that the assumption of acute angle overestimation was "made in order to provide an explanation for (geometrical optical illusions)" (p. 132). Recently, however, acute angle enlargement has been established independently of illusions by both psychophysical and neurophysiological means. For example, judgments of line extension (Bouma & Andrissen, 1968, 1970; Weintraub & Virsu, 1971), subjective naming (Fisher, 1969), and a matching technique (Carpenter & Blakemore, 1973) have all provided evidence supporting the view that acute angles are overestimated and that the overestimation can be measured directly. As well, evidence from single cell studies in cats shows that acute angles undergo neurological distortion in a manner consistent with their being overestimated (Burns & Pritchard, 1971).

Once the principle of acute angle overestimation is accepted, its application to the Poggendorff illusion is straightforward. The obliques are simply rotated about their points of interception by an amount expressing perceptual enlargement and apparent non-collinearity necessarily results (see Figure 5). However, despite the volume of study, there is considerable disagreement about the relationship between angle size and perceptual error. Hering (1861, cited by Pratt, 1926) states that 60° is the dividing line between over- and underestimation, while most others have

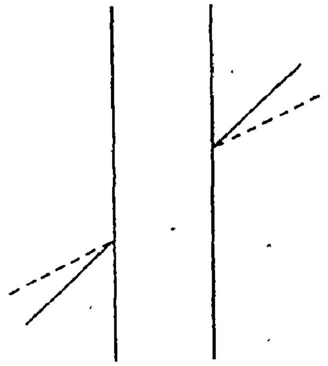


Figure 5. Rotation of the obliques about their points of interception.

taken 90°. Helmholtz (1866) and Wundt (1898) merely remark that acute angles are perceptually enlarged. Fisher (1969) assessed maximal acute angle enlargement at 45°, while Piaget (1969) found maximal overestimation between 50° and 60°. In a more direct attempt Blakemore, Carpenter, and Georgeson (1970) found a maximal enlargement of 2° for a 15° angle. Further, various other investigators have assessed angular enlargement as well and have noted an expansion too small to account for the Poggendorff illusion. For example, Hotopf and Ollerearnshaw (1972a) found an enlargement of only 0.5° for a 30° angle.

Challenges to the notion that acute angles tend to be overestimated have also appeared. Pierce (1901) accepted the involvement of acute angles but in the opposite direction, that is acute angles are underestimated. Earlier Jastrow (1891-92) asserted that all angles are underestimated with obtuse more than acute. More recently Beery (1968) arrived at the same conclusion. Further, Blix (1902) felt that some of his work gave an endorsement to Jastrow's law when he observed a negative illusion with an acute angle figure. Underestimation of acute angles was also demonstrated by Weintraub and Virsu (1971), while Pratt (1926) found that "both acute angles and obtuse angles were as apt to be overestimated as they were to be underestimated" (p. 140). In an early attempt to disclaim angular distortion, Ladd and Woodworth (1911) stated that it is "doubtful whether the overestimation of acute angles is, in reality, a universal principle which can be fully invoked for the explanation (of geometrical illusions)" (p. 445). Another early criticism against angle interpretations in general and their application to the Poggendorff in particular was that by Judd (1899). As evidence against the involvement of angles Judd cited the disappearance of the illusion with only acute angles and the occurrence of an obtuse angle effect. Further, he noted that it was difficult to reconcile the disappearance of the illusion when the obliques are vertical or horizontal with a theory that says the illusion is due to the incorrect estimation of angles.

At the descriptive level angular distortion as it relates to the Poggendorff illusion has received wide circulation and acceptance. However, the problem of why (and how) angular distortion occurs has often been neglected and is the subject of considerable disagreement. Various reasons as to why subjects should show this angular expansion or regression to right angles tendency (the tendency for the angle to appear nearer to right angles), have been put forward. For example, Wundt (1898) explained it in terms of eye movements; Helmholtz (1866) emphasized physiological irradiation; Thiery (1896), Sanford (1901), and Tausch (1954) suggested an explanation in terms of perspective. Recently developments in neurophysiology have been the main source of new ideas concerning the effect.

PHYSIOLOGICAL MECHANISMS

Physiological explanations emphasize structural characteristics of the visual and nervous systems. Structural mechanisms which have been proposed include eye movements, retinal interactions, cortical interactions, and processes occurring in the visual system.

Eye movements Many studies have been conducted on the movement of the eyes in viewing the Poggendorff figure. Photographs, in fact, have shown that observers actively view the figure, exploring it in detail with deflections and hesitations occurring at the junction of the oblique lines. The notion of the involvement of eye movements in the production of the Poggendorff illusion has been one of recurring interest. Typical of early explanations based on eye movements was the one proposed by Richmond (1881, cited by Pierce, 1901). Richmond argued that movements along the obliques are more complex then are those along vertical or horizontal lines. Thus when the eye moves, or attempts to move, along an oblique line it's true course is disrupted by the space between the parallel lines. One problem with this account, however, was that there was no provision for a particular direction of distortion. Newer versions which have appealed to the peculiarities of eye movements evidenced in the Poggendorff have done much better.

Dresslar (1893-95) offered a novel eye movement explanation based upon the Poggendorff's slight resemblance to a tactual illusion. In the tacual illusion Dresslar noted the apparent shifting of the lower half of one of the obliques when the finger tip was run across one of two perforated crossing oblique lines. He then proceeded to derive a visual analog in which the eyes were similarly duped. The supposed analogy is indeed remote and, consequently, this interpretation is of little more than historical interest.

The theoretical position of Wundt (1898) was based on eye movements. Wundt accepted the principle of acute angle overestimation and attributed it to eye movements. He argued that during movements of short duration (i.e., passing over an angle) more energy is consumed than by movements of longer duration. Just how this energy is translated into spatial terms was not indicated, however.

Carr (1935), in his formulation, described the situation as follows:

> the eyes react to the presence of the accessory lines in observing the parts to be compared,

> and our judgments are distorted by these deviations of movement ... In passing over the arms of the Poggendorff figure, the movement of the eyes is deflected in direction when they approach the intercepting parallel line. (P. 399)

Although advocating eye movements Carr did not subscribe exclusively to a theory based on them, but rather saw them as a contributing factor acting in concert with other causal factors. He stressed the correlational nature of the relationship between eye movements and the displacement observed and added that "further data are required for a final decision" (p. 402). Others who stressed the involvement of eye movements as a contributing factor include: Cameron and Steele (1905), Hotopf, Ollerearnshaw, and Brown (1974), Novak (1966), Tüchý (1912), and Velinsky (1925). However, while eye movements might be a contributing factor they are not required because, as noted earlier, brief exposure, fixation, presentation as a stablized image or as an afterimage produce the same illusory effect. Additional comments on the importance of eye movements include Helmholtz's (1866) statement that "movements of the eye has no distinct influence on heightening the illusion. On the contrary, the illusion disappears, provided my eye moves along the (obliques)" (p. 196). Similarly, Blix (1902) contended that eye movements are important only in so far as continued back and forth skimming along the obliques diminished or even abolished the illusion.

Retinal interactions. An early attempt at a general explanatory principle that would apply to all illusions was put forward by Eithoven (1898). Eithoven suggested that blurring of the retinal image was the basic mechanism for illusion formation. His explanation emphasized physiological image dispersion resulting from the rapid decline of visual acuity from the center of the retina to the periphery. Thus for the cause of the apparent displacement from collinearity in the Poggendorff illusion we have physiological irradiation. In an early critique of this position Pierce (1901) stated that it was a "relatively unimportant attempt" (p. 257) and left the matter there.

This account, however, has found favor with Chiang (1968) who gives it its principal modern statement. Chiang, by the way, fails to mention the work of Einthoven. To account for the phenomenon of acute angle enlargement Chiang proposed the peripheral interaction mechanism of optical blurring. The arguments are made in relation to the Poggendorff illusion and the Poggendorff is then used to explain all geometrical illusions produced by crossing lines. Chiang argues that as light passes through the pupil and the crystalline lens it becomes blurred, in the first instance by diffraction and secondarily by spherical and chromatic aberrations. The consequence of this blurring is that the retinal image of an object does not quite correspond to physical reality. In the case of acute angles this means that there may be alterations in the pattern of stimulation.

When two objects are close enough the two images of the object overlap to form one image, which is located somewhere between the original two images. Thus perceptually the lines converge before they reach the intersection point, the locus of the contour corresponding to the peak of the blurred distribution. The obliques in the Poggendorff figure, therefore, seem to be misaligned. The important factors here are the angle of interception and the number of crossing points per unit length. While optical blurring can predict the Poggendorff illusion, it has not been generally accepted and, in fact, has been cogently criticized by a number of investigators.

One evident problem for this account, indeed for any peripheral explanation, is the occurrence of the illusion under stereoscopic presentation. If the Poggendorff is due to retinal interactions then it should not appear when part of the pattern is presented to one eye and the remaining part to the other eye. Another obvious problem is the occurrence of a practice effect. It is not at all obvious how such a physiological mechanism would be affected by repeated presentations. In fact, practice effects have been cited as the main criticism against physiological explanations (Over, 1968).

Cumming (1968) criticized Chiang's diffraction theory on two main counts. First, it did not provide a satisfactory explanation of the displacement and rotation of lines intersecting at acute angles; and second, this distortion, even if diffraction is admitted, is not sufficient to account for the Poggendorff illusion. For example, consider the effects of the orientation of the figure. Why should orienting the obliques vertically or horizontally reduce the illusion? The angle on which diffraction operates is still present. Cumming also noted that angular distortions occur when line segments near their points of intersection are omitted so that no lines approach near to one another.

The most frequently cited evidence against this position, however, is that the Poggendorff illusion still occurs when the figure has been modified. In fact, versions of the Poggendorff figure which do not fit the theory are easy to find. Pressey and den Heyer (1968) presented several figures with which Chiang's theory has difficulty. For example, while Chiang can explain how one acute angle appears perceptually larger, he cannot account for the occurrence of the illusion in a figure produced by crossing the parallels by the obliques to generate two additional acute angles. Further, displacement not rotation, as Chiang would predict, appears in a figure consisting of two oblique parallel lines separating one vertical line placed above and physically in the middle of two parallel vertical lines placed below. In addition, as noted earlier, a smaller illusory effect is observed in an acute angle figure than in an obtuse angle figure. In the obtuse angle figure Chiang would predict a small negative effect, if any, since the contours forming the obtuse angles are farther apart than those forming the acute angles. An even more damaging figure is the oblique only figure. According to Chiang an acute angle must be formed, yet in the case of the oblique only figure there are no closed angles and yet the illusion persists.

While subjected to considerable criticism, support for Chiang's position has appeared. Coren (1969) investigated the influence of optical aberrations as well as the degree of diffraction. He employed an artifical pupil and a chromatic filter to reduce the blurring of retinal images and found that the illusion magnitude was reduced but only by 22%. On the basis of this Coren concluded that the Poggendorff illusion was not predominatly determined by blurring due to optical aberrations in the eye. However, optical aberrations were implicated in the formation of the illusion.

Another retinal mechanism has been proposed by Ganz (1966). Ganz suggests, but does not elaborate, a way in which simple lateral inhibition between point or line analyzers in the retina could result in acute angles being perceptually enlarged and thus bring about the Poggendorff illusion. Ganz proposes a quantitative theory involving the interaction of contours. In this account eye movements are of central importance. Ganz argues that the resulting distribution of neural excitation that occurs when two contours lie on adjacent parts of the retina is such that they mutually interact with one another, with inhibition being stronger closer to the ridges of excitation and gradually diminishing (displacement being greater at a small distance from the contour). Accordingly, the apparent position of a contour is seen as being determined by the position of a peak of excitation. In other words, inhibition acts on the distribution caused by one of the contours. It substracts asymmetrically and so shifts its peak further away from the position of the other contour.

A limited application of Ganz's theory to angular distortions was proposed by Robinson (1968). At the vertex of an acute angle the contours should appear displaced from each other as a result of retinal lateral inhibition. Perceptually this results in the enlargement of acute angles of the sort shown by the dotted line in Figure 6. The fact

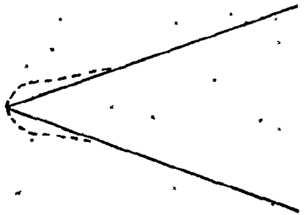


Figure 6. The perceptual enlargement of an acute angle.

that long obliques decrease the illusory effect in the Poggendorff illusion while short obliques enhance it, was seen as evidence supporting the view that the distorting effects come chiefly from the parts of the oblique lines close to the intersection with the parallel lines.

In addition to acute angles being perceptually enlarged by lateral inhibition. Békésy (1967) has also shown that the location of the vertex of an angle is perceptually displaced inwards (Figure 7).

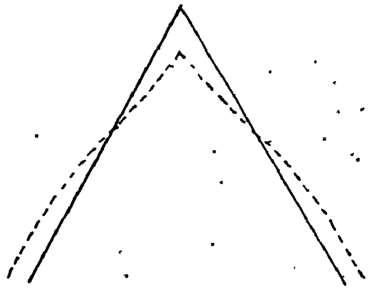


Figure 7. The perceptual enlargement and displacement of an acute angle.

Like Chiang's (1968) explanation in terms of optical blurring, lateral inhibition on the retina has also been subjected to considerable criticism and many of the arguments cited against Chiang are also used against an interpretation in terms of lateral inhibition.

The question of lateral inhibition and visual illusions was examined by Coren (1970). Coren generated a modified form of the Poggendorff illusion by removing the spatially adjacent contours and replacing the end points and intersections with dots (Figure 4H). As noted earlier, the illusion in this figure was still present although greatly reduced in magnitude. The data indicated that lateral inhibitory processes may not be necessary for the existence of the illusion. However, while not primary, lateral inhibition may still contribute to illusion magnitude. Coren concluded that the Poggendorff is "caused by the interaction of several variables, rather than one dominant process" (p. 227).

Several investigators have addressed themselves to the problem of whether illusions are a retinal phenomenon or whether they are generated higher up in the system. These studies, therefore, provide a direct test of retinal interaction interpretations. The usual manner of testing the adequacy of peripheral explanations is to present the illusion under stereoscopic conditions. As noted earlier, a marked reduction in effect is observed under these conditions. The presence of an illusion under these conditions argues against retinal interactions as the causal factor and for a central or cognitive mechanism or strategy. However, it is possible that, for example, lateral inhibitory interactions at a higher level where binocular recombination occurs is responsible for the illusion.

It is interesting to note that in a recent paper on the generation of an illusion taxonomy using factor analysis Coren, Girgus, Erlichman, and Hakstain (1976) found that the Poggendorff illusion loaded high on the first of five factors extracted. This factor was said to be basically directional in nature and they concluded that the Poggendorff illusion, among others, "can easily be explained by such relatively structural mechanisms" (p. 132) as optical blurring or lateral inhibition.

Cortical inhibition In a short report Blakemore, Carpenter, and Georgeson (1970) present psychophysical evidence from measurements of interactions between line segments in human vision for the idea that lateral inhibition takes place between orientation detectors in the visual cortex. They found that the cortical representations of two lines differing in orientation interact so as to seem displaced. These inhibitory interactions are said to cause acute angles to be overestimated and obtuse angles to be underestimated. These findings are reported in full in a paper by Carpenter and Blakemore (1973). Using a matching technique Carpenter and Blakemore directly measured angle expansion. They argue that lateral inhibition between straight-line orientation detectors in the visual cortex results in acute angles being overestimated and obtuse angles being underestimated. Figure 8 shows their explanation for angle expansion. This perceptual distortion was attributed to recurrent inhibitory interactions among orientation selective neural channels. Their psychophysical results were interpretated in terms of the organization of neurons in the visual cortex. The mechanism they propose and their explanation in terms of the "orientation domain" is able to handle several pieces of data that heretofore could not be accommodated by angle theorists. For example,

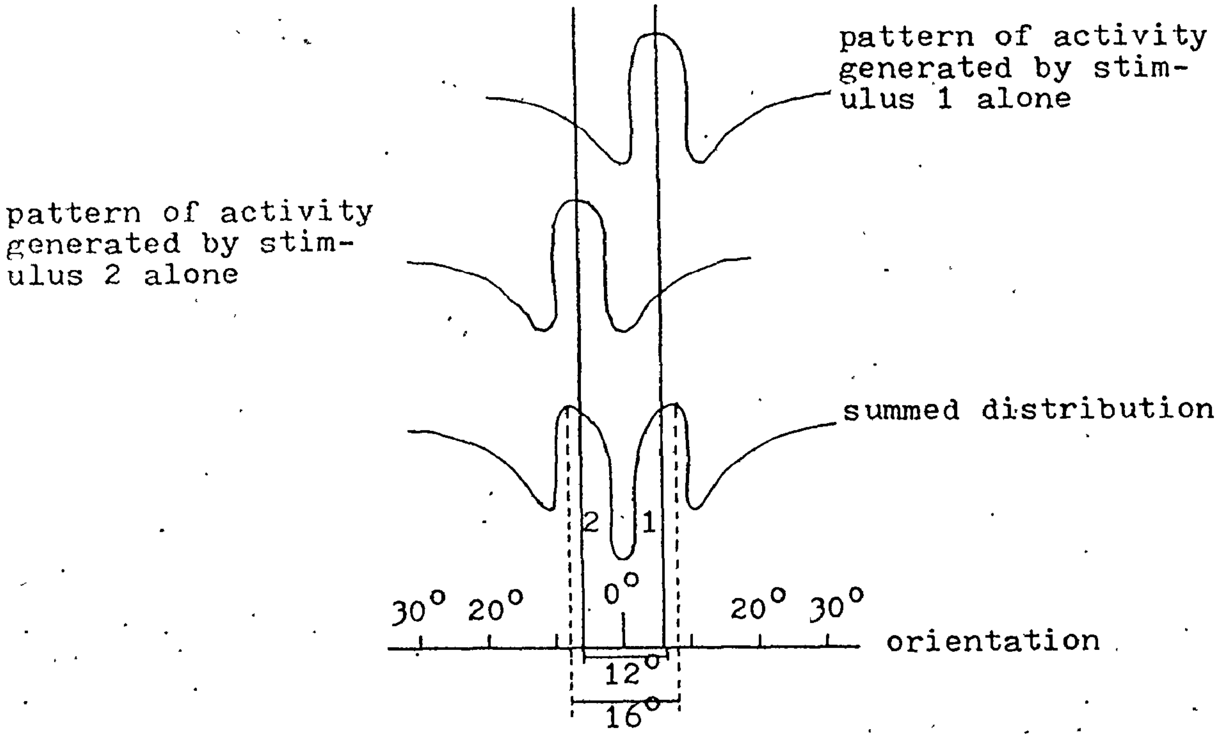


Figure 8. Carpenter and Blakemore's (1973) explanation for angle expnasion.

such an explanation can account for the distortion observed in figures without closed angles. In the "dot" figure, for example, orientation detectors could be adequately stimulated by a pair of dots at the appropriate orientation. Also, the effects of rotating the Poggendorff figure so that the obliques are 90° or 180° presents no problem. Here one can consider the differential tuning of orientation detectors and the fact that considerable evidence exists which shows that sensitivity is greater for vertical and horizontal orientations, resolving powers being worse for oblique orientations. Further, the fact that the illusion is obtained stereoscopically, with the obliques presented to one eye and the parallels to the other, can be easily handled since convergence of inputs from the two retina to single cells at the visual cortex has been found (e.g., Hubel & Wiesel, 1962). To date there has been little reaction to Carpenter and Blakemore's position.

Visual system In a micro-electrode study of neurons in the cat's visual cortex, Burns and Pritchard (1971) deduced that the cortical representation of patterns containing acute angles underwent neurological distortion such that the cortical "excitation image" was displaced. They determined that the cortical image of the vertex of an angle of 30° was displaced inward toward the arms of the angle; further back from the vertex, displacement away from the arms occurred, while no discernible displacement occurred even further back from the vertex (Figure 9). Thus as with Békésy's (1967) proposal both angular enlargement and downward displacement of an acute angle were observed. Burns and Pritchard suggest that the probable cause of this

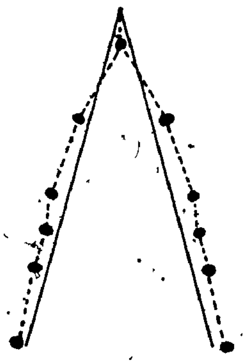


Figure 9. Burns and Pritchard's (1971) deduced cortical image of a 30° angle pattern.

neurological distortion is reciprocal inhibition in the visual system. It is reciprocal because each side simultaneously influences the other one and lateral because it travels between spatially separated regions. Whatever the cause, this neural distortion of sensory information seems adequate to explain this misrepresentation of acute angles and the Poggendorff illusion. However, the possible influence of other factors cannot be precluded, as Burns and Pritchard themselves state.

As with Carpenter and Blakemore's (1973) model, there has been little reaction to Burns and Pritchard's proposal. Pressey and Sweeney (1972a) did, however, criticize Burns and Pritchard's explanation adding that "Burns and Pritchard appear to be unaware of the literature on the Poggendorff illusion" (pp. 169-170). The results obtained by Pressey and Sweeney indicated that the orientation of the test line was perceptually altered by crossing it with an inducing line and that acute angles exert only a small influence. Further, it was contended that acute angles produce a contraction not an enlargement. However, from their paper it is not at all clear just how this addresses the Burns and Pritchard result.

Another recent angular theory based in the visual system is that by Walker (1973). Walker proposes an extensive mathematical theory of illusions. He sees illusions, especially the Poggendorff, as reflecting errors produced by data reduction processes at the retinal level. Walker argues that patterns of neural excitation (data points) map the line element onto the cortical receptive field. Both excitatory and inhibitory impulses are involved. In the generation of spurious data points, however, only spurious excitations are involved. These spurious data points are neural excitations arising from receptive fields that give rise to an enhanced response due to excitation by one image line in the presence of the other. The spurious enhancement of receptive field excitations near the intersection of contours on the retina is assumed to contribute to the cortical determination of the geometry of two-dimensional figures. This enhancement causes a slight shift of the lines, acute angle enlargement, thus producing the illusion. The Poggendorff illusion is, therefore, attributed to both retinal and cortical events. Walker talks about line orientation discrimination and postulates a two-step process for the determination of the orientation of the obliques in the Poggendorff figure. The first step is the establishment of the cortical representation of one oblique. This is accomplished by data reduction which leads to apparent displacement. In the second step, the oblique is projected to the opposite parallel (and to the other oblique). This extraction-synthesis process results in the Poggendorff illusion. This analysis is extended to other illusions and Walker shows that, for example, the Müller-Lyer illusion is but a variation of the Poggendorff illusion. In sum, Walker's is an angle processing theory concerned with the cortical determinants of the figural geometry. Rather than angular distortion Walker talks about directional/orientational distortion. The direction/orientation of intersecting contours is inaccurately computed by the visual system. Walker has also successfully applied this analysis to an interpretation of Gillam's (1971) results on the vanishing point figure. According to Walker, the reduction in illusory magnitude observed is due to the presence of additional data points (the double parallels) which allows for the more accurate determination of the slope of the oblique line. In general, Walker's theory has received little serious consideration. Criticism of his approach has been principally levelled against the lack of support for its physiological premises (MacLeod, Virsu, & Carpenter, 1974).

COGNITIVE STRATEGIES

Most other explanations of the Poggendorff illusion are central or cognitive in emphasis. Cognitive theories emphasize how the visual information is processed. Proposed explanations include: perspective perception and processess occurring between the parallels.

Perspective perception The most popular of the cognitive theories are the various perspective interpretations. Historically these theories have had a substantial intuitive appeal: the basic assumption is that the visual system interprets geometrical illusions as two-dimensional projections of three-dimensional displays. Although perspective processing was considered sufficient to produce illusions, it has only been recently that this notion has been subject to experimental test.

Hering (1861, cited by Pierce, 1901) appears to be the first person to draw attention to the fact that the ends of the obliques do not seem to lie in the same spatial plane as the paper, but rather to pass into the third dimension. This observation is what is appealed to. Theorizing in perspective terms has undergone several stages. Thiery (1896) was one of the first persons to systematically advocate this approach. Initially application to the Poggendorff illusion followed traditional perspective arguments as employed for the other illusions. One consequence of this was that acute angles were inevitably seen as larger than they were, thus this explanation was effectively identical to acute angle overestimation. Filehne's (1898, cited by Pierce, 1901) approach was somewhat different. Here the parallel lines served to separate the obliques such that they appear in different spatial planes. Consider the following figure (Figure 10). Physically the shaft and the handle are continuous but as represented objects their directions are different. It is possible, therefore, that in the Poggendorff illusion the obliques recall some "real

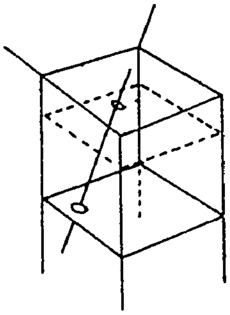


Figure 10. Drawing showing that two detached portions of the same line can represent objects in different planes.

life" scenes in which the objects are discontinous. Filehne finds support for this view in the allegation that the illusion vanishes when the parallels are somehow united or when the obliques can be shown to be portions of a continuous whole. Thus, the illusion should not arise in "real life". For example, in Figure 11 Filehne contends that

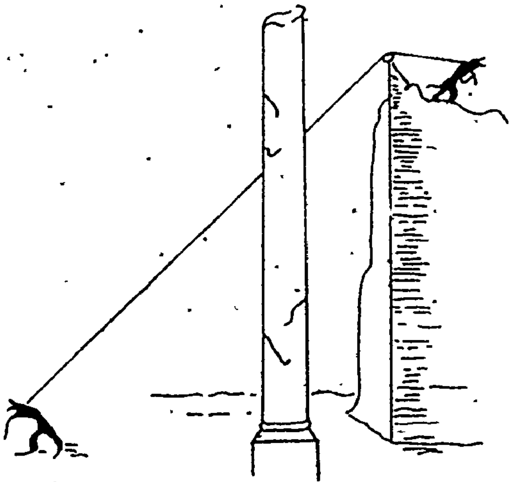


Figure 11. The concrete scene used by Filehne (1898).

while the spatial features are unchanged, the devils at the ends (concrete features) change the connotations of the abstract form such that the illusion disappears immediately. However, as one can see from the figure, and as noted earlier, the illusion persists under such conditions.

Helmholtz (1866) and Mach (1898) were also early advocates of a form of perspective perception. Other statements on the relation of perspective perception to the Poggendorff illusion include Sanford's (1901) assertion that there exists a "tendency to perceive oblique angles as perspective pictures of right angles" (p.217); and Titchener's (1901) contention that "steady fixation of a point on (the parallels) brings out the perspective effect" (p. 317). It has only been within the past 20 years, however, that any substantial developments have occurred along these lines although perspective perception, along with notions of constancy, have been a recurrent notion not only for the Poggendorff but for illusions in general. The assumption is that illusory distortions arise as a consequence of the inappropriate perceptual impression of depth. This assumption manifests itself in the "room geometry" hypothesis of Green and Hoyle (1964), the "carpentered world hypothesis" of Segall, Campbell, and Herskovits (1966), Gregory's (1963, 1966, 1968) "misapplied constancy" theory, and Gillam's (1971) "depth processing" theory. These theories are all fundamentally similiar and are usually treated alike, often ignoring differences in detail and expression. Perspective theories of illusions have generated alot of controversy and criticisms against them are many and varied (Fisher, 1968, 1970; Hotopf, 1966).

While Gregory's (1963, 1966, 1968) "inappropriate constancy scaling" theory is the most global and most publized account, he has not explicitly indicated how this theory might explain the Poggendorff illusion, although it is implied that the Poggendorff illusion is the result of erroreous impressions of depth. Others, however, have attempted to apply his theory to the Poggendorff illusion.

The "room geometry" hypothesis of Green and Hoyle (1963, 1964) was a modified version of the misapplied constancy hypothesis combined with adaptation level theory. Green and Hoyle claimed that the Poggendorff figure resembled the "typical" projections of a three-dimensional room (Figure 12). They see the effect as being due to an attempt

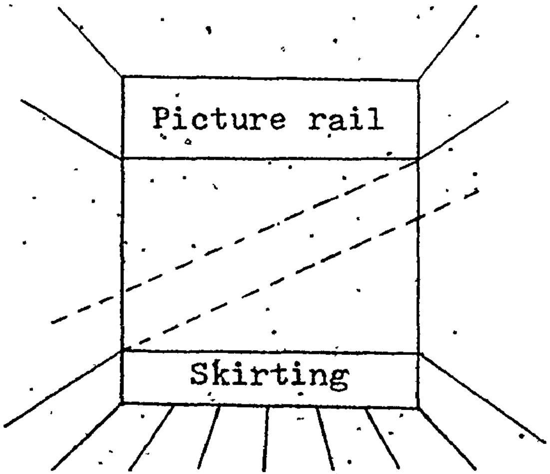


Figure 12. Green and Hoyle's (1964) "room geometry" hypothesis.

by the subject to make a three-dimensional interpretation of a two-dimensional display. The reductions which are evidenced when you rotate or amputate the figure are seen as being due to its decreased correspondence with room geometry. However, the occurrence of the illusion when "typical" perspective is missing presents problems for their approach. For example, Hotopf's (1966) "Australian Poggendorff" (Figure 13) and the persistence of the illusion in "concrete" situations.

Figure 13. Hotopf's (1966) "Australian Poggendorff".

Gillam (1971) offers an interpretation of the Poggendorff illusion based on the unconscious depth processing of two-dimensional figures as three-dimensional linear perspective. According to Gillam, "unconscious depth processing" occurs in the following manner. Oblique lines are normally processed as receding in three-dimensional space. Thus in an oblique only figure the angular recession of the obliques should be the same and no illusory misalignment will occur. Because of the arrangement of lines in the Poggendorff figure, however, a different perceptual interpretation arises. While the obliques are still processed as receding in depth, the parallels, because of their equal length and height, are processed as a frontoparallel plane. The points of interception of the obliques and parallels cause these points to be processed as "equidistant" thus their height difference can no longer be processed as a difference in depth. The obliques, therefore, do not appear collinear and are processed as two receding lines at different heights. A figure need not be regular for this processing to occur, a strong "equidistance" tendency is all that is required, thus Hotopf's (1966) figure can be explained. The following figure (Figure 14) from Rock (1975) illustrates this

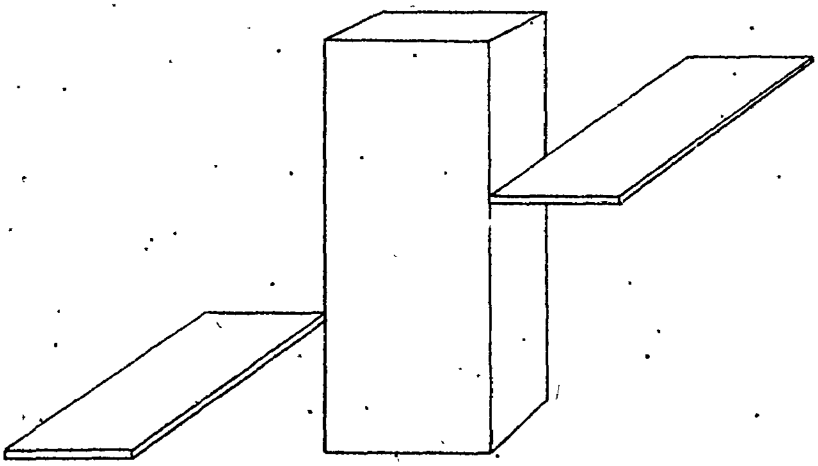


Figure 14. The depth implied by Gillam's (1971) theory.

reasoning by emphasizing the depth features of the display. Although some of the basic assumptions of Gillam's theory are not supported by available data, (i.e., while the data on the oblique only figure vary, the weight of the experimental evidence contradicts her assumption of no misalignment) and in spite of difficulties with some aspects of the Poggendorff illusion, (i.e., age trends and fixation) her theory, when considered in relation to other perspective theories, fares considerably better and, according to Rock (1975), an impressive case for a perspective interpretation can be made. Nevertheless, in the main her approach has been ignored. Recently, however, Young (1976) found some support for Gillam's premises although her explanation was noted not to be entirely satisfactory.

Particularly damaging to perspective theories is the failure of the evidence to support the assumption that the addition of appropriate depth cues will cause the illusion to vanish. Both Gillam (1971) and Young (1976) obtained a reduction of approximately 50% when perspective cues were added to a Poggendorff figure. Further, Gregory and Harris (1975) claim that the Poggendorff illusion vanishes in the appropriate projection mode (when perspective and stereoscopic disparities are geometrically correct) at the critical viewing distance.

Finally, in a recent examination of constancy theory Caelli, Finlay, and Hall (1975) tested Hoffman's model for the processess of visual perception based on Lie transformation groups. A significant change in performance as a function of separation and angle was observed. In addition, and more importantly, the function relating separation and angle was multiplicative in nature. They concluded that this result places the Poggendorff illusion "unequivocally within the context of constancy theory. Illusions ... are special combinations of basic constancy orbits which have some distortive effect" (p. 184).

Processess occurring between the parallels Another recurring explanation, in one form or another, is in terms of processess occurring between the parallels. The basic idea is that of the underestimation of the distance between the parallel lines; the greater the underestimation the greater the discontinuity. Accordingly, the Poggendorff illusion is said to result if the parallels appear perceptually as too close together. One of the earliest advocates of an explanation in these terms was Foster (1881, cited by Pierce, 1901). Foster suggested that the underestimation of the width between the parallel lines was the cause of the illusion. The notion here was that of relative remoteness. The parallels are perceived as closer than the obliques and because they seem nearer they are also perceived as narrower than they actually are. As a consequence of this the parts are pushed together and because the inner parts of the obliques are attached to the parallels, the outer parts seem to have been shifted out of line of continuity.

A recent attempt at a global theory emphasizing this attraction/underestimation is that expressed by Eriksson (1970). Eriksson proposes a field theory of illusions. His position is an attempt to apply electrical potential theory to illusions. The theory is based on the concept of the perceptual field and it gives a description of the joint output from the nervous system. Eriksson argues that lines in the visual field affect one another as a function of the distance separating them. In the Poggendorff illusion two factors are said to be operating: the regression to right angles (acute angle enlargement) and the attraction of the parallel lines..

More detailed and specific explanations have also been advanced, these include Pressey's (1971) assimilation theory and Day and Dickinson's (1976) component explanation.

Pressey (1971) reduced the Poggendorff illusion to assimilative processes similar to those proposed for the Müller-Lyer illusion. This theory was also advanced to account for a number of other illusions as well. Although not fully articulated, this explanation focuses on the apparent distance between the inner tips of the obliques. The basic principle is that whenever judgments of a series of magnitudes are to be made, a range of values are available and the judgments of those values tend toward their mean, the smaller values being overestimated and the larger ones underestimated. Context is also important and here Pressey proposes the notion of "attentive fields". An attentive field is an area over which attention is distributed and it is from this that the average is obtained. When asked to extend the oblique in a Poggendorff figure the subject is assumed to extend a series of lines that are shorter than objective continuation, see Figure 15. In this figure the

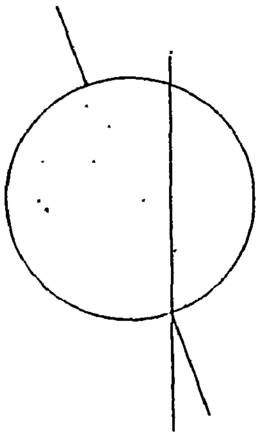


Figure 15. A hypothetical attentive field from Pressey (1971).

dominant contextual contour is that portion of the parallel above the point of objective continuation. Because of differential attention the shorter obliques are weighted more heavily than the longer obliques. The preferred line will be one representing the mean of the series. Thus when the subject chooses a line he chooses one that is shorter than the standard. Pressey argues that the Poggendorff illusion is a compound Müller-Lyer illusion, simultaneously reflecting both shrinkage and expansion of the standard magnitude. Using this assumption Pressey is able to explain most of the variants of the classical display. For example, in an acute angle figure expansion is dominant and a negative illusion results; while in an obtuse angle figure shrinkage is dominant and the illusion is positive. The classical Poggendorff figure contains both acute and obtuse angles, but because of the attentive field the shrinkage effect is dominant. While assimilation theory can accommodate many configurations, some of the amputations presented by Weintraub and Krantz (1971) present problems. For example, in Figure 16A assimilation theory would predict no illusion because

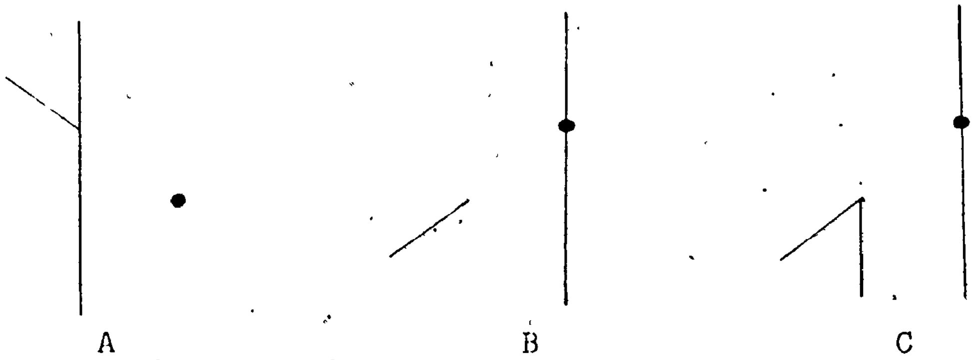


Figure 16. Variants used by Weintraub and Krantz (1971).

the oblique line can be projected unequivocally to only one spot, the dot. However, a large illusion is obtained with this figure. Further, in Figures 16B and 16C Weintraub and Krantz found no illusion, while assimilation theory states that a positive illusion will occur. However, these latter two figures, like other variants, have given contradictory results with Kobayashi (1956), Pressey and Dewar (1970), and Pressey and Sweeney (1969, 1972a) all reporting large positive illusions. The effects of orientation and fixation are amenable to this approach as well. In the case of the former, correspondence with a spatial norm occurs with the obliques vertical or horizontal and a dominant influence would be exercised; while in the latter case central fixation causes the objective extension to be processed to a higher degree. In sum, Pressey contends that the Poggendorff effect is produced by the apparent shrinkage of the distance between the inner tips of the obliques and reversed effects are produced by the apparent elongation of that distance.

Experimental support for the idea that the distance between the obliques is underestimated has come from Quina-Holland (1977), who noted that the apparent non-collinearity of the two obliques was produced by a factor causing the parallels to appear closer to one another than they actually are. However, in a direct measurement of apparent distance Wilson and Pressey (1976) found overestimation of the distance between the parallels, a result obtained by Pierce (1901) 75 years earlier. Thus, apparent expansion rather than apparent shrinkage, as assimilation theory postulates, appears to be involved. In the light of this evidence Wilson and Pressey concluded that assimilation theory should be critically re-examined and possibly abandoned. In addition, many investigators have objected to assimilation theory on the grounds that it is based on a loosely defined hypothetical construct, the attentive field.

Recently Day and Dickinson (1976) derived a component model of the Poggendorff illusion. The explanation they offer is "in terms of differences in apparent extent in the space between the aligned elements, with consequent changes in apparent oblique direction" (p. 538). It is argued that apparent extent is perceptually elongated in one direction and perceptually foreshortened in a direction perpendicular to it. The singular or joint effect of three independent components: the Horizontal-Vertical, the Longitudinal-Transverse, and the Obtuse angle, is said to determine this apparent distortion. As a consequence of this linear distortion the distance between the points of interception of the obliques and parallel lines is misrepresented and apparent non-collinearity results. Thus the displacement observed in the Poggendorff illusion is a secondary effect produced by one or more of three basic illusions. The Horizontal-Vertical component consists of the fact that vertical lines are perceptually longer than physically equal horizontal lines. The Longitudinal-Transverse component states that longitudinal extent is perceptually larger than a physically equal transverse extent. The Obtuse angle component comprises the observation that the arm of an obtuse angle is perceptually greater than an equivalent acute angle arm, the notion here is that the obtuse angle (because of the large illusion which obtuse angles generate) is more important than acute angles. These three effects, therefore, each result in the distortion of direction. In the Poggendorff illusion, and variations to it, the magnitude of displacement will be a function of the number of these components present, the relative strength of each component, and the contribution (positive or negative) of each component.

As with other recent explanations, there has been little reaction to this position. Earlier, however, Finlay and Caelli (1975) examined the Longitudinal-Transverse component and found that, although showing some evidence of underestimation, estimates of transverse extent could not form the basis of the Poggendorff illusion.

CONCLUSION

This review of the experimental and theoretical literature on the Poggendorff illusion has led to the formulation of two very broad questions to which the experiments which follow are addressed.

The first is, do the classic Poggendorff figure and its variants activate the same perceptual process(es) or are they distinct and give rise to different phenomena? This is an important question because observations of the variants are often used to refute theoretical explanations of the effect associated with the classical pattern. For example, the fact that the variant which includes only obtuse angles gives rise to a large illusion seems to contradict an explanation in terms of acute angle enlargement. In the light of this then it becomes important to know if the obtuse angled figure and the classical figure are indeed tapping the same underlying process(es). The first five experiments were designed to provide evidence relevant to this general question and the data they provide strongly suggests that indeed the classical figure and the variants all activate a single underlying process but to varying degrees.

The second question is "how is the Poggendorff figure represented perceptually?" The second set of three experiments constitute an attempt to determine the ways in which the perceptual geometry of the Poggendorff differs from its Euclidean geometry. Specifically, is there evidence for angular enlargement sufficient to account for the magnitude of the illusory effect observed with the classical figure? How does increasing the separation of the parallels operate to increase illusion magnitude? On the basis of these experiments a model of the perceptual geometry of the Poggendorff illusion is derived.

The ninth and final experiment is addressed to the cause of the illusion and it strongly implicates angular enlargement due to lateral inhibition in the visual system as a major, if not the only, factor causally involved.

While these experiments appear to go some way in elucidating the nature of the Poggendorff illusion, important questions remain unanswered. These are set out in the final and concluding chapter of this thesis.

CHAPTER III

EXPERIMENTS 1 TO 5

The first set of experiments to be reported is concerned with variants of the classical Poggendorff figure. While much is known of the details of the Poggendorff effect, there is considerable disagreement as to the effect of various modifications to the classical Poggendorff figure and their implications for the cause of the illusion. An analysis of the Poggendorff illusion into its component parts has long been an appealing proposition (Blix, 1902; Day, 1973a,b; Weintraub & Krantz, 1971). The assumption is that by modifying the figure those components that are critical in determining the illusion will be revealed and so too the cause of this, as yet unexplained, illusion.

As pointed out in Chapter II, while data on various variants of the Poggendorff are numerous, no clear empirical picture can be assembled. This is because of conflicting experimental outcomes both from different laboratories and from within a single laboratory. For example, in figures containing only acute angles, it has been found that: (a) a negative (reversed) illusion occurs (Blix, 1902; Restle, 1969), (b) a negligible or no illusion occurs (Green & Hoyle, 1964; Krantz & Weintraub, 1973; Weintraub & Krantz, 1971), and (c) a reduced but significant positive illusion occurs (Day, 1973b; Pressey & Sweeney, 1972a). Discrepant results have been reported for other variants of the illusion as well.

There are a number of possible reasons for these discrepant results and prominent among them is the fact that different investigators have used widely different values of two critical variables known to effect the magnitude of illusion: the angle at which the oblique lines intercept the parallels and the extent by which the parallels themselves are separated. The effect of these two variables, that the illusion increases regularly as angle of interception decreases and as the separation of the parallels increases, is well documented (Burmester, 1896; Velinsky, 1925). In addition, displays have differed in size and in the nature of the surrounding field; modes of presentation have differed as have psychophysical procedures. How these variations or combinations of them affect the magnitude of the illusion observed is difficult to say. For example, Day (1973b) found that a 45° acute angle figure gave a negative illusion with a forced choice technique as compared to a significant positive illusion with the method of adjustment. In a figure containing only the left hand oblique and right hand parallel Pressey and Dewar (1970) obtained an illusion of 19.4 mm with the method of production; while Weintraub and Krantz (1971) using essentially the same figure obtained an illusion of only 0.8 mm with the method of constant stimuli. In addition to these reasons, there is the question of whether or not modifications to the classical Poggendorff figure have, in fact, altered the illusion sufficiently so that what we are dealing with is another illusion (Goldstein & Weintraub, 1972; Pierce, 1901; Sanford, 1901).

Accordingly, against this background, and accepting that a quantitative comparison of major variants of the Poggendorff might give some insight into the cause of the illusion, the first two experiments in this thesis were designed to answer three main questions. They are: (1) Do the variants used produce the same illusory effect as the classical Poggendorff? (2) Do the variants respond in the same way as the classical figure to manipulations of angle of interception and separation of the parallels? (3) Do individuals respond consistently to the variants? If the answer to the above three questions is "yes", then there would seem to be some basis for assuming that the variants were arousing the same perceptual process.

EXPERIMENT 1

Given some of the inconsistencies existing in the literature, along with the variety of angles and separations of the parallels employed in these studies, it is important to know whether the relationship between angle of interception and magnitude of the illusion holds for various variants of the Poggendorff figure. In the available data that have any bearing on this issue no satisfactory answer exists. For example, using 30° and 45° obtuse angle and acute angle figures, Day (1973b) obtained significantly greater illusions with the 45° figures - the opposite of the usual relationship that exists with the classical figure. One explanation for this particular result could lie in the fact that the collinear distance (i.e., the distance between the inner ends of the obliques) was kept constant in all figures. Since the distance separating the obliques decreases as the angle of interception increases, if the parallels are a fixed distance apart, the distance between the parallels would be greater in the 45° figures and separation between the parallels is known to be another important stimulus variable. Further, after systematically varying the angle of two oblique lines between 0° and 90°, Day (1973a) obtained a function asymmetrical about 45°, a relationship different from that for the classical figure. Again, this discrepancy could lie in the fact that the collinear distance was kept constant across all angles. In addition, Goldstein and Weintraub (1972) found that changing the angle of two oblique lines altered "the illusion in a direction opposite to that of the conventional Poggendorff display" (p. 355).

In this first experiment, the angle at which the oblique line intercepts the parallel was systematically varied between 15° and 75° in 15° steps in each of three incomplete Poggendorff figures and the classical figure.

Method

Stimuli. Each of the four figures shown in Figure 17 was drawn in each of five versions. The versions differed in terms of the angle at which the oblique line intercepted the parallel. The angles used were 15°, 30°, 45°, 60°, and 75°. The figures were drawn on 21.5 cm x 28 cm ditto paper with lines 1 mm in width, the parallels 18 cm long, and the oblique lines 3.5 cm in length. The parallels were separated by 3 cm. In this way, a total of 20 (4 figures x 5 angles) different figures were prepared. The figures were reproduced by a ditto machine. Three copies of each of these figures were bound in a random order in a booklet. Each page containing one of the figures was separated from adjacent figures by a blank page of opaque blue paper so that the subject could see only one figure at a time as he worked his way through the booklet.

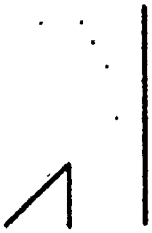
Subjects The subjects were six men and four women undergraduate students, between the ages of 18 and 22, who were paid for their participation. None had taken part in illusion studies previously nor had they any knowledge of the purpose of the experiment.

Procedure. The subjects were tested in a single group in a room with normal florescent lighting. They were seated at tables and provided with a booklet containing the

Figure 17. Figures used in Experiments 1 and 2. (A) Complete, (B) Obtuse, (C) Acute, and (D) Oblique.

A

B



C

D

illusion figures and instructed that their task was to visually project the left-hand oblique and to draw, on signal, a clear well defined mark on the right-hand parallel at the point where the oblique would meet it if it were, in fact, extended. Viewing distance was approximately 35 cm and the viewing angle approximately 80°. They were told that only one choice could be made on a trial and that projecting the oblique by arm movements or tilting the head was not permitted (see Appendix A for a copy of the instructions used). This procedure was illustrated with a Poggendorff figure drawn on the blackboard.

A yellow dot was placed on the table convenient to the subject's preferred hand. The subjects were instructed to keep their hands on the dot between trials. A trial was begun by the experimenter saying "turn". The subjects then turned the blue sheet to expose one of the Poggendorff figures. After 10 seconds, the experimenter said "now", and on this signal the subjects removed their preferred hands from the yellow dot and made their mark. This done, they turned the figure over, exposing the next blue sheet. The intertrial interval was approximately 5-10 seconds. This procedure was continued until all 60 figures had been completed, the entire session lasting about 40 minutes.

Results and Discussion

The data are the average differences between where the subjects made their marks (points of subjective collinearity) and true collinearity. A Poggendorff illusion effect is observed when the subject places his mark below the point of true collinearity. The group data are shown in Figure 18. The mean and standard deviation for all conditions may be seen in Appendix B. A two-factor repeated measures analysis of variance was performed on these data and the results are summarized in Table 1. This analysis showed a significant effect of Angle ($F(4, 36)=3.81$, $p<.025$), of Figure ($F(3,27)=8.49$, $p<.001$), and a significant Angle x Figure interaction ($F(12, 108)=2.84$, $p<.01$). The nature of this interaction is apparent from Figure 18, and it is clear that angle size has a smaller effect on the acute and oblique figures than it does on the other two, although for these two an illusory effect significantly greater than zero is observed with the smaller angles. The strong inverse relationship between magnitude of illusion and angle of interception is evident from Figure 18.

Since a within-subjects design was used, it was possible to intercorrelate the illusion scores obtained on the four different figures. The product-moment correlation coefficients were all significant. These coefficients had an average value of +0.80 and ranged from +0.71 ($p<.02$) to +0.88 ($p<.005$).

EXPERIMENT 2

In this experiment the separation between the parallel lines was systematically varied between 1 cm and 5 cm

Figure 18. Mean illusion in millimeters plotted as a function of angle of interception of the oblique line for each of the complete, obtuse, acute, and oblique Poggendorff figures.

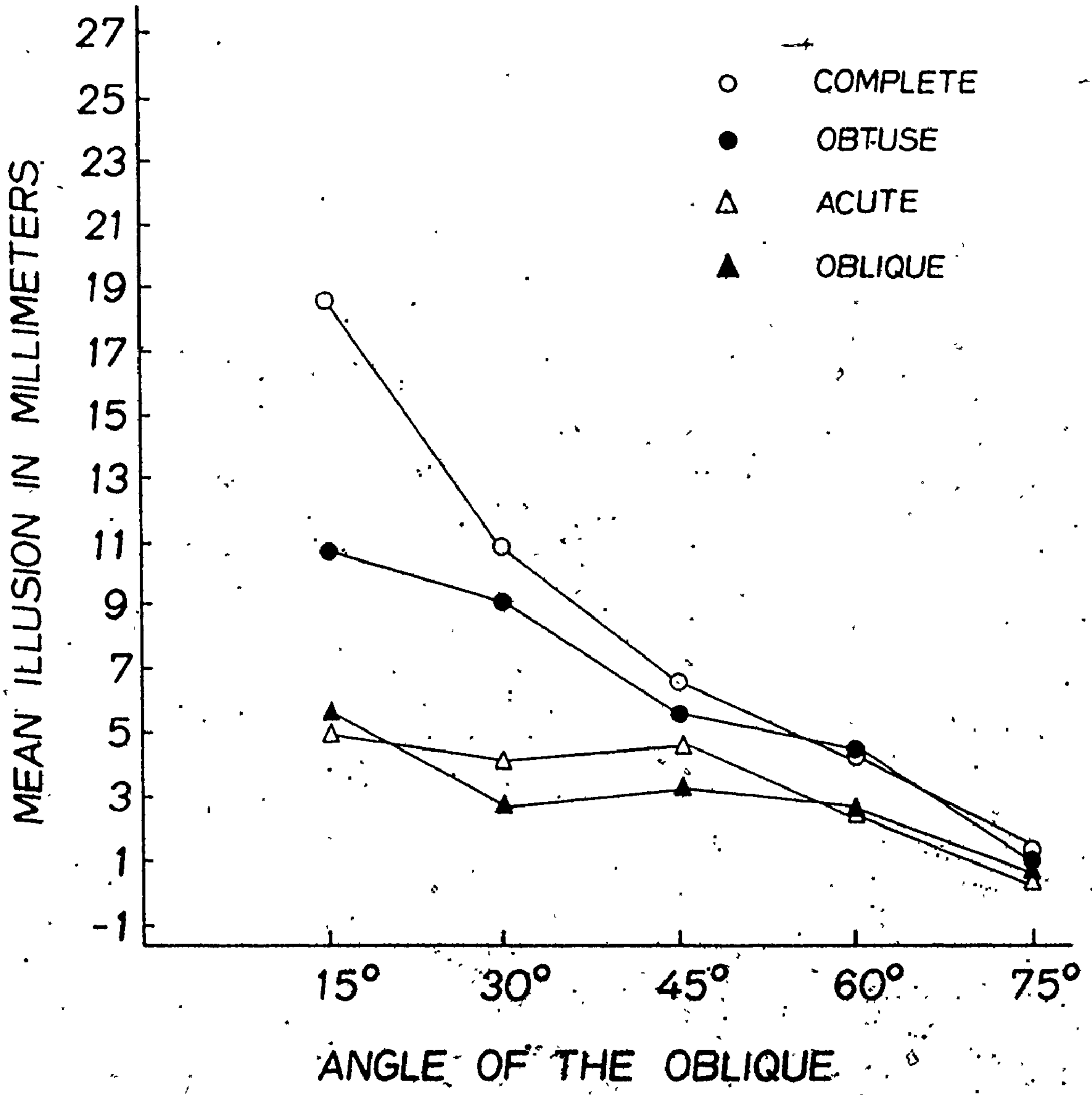

○ COMPLETE
● OBTUSE
△ ACUTE
▲ OBLIQUE
MEAN ILLUSION IN MILLIMETERS
27
25
23
21
19
17
15
13
11
9
7
5
3
1
-1
15°
30°
45°
60°
75°
ANGLE OF THE OBLIQUE

TABLE 1

SUMMARY OF ANALYSIS OF VARIANCE ON THE DATA FOR EXPERIMENT 1.

SOURCE	SS	df	MS	F	p
Angle	1885.304	4	471.326	3.812	.025
Angle X Subjects	4451.464	36	123.652		
Figure	935.682	3	311.894	8.486	.001
Figure X Subjects	992.329	27	36.753		
Angle X Figure	776.349	12	64.696	2.844	.01
Angle X Figure X Subjects	2457.095	108	22.751		
Subjects	4780.430	9			
Total	16278.654	199			

in 1 cm steps in each of the three incomplete Poggendorff figures and in the complete figure.

Method

Stimuli The stimuli were identical to those used in Experiment 1, except that the angle of interception was fixed at 30^{0} and the separation of the parallels was varied. The values of the separations used were 1, 2, 3, 4, and 5 cm.

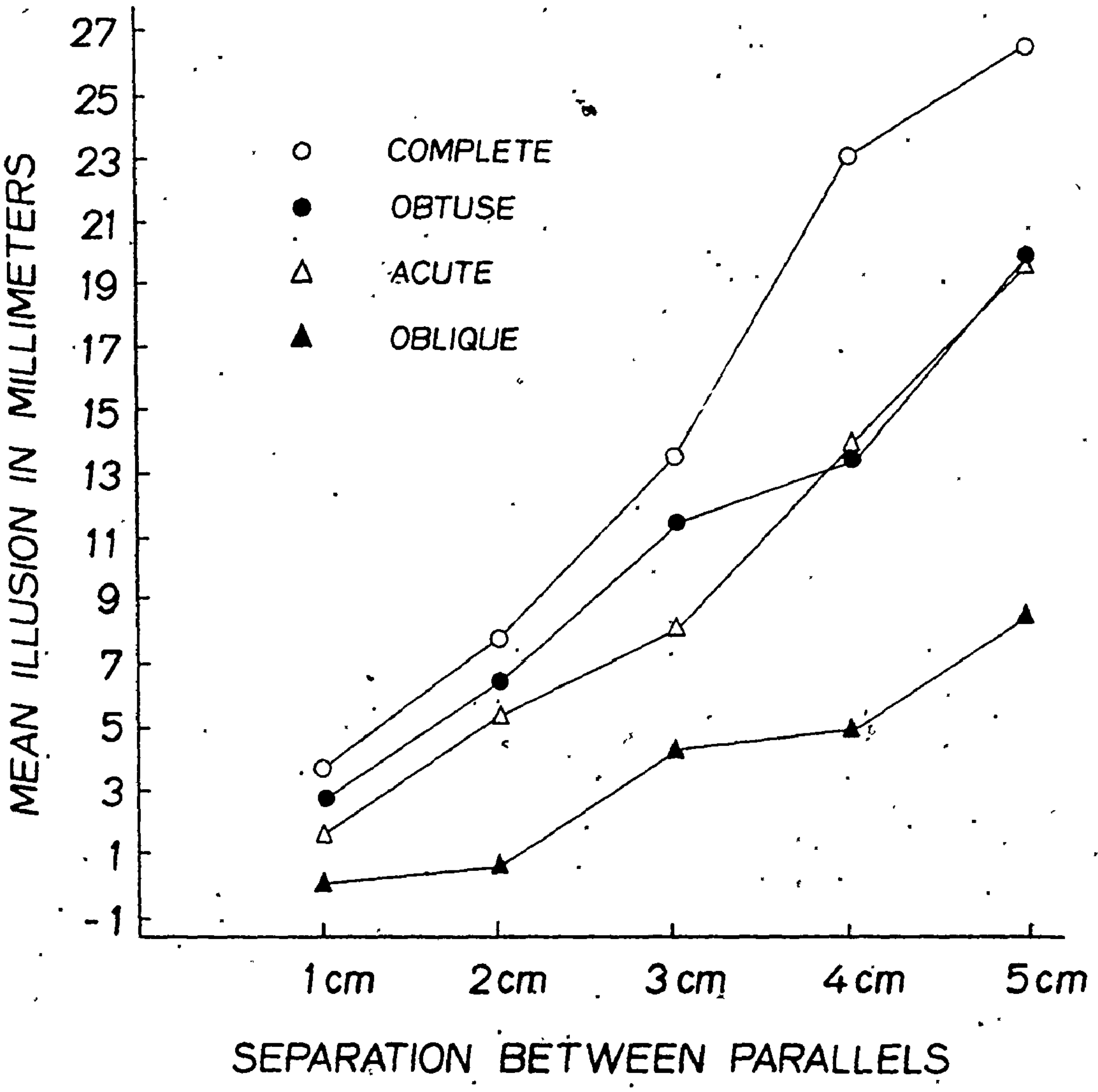
Subjects The subjects were five men and five women undergraduate students, between the ages of 18 to 21, who were paid for their participation. None had taken part in illusion studies previously nor had they any knowledge of the purpose of the experiment.

Procedure The procedure was identical in all respects to that used in Experiment 1.

Results and Discussion

The group data for this experiment are shown in Figure 19. The mean and standard deviation for all conditions may be seen in Appendix C. The analysis of variance (Table 2) showed a significant effect of Separation ($F(4, 36)=5.88$, $p<.001$), of Figure ($F(3, 27)=42.70$, $p<.001$), and a significant Separation x Figure interaction ($F(12, 108)=7.70$, $p<.001$). The strong direct relationship between magnitude of illusion and separation between the parallels can be seen in Figure 19. As seen in Figure 19, the interaction seems mainly attributable to the weaker effect of separation

Figure 19. Mean illusion in millimeters plotted as a function of the separation of the parallel lines for each of the complete, obtuse, acute, and oblique Poggendorff figures.


27
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MEAN ILLUSION IN MILLIMETERS
○ COMPLETE
● OBTUSE
△ ACUTE
▲ OBLIQUE
1 cm
2 cm
3 cm
4 cm
5 cm
SEPARATION BETWEEN PARALLELS

TABLE 2

SUMMARY OF ANALYSIS OF VARIANCE ON THE DATA FOR EXPERIMENT 2.

SOURCE	SS	df	MS	F	p
Separation	7069.586	4	1767.397	45.877	.001
Separation X Subjects	1386.902	36	38.525		
Figure	3276.259	3	1092.086	42.701	.001
Figure X Subjects	690.517	27	25.575		
Separation X Figure	950.972	12	79.248	7.705	.001
Separation X Figure X Subjects	1110.830	108	10.285		
Subjects	1852.473	9			
Total	16337.539	199			

of the parallels on the oblique figure. As for Experiment 1, the illusion scores for the four figures were intercorrelated. These coefficients had an average value of +0.67 and ranged from +0.48 ($p < .10$) to +0.80 ($p < .005$). The correlation between the obtuse and acute figures (+0.48) was the only one of the 12 computed in the two experiments that failed to reach significance at at least the .05 level.

The results of the first two experiments provide a clear affirmative answer to each of the three questions phrased earlier. The three variants do produce the same illusory effect as the classical Poggendorff figure; they do respond in the same way to manipulation of two major variables that determine the magnitude of the illusory effect, angle of interception and separation of the parallels; and, as the strong positive correlations among illusion scores on the different figures show, individuals do respond in a consistent way to all four figures.

EXPERIMENT 3

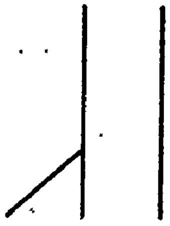
Because of the findings of the first two experiments, one is tempted to conclude that the different components represented in the three variants used all arouse the same perceptual process as the classical Poggendorff figure, but to different degrees, and that this is the explanation of the consistently ordered magnitude of the illusory effect associated with the four figures. One difficulty in the way of this conclusion, however, is that while the figures each contain a different component of the classical figure, they also differ in terms of the total amount of the classical figure which they contain. Thus, for example, the obtuse and acute angle figures differ in angular components, but the obtuse figure contains more of the left-hand parallel as well. The greater illusion generated by the obtuse as compared to the acute figure could as readily be attributed to the amount of figure difference as to the angular difference. The present experiment was designed to examine the possibility that variation in illusion magnitude might depend on the total amount of illusion figure present, independently of the presence of particular angular components.

The obtuse angled figure is the only variant suited to the purpose of this experiment, since the left-hand parallel can be systematically shortened, leaving the angle component intact. Lengthening the left-hand parallel in the acute angled figure inevitably adds the obtuse angle and thus another component, rendering this variant unsuitable for an examination of the question at hand. Accordingly, the obtuse angle figure was chosen and the total amount of the figure present was varied.

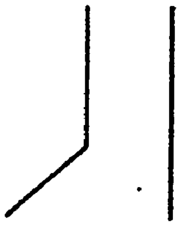
Method

Stimuli The three versions of the obtuse angle figure and the classical Poggendorff figure used in this experiment are shown in Figure 20. As for Experiments 1 and 2 the figures were duplicated on 21.5 cm x 28 cm ditto paper

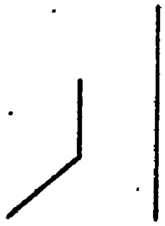
Figure 20. Figures used in Experiment 3. In pattern B, C, and D, the left-hand parallel is progressively shortened.



A



B



C

D

with lines 1 mm in width. In all figures, the right-hand parallel was 18 cm long, the oblique line was 3.5 cm in length, and the obtuse angle was 150°. The separation of the parallels was fixed at 3 cm. Three copies of each figure were randomly arranged in a booklet with opaque blue pages interleaved, again, exactly as in the previous experiments.

Subjects The subjects were nine men and two women undergraduate ~~students,~~ between the ages of 18 and 23, who were paid for their participation. None had taken part in illusion studies previously nor had they any knowledge of the purpose of the experiment.

Procedure All details of procedure are exactly as for Experiments 1 and 2.

Results and Discussion

Analysis of variance of the data (Table 3) showed a significant effect of Figure ($F(3, 30)=21.84$, $p<.001$). In order to determine the locus of the difference that produced the significant F, Tukey's HSD test was conducted on the totals. It was found that the classical Poggendorff gave a larger illusion than any of the three variants used and that these figures did not differ among themselves. The actual mean illusions (mms) associated with the figures in the order in which they appear in Figure 20 are 17.0, 11.8, 12.0, and 12.7. This outcome provides some assurance that it is the particular angular components of the classical

TABLE 3

SUMMARY OF ANALYSIS OF VARIANCE ON THE DATA FOR EXPERIMENT 3.

SOURCE	SS	df	MS	F	p
Figure	196.922	3	65.641	65.641	.001
Figure X Subjects	95.178	30	3.173		
Subjects	815.847	10			
Total	1107.947	43			

figure that are contained in the variants that is important and not just the total amount of the figure that is retained.

EXPERIMENT 4

While the results of the first three experiments provide strong evidence that the classical Poggendorff and the three variants studied produce the same illusory effect, differing only in amount, they do not tell us much about the underlying perceptual process or processes. It is possible that all of the variants arouse a single process, but to varying degrees, or, alternatively, that the three figures arouse different processes, each of which produces the same illusory effect, but of different magnitudes. If the latter were the case, then it would follow that the classical figure arouses all three processes and that in combination they produce the large illusory effect that we observe.

Whatever the case, a single or multiple process, it is clear that its effectiveness in producing the illusion diminishes with successive trials or repeated exposure (Cameron & Steele, 1905; Coren & Girgus, 1972; Pressey & Sweeney, 1969). Indeed, Cameron and Steele (1905) report that after 3,200 trials the illusion was virtually eliminated and the effects persisted for over a year. It would seem possible to use this practice effect to examine the question of a single or multiple processes, and such is intended in this experiment.

The logic is this. Consider the hypothetical case of three processes, a different one for each of the obtuse angled, acute angled, and oblique only figures that were used in Experiments 1 and 2. Further, suppose that these three processes are all activated by the classical figure. It would follow that practice effects obtained with all three variants should transfer positively to the classical figure, the amount of transfer being related to the degree to which the particular process contributes to the total illusion. For example, practice with the obtuse angled figure should reduce the illusion on the classical figure when it is subsequently presented more than would be the case for the acute angled figure. This is because, as shown in Experiments 1 and 2, the obtuse angled figure produces a larger illusion than the acute angled figure and therefore the process it activates must contribute more to the total illusion. Reducing the effectiveness of this process by prior exposure should eliminate or markedly reduce its contribution to the illusion when the classical figure is presented. Another prediction required by this analysis is that practice on any one of the variants should not transfer to any of the others since different processes are involved.

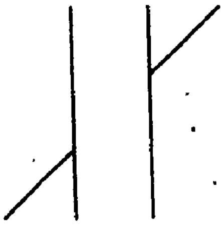
The alternate case, that of a single process that is aroused to a greater or lesser degree by the different figures, leads to different predictions. It would still be expected that practice with the variants would transfer positively to the classical figure, but it would also be expected that practice with the variants would show positive transfer to one another.

Method

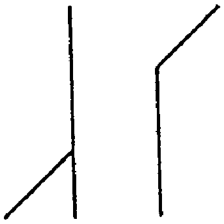
Stimuli The figures used in this experiment are shown in Figure 21. It will be noted that unlike the figures used in Experiments 1, 2, and 3, here the left-hand parallel is intact in all figures and the appropriate sections of the right-hand parallel are removed to produce the variants. Again unlike the case in the previous experiments, both oblique lines are present in all figures. These stimuli were produced on white construction paper with black matte graphic tape, 1.6 mm in width. The parallel lines were 18 cm long and 3 cm apart. The obliques were 3.5 cm long and intercepted the parallels at a 45° angle.

Apparatus The apparatus consisted of a wooden frame in which two Plexiglass panels were affixed. The one on the right, from a frontal view, was immovable, while the one on the left could be moved freely up and down by a reversible electric motor that could be controlled by either the experimenter or the subject. The whole of the Poggendorff figure, except for the left-hand oblique, was fastened to the immovable panel. The left-hand oblique was fixed to the movable panel. A 66-cm wide and 51-cm high piece of black bristol board was placed in front of the apparatus. It had an opening, 23 cm in width and 30 cm in height, cut from its center, through which the illusion figure could be seen

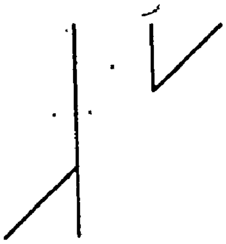
Figure 21. Figures used in Experiment 4. (A) Complete, (B) Obtuse, (C) Acute, and (D) Oblique. Figures A and D were also used in Experiment 5.



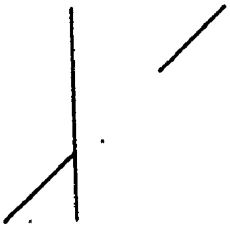
A



B



C



D

immediately behind.

Subjects The subjects were 20 men and 20 women undergraduate students, between the ages of 18 and 22, who were paid for their participation. None had taken part in illusion studies previously nor had they any knowledge of the purpose of the experiment. They were randomly assigned to one of four groups of 10 subjects each, with the constraint that they be five men and five women in each group.

Procedure Each of the four groups was given 50 trials of practice on one of the four figures shown in Figure 21 and, after a 5 minute break while the pattern was changed, an additional 25 trials on the classical Poggendorff figure.

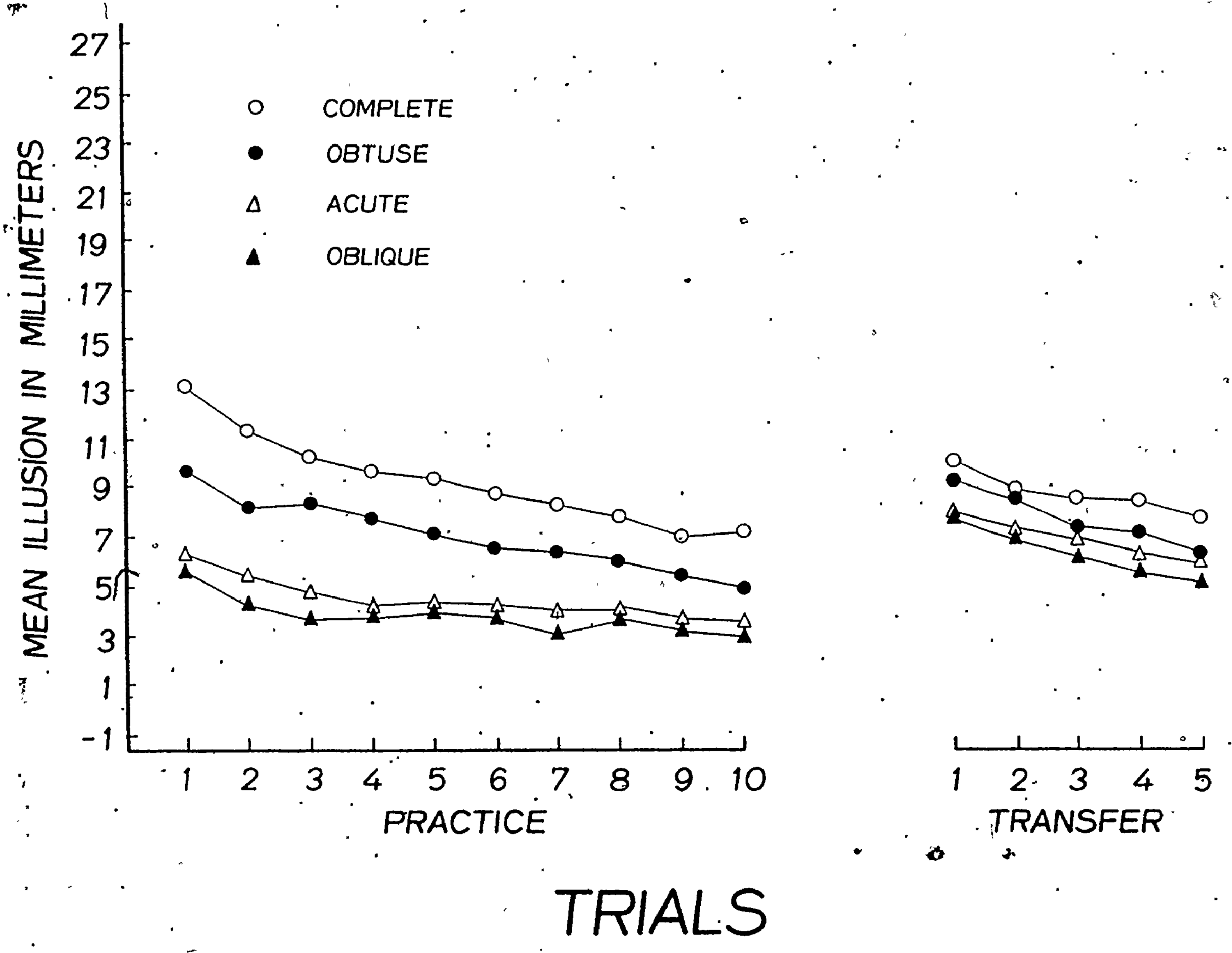
The subjects were tested individually in a room with standard flourescent lighting. When the subject arrived at the experimental room, he was seated at a table one meter in front of the apparatus (and so from the stimulus) and placed his chin in a chin rest. The subject was instructed that his task was to adjust the position of the left-hand oblique until it appeared collinear with the one on the right. He could move the oblique up or down, by depressing a hand held push button switch, whichever was appropriate given the presetting, until he was satisfied. On any given trial, he could move the oblique in one direction only. (See Appendix A for a copy of the instructions used.)

Following the subject's setting, the experimenter read off the error of misalignment from a centimeter scale on the back of the apparatus. The experimenter then reset the position of the oblique to one of eight positions, four of which were obviously "too high" and four of which were obviously "too low" for collinearity. The subject then again made his setting. After 50 trials conducted in this manner, the subject was asked to wait in the corridor for 5 minutes while, in all cases except where practice was on the classical figure, the classical figure was placed on the apparatus to replace the practiced variant. Those subjects who practiced on the classical figure were also sent out into the corridor for 5 minutes so that all subjects were treated in the same way. After 5 minutes, the subject was brought back into the experimental room and performed 25 trials on the classical figure.

Results and Discussion

The results for both practice and transfer trials are shown in Figure 22. The mean and standard deviation per trial block per figure for both practice and transfer trials may be seen in Appendix E. A Lindquist Type I (Lindquist, 1953) analysis of variance of the data for the practice trials in blocks of five (Table 4) showed a significant effect of Figure ($F(3, 36)=11.97$, $p<.001$), of Trials ($F(9, 324)=54.13$, $p<.001$), and a significant Figure x Trials interaction ($F(27, 324)=3.76$, $p<.001$). Magnitude of the illusion decreased with practice as expected and it was related to figure. The significant interaction indicates

Figure 22. Practice data show mean illusion in millimeters plotted as a function of 10 blocks of five trials each of the complete, obtuse, acute, and oblique figures. Transfer data show mean illusion in millimeters plotted as a function of 5 blocks of five trials on the complete figure following practice on each of the complete, obtuse, acute and oblique figures.


MEAN ILLUSION IN MILLIMETERS
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1 2 3 4 5 6 7 8 9 10
PRACTICE
1 2 3 4 5
TRANSFER
TRIALS

TABLE 4

SUMMARY OF ANALYSIS OF VARIANCE ON THE PRACTICE TRIAL DATA FOR EXPERIMENT 4.

SOURCE	SS	df	MS	F	p
Between Subjects	3625.891	39			
Figure	1810.872	3	603.624	11.973	.001
Error	1815.019	36	50.417		
Within Subjects	898.864	360			
Trial Blocks	478.878	9	53.209	54.127	.001
Figure X Trial Blocks	101.475	27	3.758	3.823	.001
Error	318.511	324	0.983		
Total	4524.755	399			

differences in the rate of decrement of the illusion due to figure. The rate of decrement was greater for the classical and obtuse angled figures. The percent decrement associated with the figures in the order in which they appear in Figure 22 is 56%, 52%, 58%, and 55%. It will be noted that in terms of magnitude of illusion, the figures in this experiment are ordered precisely as they were in Experiments 1 and 2, providing assurance that the effects are not dependent on the details of the stimuli or on either psychophysical method or mode of presentation, all three of which were different in this experiment.

Analysis of the transfer data (Table 5) showed that the figure on which practice was carried out had no significant effect on subsequent performance on the classical figure (F(3, 36)=1.80, n.s.). Over the 25 transfer trials, there was a significant decrement (F(4, 12)=52.0, $p < .001$) but not a significant interaction (F(12, 144)=0.60, n.s.). It appears, then, that practice on any one of the three variants was equally effective in reducing the illusion on the subsequently presented classical figure as was prior practice on the classical figure itself.

To test to see if prior practice did significantly reduce the illusion, t tests were done on the mean for the first five practice trials for the classical figure and the means of the first five transfer trials for all four groups. In all cases significant transfer was observed, t(9 for the

TABLE 5

SUMMARY OF ANALYSIS OF VARIANCE ON THE TRANSFER TRIAL DATA FOR EXPERIMENT 4.

SOURCE	SS	df	MS	F	p
Between Subjects	1108.229	39			
Figure	144.353	3	48.118	1.797	
Error	963.876	36	26.774		
Within Subjects	246.532	160			
Trial Blocks	141.420	4	35.355	51.993	.001
Figure X Trial Blocks	7.168	12	0.597	0.878	
Error	97.944	144	0.680		
Total	1354.761	199			

classical, 18 for the variants) ≥ 3.12, $p < .01$.

Two features of the data warrent particular mention. The first is the significant recovery of the illusion during the 5 minute break between the end of practice on the classical figure and the beginning of the transfer trials, $t(9) = 4.33$, $p < .001$. There is little to be said at the moment concerning this rebound effect, except that it clearly warrants further study in connection with the process involved in the decrement of the illusion with practice.

The second feature of the data worth special note concerns the transfer trials. While there is no significant effect of practice figure on subsequent performance on the classical figure, it is noteworthy that on the transfer trials the groups are ordered exactly opposite to what one might expect on the basis of a similarity explanation of transfer. Practice on the classical figure, in fact, shows the least transfer, while practice on the oblique figure, the most dissimilar, shows the most transfer.

Singling out the practice data for the classical and oblique figures for detailed study suggests the reason why the amounts of transfer associated with these two figures were not more different than they are. It will be noted from Figure 22 that the practice decrement for the classical figure proceeds regularly downward from the first trial block to the last block of trials. For the oblique figure, however, there is a substantial decrement from Trial Block

1 to Trial Block 3, but thereafter the illusory effect remains essentially stable at around 3.5 mm. Whatever process brings about the decrement then, appears to work continuously in the case of the classical figure and brings the illusory effect progressively closer to the stable state obtained early on the oblique figure. This suggests that if fewer practice trials were given with these two figures, significantly different amounts of transfer might be observed. This prediction was tested in the following experiment.

3

EXPERIMENT 5

Method

<u>Stimuli</u> All details of stimuli were identical to those of Experiment 4, except that only the classical and oblique figures were used.

<u>Apparatus</u> The apparatus was the same as in Experiment 4.

<u>Subjects</u> The subjects were 10 men and 10 women undergraduate students, between the ages of 18 and 31, who were paid for their participation. None had taken part in illusion studies previously nor had they any knowledge of the purpose of the experiment. They were randomly assigned to one of two experimental groups, with the constraint that there be five men and five women in each group.

<u>Procedure</u> All details of procedure were identical

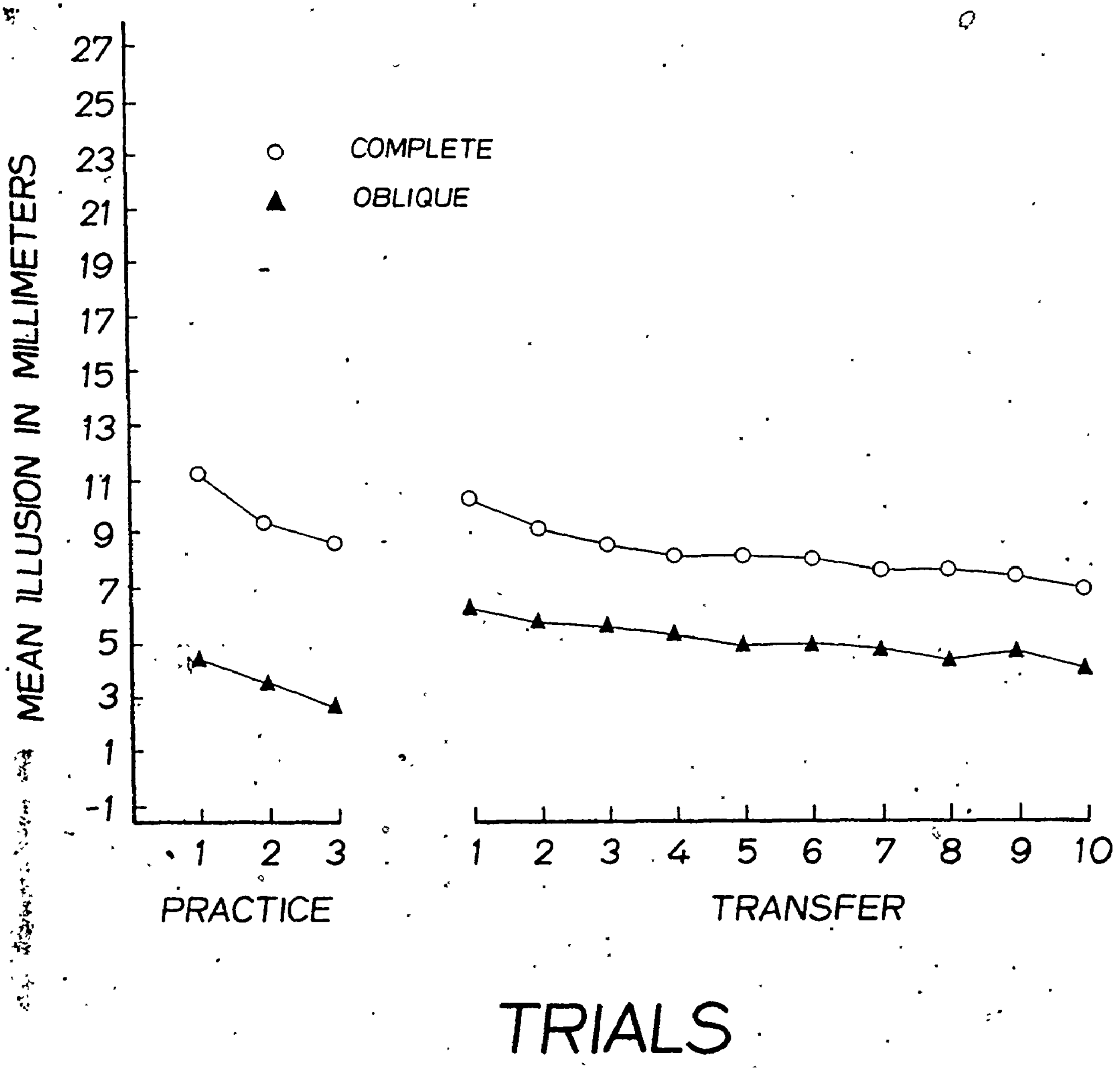
to those of Experiment 4, except that there were 15 practice trials on each of the two figures followed by 50 transfer trials on the classical figure.

Results and Discussion

The results of the experiment are shown graphically in Figure 23. The mean and standard deviation per trial block per figure for both practice and transfer trials may be seen in Appendix F. Analysis of variance of the practice data (Table 6) showed a significant effect of Figure ($F(1, 18)=53.48$, $p<.001$) and of Trials ($F(2, 36)=23.97$, $p<.001$). The Figure x Trials interaction did not reach significance ($F(2, 36)=1.34$, n.s.). This lack of a significant interaction indicates that there was no difference in the rate of decrement of the illusion due to figure and suggests that the process responsible for the decrement acts equally for both figures over these relatively few trials, although the levels of illusion associated with the two figures are significantly different.

The analysis of variance of the transfer data is summarized in Table 7. This analysis showed a significant effect of Figure ($F(1, 18)=5.95$, $p<.05$) and of Trials ($F(9, 162)=27.92$, $p<.001$). The Figure x Trials interaction was not significant ($F(9, 162)=0.58$, n.s.) and leads to the conclusion that the advantage gained by practice on the oblique figure was neither enhanced nor reduced over the long series of 50 transfer trials.

Figure 23. Practice data show mean illusion in millimeters plotted as a function of 3 blocks of five trials for each of the complete and oblique figures. Transfer data show mean illusion in millimeters plotted as a function of 10 blocks of five trilas on the complete figure following practice on each of the complete and oblique figures.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TRANSFER
TRIALS

TABLE 6

SUMMARY OF ANALYSIS OF VARIANCE ON THE PRACTICE TRIAL DATA FOR EXPERIMENT 5.

SOURCE	SS	df	MS	F	p
Between Subjects	754.176	19			
Figure	564.266	1	564.266	53.480	.001
Error	189.910	18	10.551		
Within Subjects	72.693	40			
Trial Blocks	47.932	2	23.966	39.033	.001
Figure X Trial Blocks	2.671	2	1.336	2.176	
Error	22.090	36	0.614		
Total	826.869	59			

TABLE 7

SUMMARY OF ANALYSIS OF VARIANCE ON THE TRANSFER TRIAL DATA FOR EXPERIMENT 5.

SOURCE	SS	df	MS	F	p
Between Subjects	1995.349	19			
Figure	495.810	1	495.810	5.952	.05
Error	1499.539	18	83.308		
Within Subjects	198.191	180			
Trial Blocks	117.365	9	13.041	27.925	.001
Figure X Trial Blocks	5.214	9	0.579	1.240	
Error	75.612	162	0.467		
Total	2193.540	199			

To see if the transfer observed was in fact significant, t tests were again done on the mean for the first five practice trials for the classical figure and the means on the first five transfer trials for both figures. Significant transfer to the classical figure was observed only following practice on the oblique figure ($t(18)=4.30$, $p<.001$) and not from the classical figure itself ($t(9)=1.57$, n.s.).

The outcome of this and the preceding experiment would seem to obviate the need for the experiments concerned with transfer among the variants outlined in the introduction to Experiment 4 as relevant to the single or multiple process question. There now seems little reason to doubt that significant transfer effects would be obtained from practice on each variant to performance on the others, as a single process explanation would predict.

In addition to the single or multiple process question, an informative observation on the question of what repeated trials accomplish in order to bring about a decrease in illusion, is contained in Figure 23. Examination of the transfer data shows that those subjects who had prior practice on the classical figure fail, after 50 transfer trials on the classical figure, to achieve as great an illusion reduction as is achieved after a mere 15 trials of practice on the oblique figure. Notice that on the transfer trials the "oblique subjects" begin with a lower illusion on the classical figure than characterizes the terminal performance on the transfer trials of those who had original practice on the classical figure. This observation makes it clear that the effectiveness of practice is not simply a matter of the number of trials, but also the figure upon which practice is obtained.

CHAPTER IV

EXPERIMENTS 6 TO 9

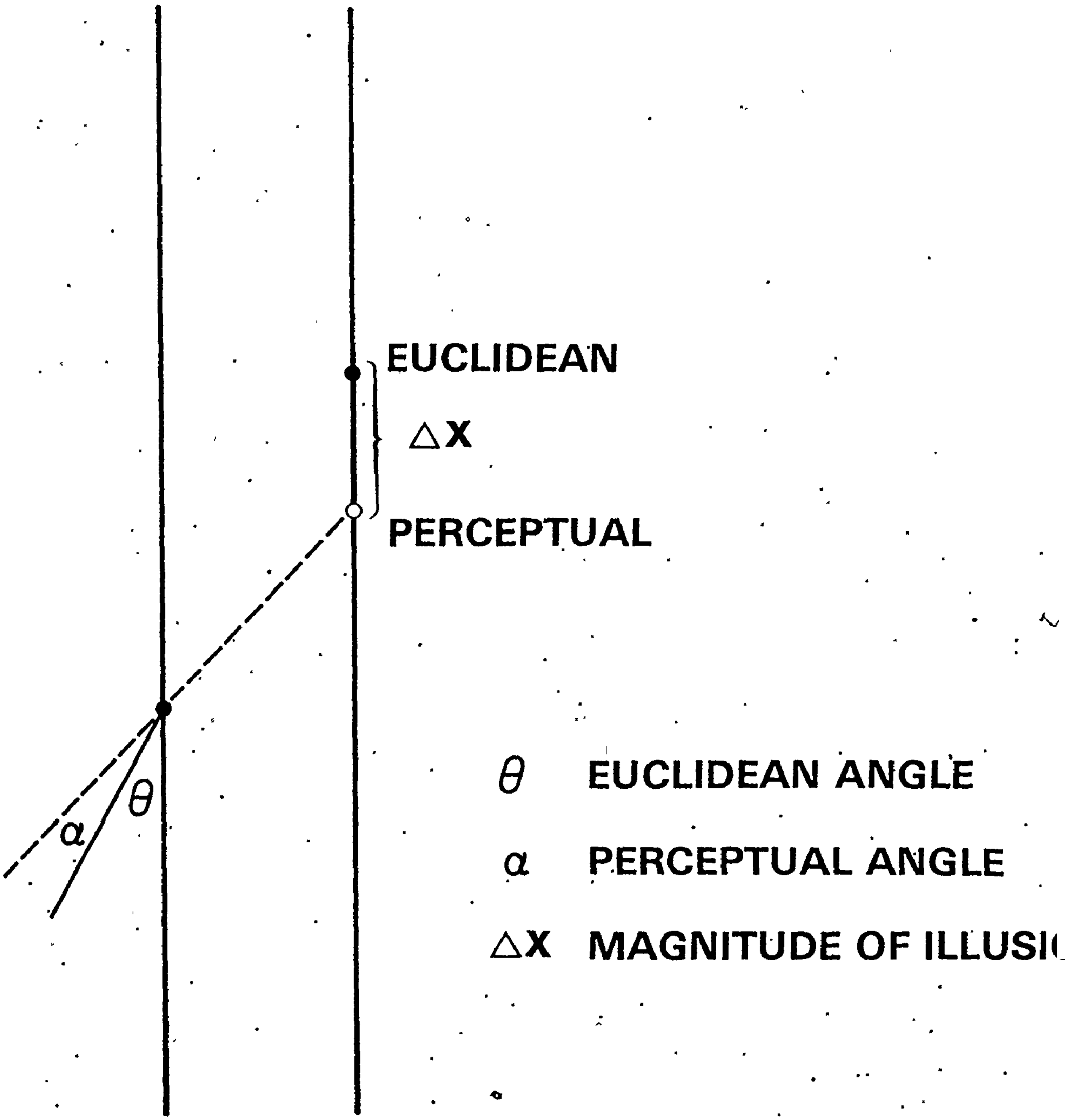
Several possible lines of research are suggested by the preceding studies. For example, there is the problem of the mechanism causing the decrement following repeated presentations and whether it is the same one causing the illusion in the first place. Another possibliity concerns the further exploration of the components of the illusion using variants of the classical figure. However, the direction taken in the remaining experiments of this thesis, is to leave the variants and to turn to a consideration of perhaps the most fundamental question of what the visual system does when confronted with the classical Poggendorff figure. It is to this question that the next three experiments are addressed.

In attempting to assess collinearity, the subject has to extrapolate the transversals along a common perceptual path. To simplify the argument, let us suppose that what he does is to perceptually extend the lower left-hand transversal across the gap between the parallels. When he does this, he consistently comes out too low and so makes a directional error. The problem, then, is one of determining the nature of this directionally consistent error.

As noted in Chapter II, the Poggendorff illusion has been the subject of numerous experimental investigations. Historically, the approach most often taken in dealing with the Poggendorff has been to test some theory about the cause of the illusory effect. According, the number of explanations offered is large as documented in the historical introduction.

However, also as noted earlier, no one theory has gained general acceptance although each is to some extent plausible given the evidence adduced in its support. One difficulty in implicating a particular causal mechanism or set of mechanisms may be due to the fact that, despite a voluminous literature, it is not clear precisely what the visual system does when confronted with the Poggendorff figure. For example, as pointed out in Experiments 1 and 2, both the angle of interception of the oblique and the distance between the parallels have large and reliable effects upon illusion magnitude. However, these and other variables which have established effects have not been studied systematically together in a way which permits a model of the perceptual representation of the Poggendorff illusion to be composed. Accordingly, the first three experiments of this chapter were designed for the purpose of generating such a model and the result is shown in Figure 24. While this model was derived from the experimental results, the exposition will be clearer if its main features

Figure 24. A model of the perceptual geometry of the Poggendorff illusion derived from the results of three experiments.


EUCLIDEAN
△X
PERCEPTUAL
θ
α
θ EUCLIDEAN ANGLE
α PERCEPTUAL ANGLE
△X MAGNITUDE OF ILLUSI

are set out in the beginning.

The main features of the model are three in number, as follows: (1) Evidence from Experiment 6 supports the view that the perceptual system extrapolates the perceptual representation of the transversal linearly across the space between the parallels as shown by the dotted line in Figure 24. There is no suggestion of any ballistic component to the perceptual path within the range of values tested. (2) The model ignores the presence of a second transversal as being significant in influencing the perceptual extrapolation. Support for this feature comes from Experiment 7 which provides direct evidence that the second transversal is not causally involved in producing the illusory effect. (3) Experiment 8 assesses directly the angle of interception of the perceptual representation of the transversal and provides evidence that the perceptual angle is indeed larger than the Euclidean angle. In sum, the model shows that the presence of a single transversal is all that is required to produce the full illusory effect. The angle at which the transversal intercepts the parallel is perceptually enlarged and this perceptual representation of the transversal is then projected linearly across the space between the parallels.

EXPERIMENT 6

It was suggested in the introduction to this chapter that the process the subject engages in when confronted by the classical Poggendorff figure is simply to perceptually extrapolate one of the transversals (e.g., the one on the lower left) across the space intervening between the parallels. If that is the case, then the form of that extrapolation as the angle of interception of the transversal and the distance between the parallels vary is of considerable interest. In four studies in which angle and separation were studied systematically together (Burmester, 1896; Caelli, Finlay, & Hall, 1975; Velinsky, 1925; Weintraub & Krantz, 1971) the results strongly suggest that for all angles, the transversal is extrapolated linearly across the separation of the parallels. Although these four studies are consistent with each other, various details are unclear, and it seemed desirable to see if the results they report are reproducible with an extended range of angles and separations of the parallels.

Method

<u>Stimuli</u> Figures were drawn with five different angles (15°, 30°, 45°, 60°, and 75°) combined with five different separations of the parallels (1, 2, 3, 4, and 5cm) generating a total of 25 different figures. As for Experiments 1, 2, and 3 the figures were duplicated on 21.5 cm x 28.0 cm ditto paper with lines 1 mm in width. The parallels were 24 cm long and the transversal 3.5 cm in length. Only the lower left transversal was present, as in previous experiments. Three copies of each figure were randomly arranged in a booklet with opaque blue pages interleaved

between figures, again, exactly as in previous experiments.

Subjects Subjects were six men and six women undergraduate students between the ages of 18 and 24 who were paid for their participation. None had taken part in illusion studies previously nor had they any knowledge of the purpose of the experiment.

Procedure All details of procedure are exactly as for Experiments 1, 2, and 3.

Results and Discussion

The results of this experiment are graphically displayed in Figure 25. The mean and standard deviation for each condition may be seen in Appendix G. The lines fitted to the data points were calculated by the method of least squares and in all cases $r^2 \geq 0.97$. Thus for all angles there is good evidence for a linear increase in the magnitude of the illusion as the separation of the parallels increases which suggests that separation acts simply as an amplifier of the illusory effect. An analysis of variance of these data (Table 8) showed a significant effect of Angle ($F(4, 44) = 55.91$, $p < .001$), of Separation ($F(4, 44) = 42.96$, $p < .001$) and a significant Angle x Separation interaction ($F(16, 176) = 26.42$, $p < .001$). The Angle x Separation interaction shows that the smaller the angle the greater the amplification effect of increasing the separation between the parallels. From these data it may be concluded that the separation between the parallels plays no causal role in generating the

Figure 25. Mean illusion in millimeters plotted as a function of separation between the parallels for patterns with five different angles of interception of the oblique.

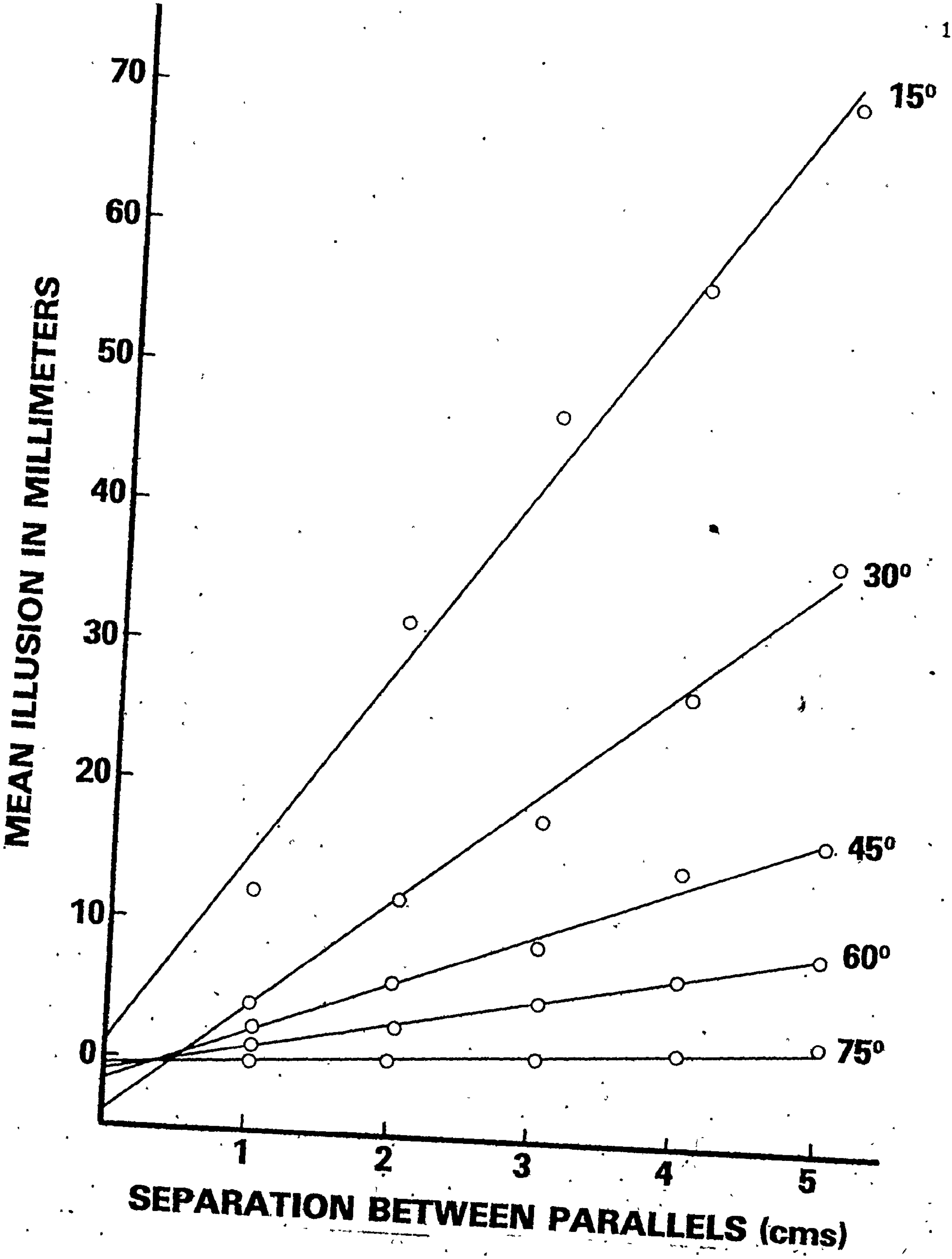

MEAN ILLUSION IN MILLIMETERS
70
60
50
40
30
20
10
0
1
2
3
4
5
SEPARATION BETWEEN PARALLELS (cms)
15°
30°
45°
60°
75°

TABLE 8

SUMMARY OF ANALYSIS OF VARIANCE ON THE DATA FOR EXPERIMENT 6.

SOURCE	SS	df	MS	F	p
Angle	68847.834	4	17211.959	55.915	.001
Angle X Subjects	13544.139	44	307.821		
Separation	19321.961	4	4830.490	42.964	.001
Separation X Subjects	4946.986	44	112.432		
Angle X Separation	14622.466	16	913.904	26.424	.001
Angle X Separation X Subjects	6087.127	176	34.586		
Subjects	13063.276	11			
Total	140433.789	299			

illusion. The data suggest that the illusion magnitude observed in the Poggendorff is a joint function of angle and separation. If angle is held constant the magnitude of illusion is a linear function of separation (Figure 26); with separation held constant the magnitude is an exponential function of the angle of interception (Figure 27). The illusion is the product of these two functions. When combined into a single equation the result is: $I=38.5\ (D-.5)e^{-.054\theta}$, where I is illusion magnitude, D is the separation between parallels (in cms) and θ is the angle of interception. This equation shows that it is the angle of interception which is important, separation between the parallels acts solely as an amplifier.

Another significant feature of the data is the existence of a cross-over point for the regression lines of the different angled obliques at approximately 0.5 cm. This indicates that at zero separation, where zero illusion magnitude has to exist, and at small separations near zero something different occurs. The exception is the 15° angle. Figure 28 is a re-drawing of Figure 25. In calculating the regression line for the 15° angle the last two data points (4 cm and 5 cm separation values) were omitted because they appeared depressed relative to the other points and could be an artifact of the presenting medium. Because of the page size, these figures occupied nearly the entire page, and therefore, the physical extension of the line was near the

Figure 26. Mean illusion in millimeters plotted as a function of separation between the parallels.

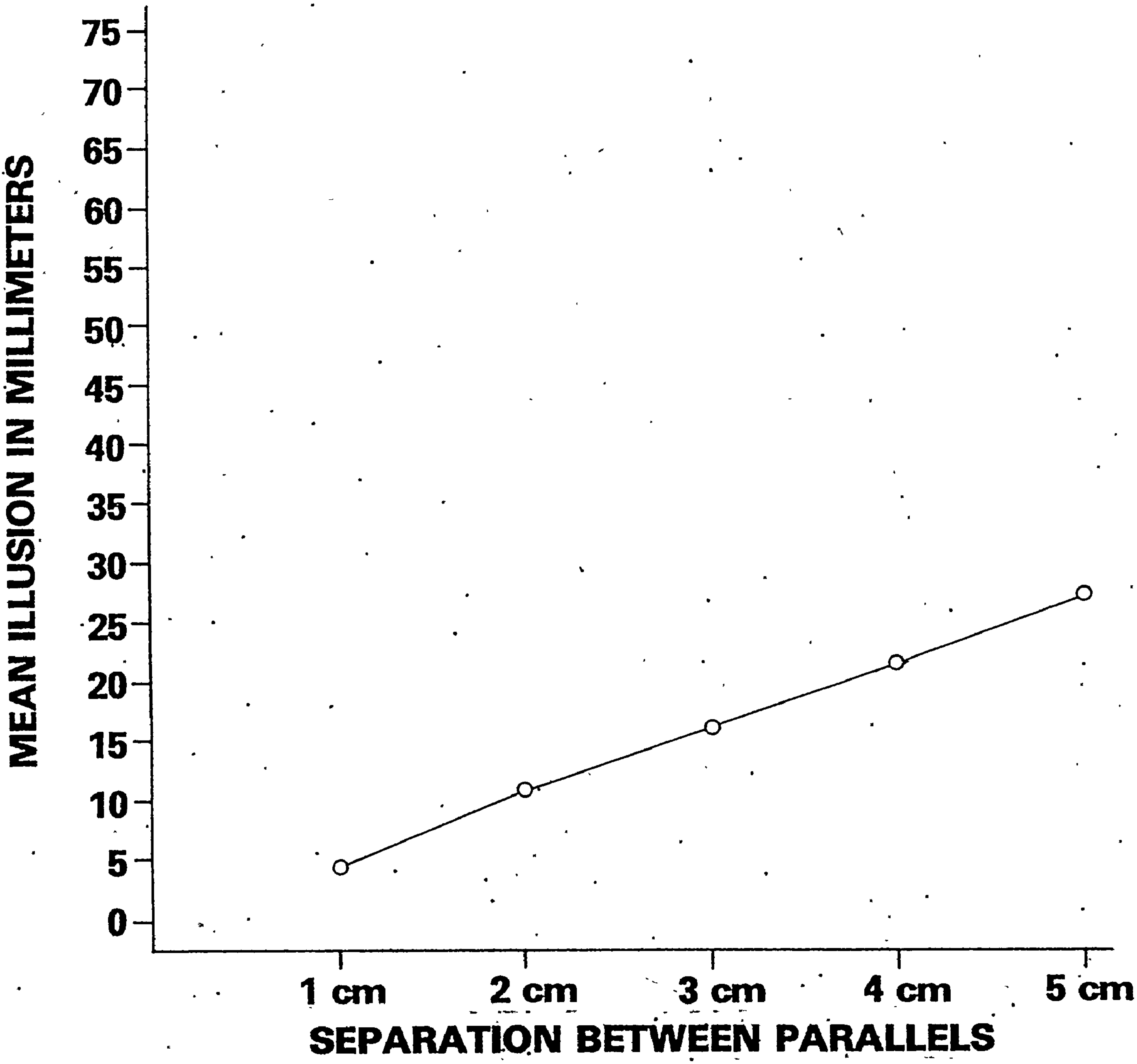

MEAN ILLUSION IN MILLIMETERS
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1 cm
2 cm
3 cm
4 cm
5 cm
SEPARATION BETWEEN PARALLELS

Figure 27. Mean illusion in millimeters plotted as a function of angle of interception of the oblique line.

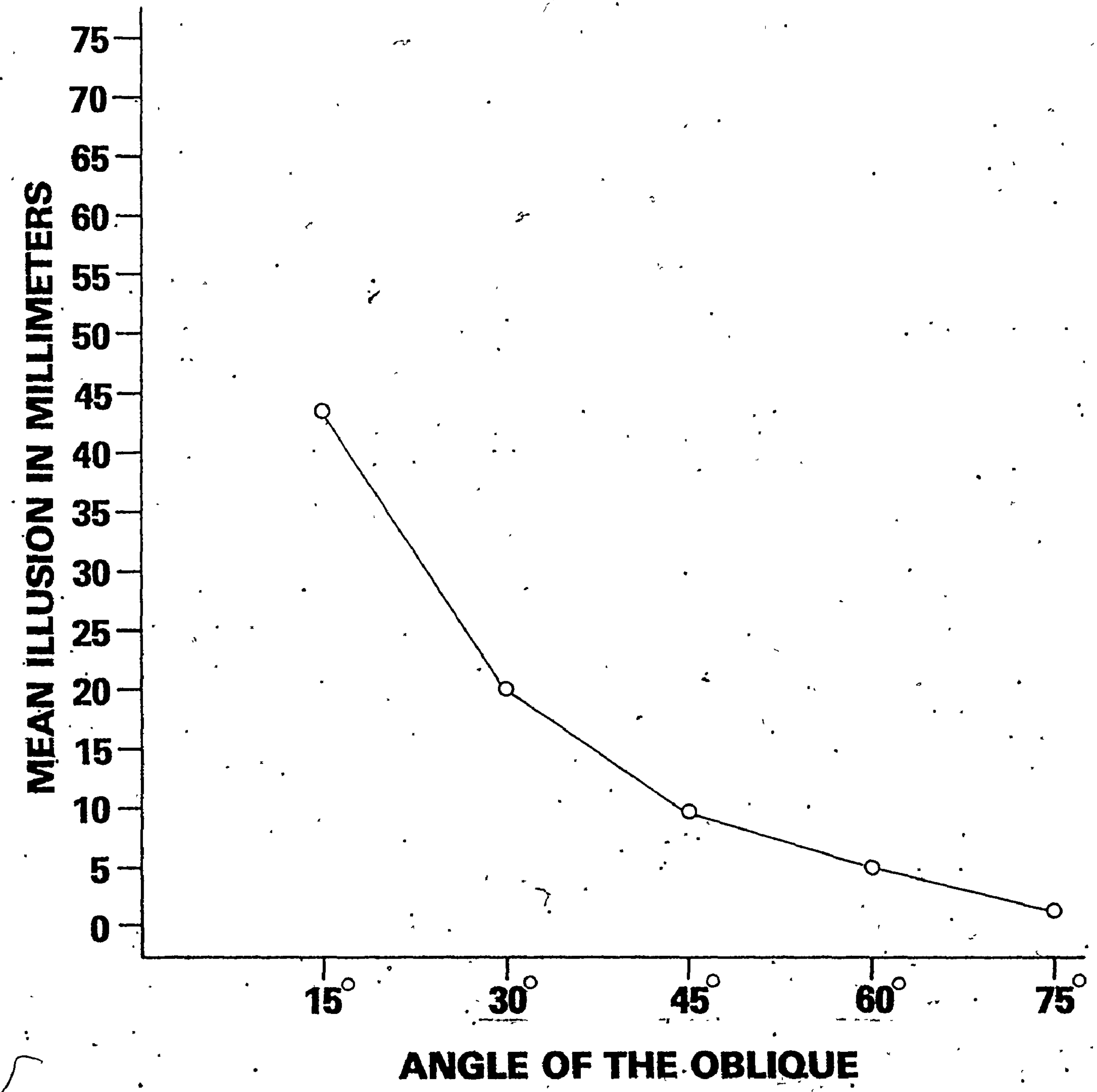
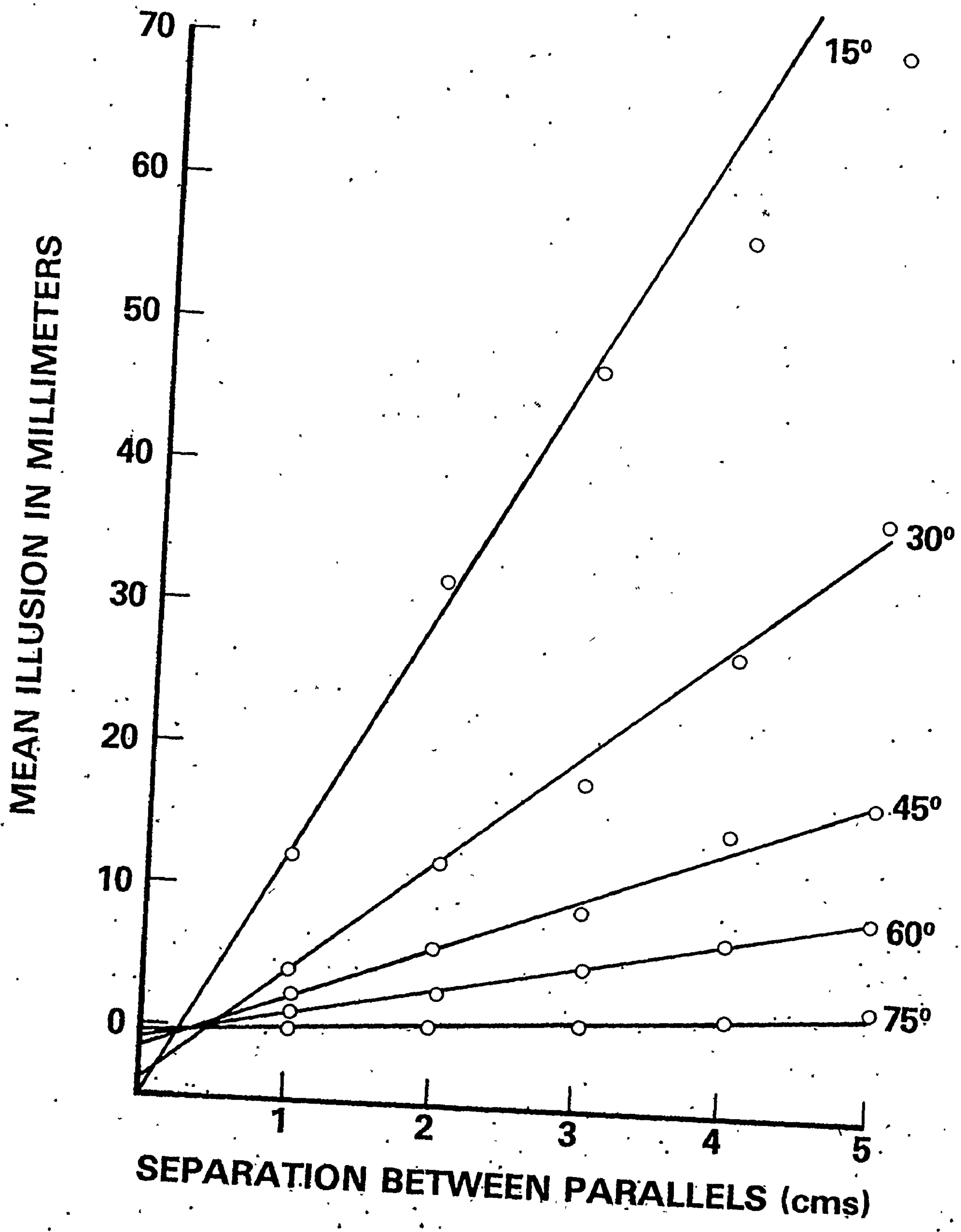

MEAN ILLUSION IN MILLIMETERS
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
15°
30°
45°
60°
75°
ANGLE OF THE OBLIQUE

Figure 28. A re-drawing of Figure 25 excluding the 4cm and 5 cm values for the 15° angle.


70
60
50
40
30
20
10
0
MEAN ILLUSION IN MILLIMETERS
1
2
3
4
5
SEPARATION BETWEEN PARALLELS (cms)
15°
30°
45°
60°
75°

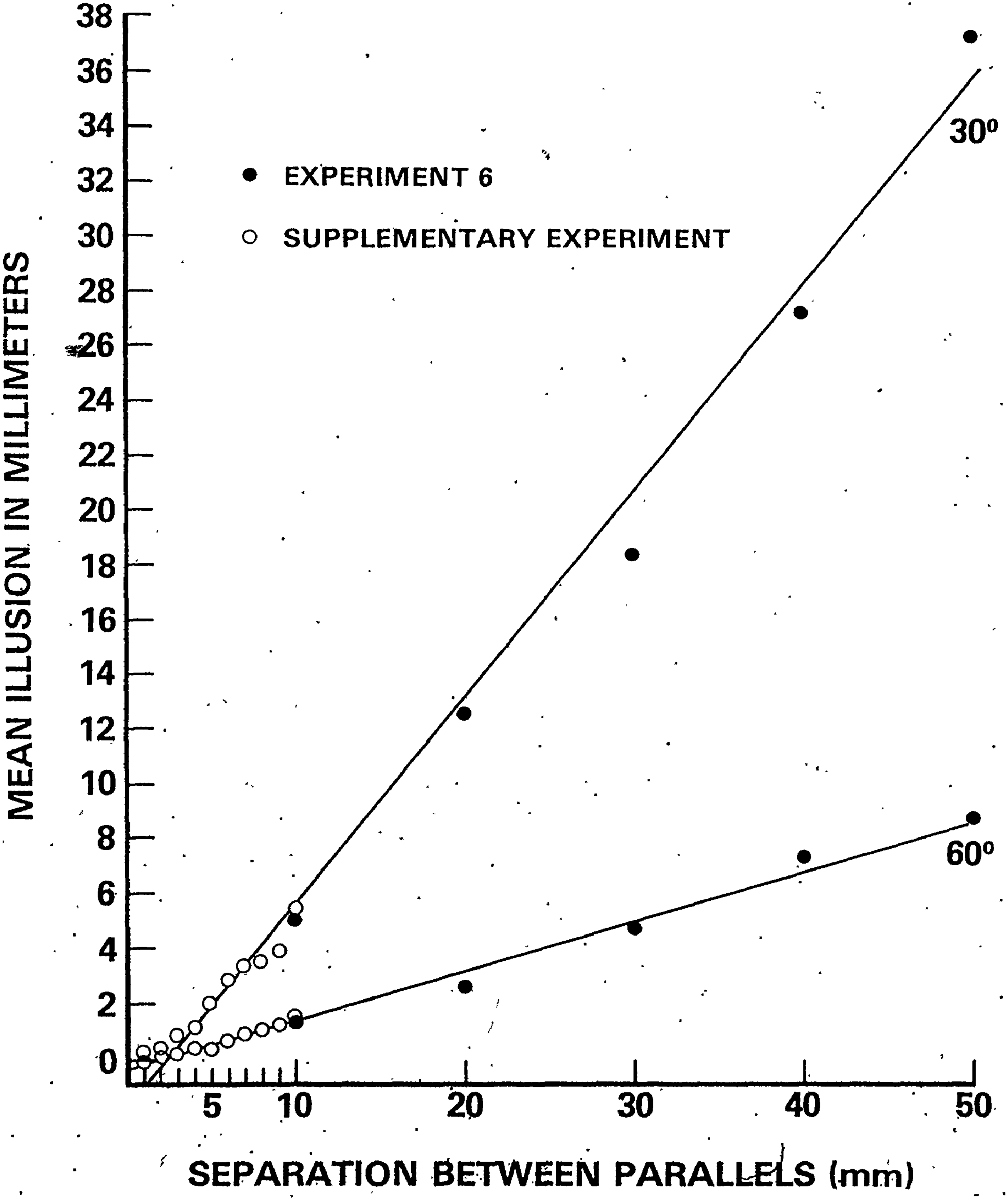
top of the page. As is apparent in Figure 28, this re-calculated regression line for the 15° angle moves it back towards the cross-over point shared by those for the other angles.

An informal supplementary experiment was conducted to explore the region between 0 and 1 cm. Ten subjects, faculty and graduate students who were available in summer, were tested using the same procedure as in Experiments 1, 2, 3, and 6. Two angles of interception (30° and 60°) and 10 separations between the parallels (1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 mms) were combined as in Experiment 6. The data are shown graphically in Figure 29 along with the relevant points from Figure 25. The lines fitted to the data points were calculated by the method of least squares. The data show that at separations close to zero the illusory effect is effectively zero. A reasonable assumption is that the function begins at zero, is essentially flat and then assumes a linear course at approximately 5 mm, the exact point of inflection being a function of the angle of interception. This experiment provides some assurance that the .5 constant in the above equation (p. 116) is not arbitary but real.

EXPERIMENT 7

The second feature of the model outlined in the introduction to this chapter is the removal of the second transversal as causally involved in producing the illusory

Figure 29. Mean illusion in millimeters plotted as a function of separation between the parallels for two different angled figures.



● EXPERIMENT 6
○ SUPPLEMENTARY EXPERIMENT
30°
60°
MEAN ILLUSION IN MILLIMETERS
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
5
10
20
30
40
50
SEPARATION BETWEEN PARALLELS (mm)

effect. There are some suggestive data in the literature. For example, Tong and Weintraub (1974), Weintraub and Krantz (1971), and Weintraub and Tong (1974) have all reported large illusory effects when a dot has been used in place of the second transversal. In these experiments the subject's task was to align a dot located on the right-hand parallel so that it appeared to be collinear with the lower left-hand transversal segment. Day (1974) presents data which shows that the same illusory effect is produced when a 45° transversal is combined with either a second 45° transversal or with a dot. However, Day used a somewhat unusual arrangement of the parallels in his experiment and it seems that the causal involvement in the illusion of the second transversal should be further examined using the classical Poggendorff figure.

Method

<u>Stimuli</u> Four figures were used in which a transversal of either 30° or 60° was combined with either a second transversal at the same angle or with a dot. These figures were made on white construction paper using black matte graphic tape 2.4 mm in width. The parallel lines were 18 cm long and 3 cm apart. The transversals were 3.5 cm long and the dots were 5 mm in diameter.

<u>Apparatus</u> The apparatus was essentially the same as that used in Experiments 4 and 5, but with a few modifications. The new apparatus consisted of an upright aluminium

frame, measuring 65 cm wide and 65 cm high and painted flat black, in which two interchangeable aluminium panels were affixed. As in the old apparatus the panel on the right, from a front view, was immovable while the one on the left could be moved freely up and down by a reversible electric motor that could be controlled by either the experimenter or the subject who was provided with a hand held push button switch. The whole of the figure, except for the lower left transversal, was fastened to the immovable panel. That transversal was fixed to the movable panel, again as before. An opening 24 cm in width and 32 cm in height was cut from the center of the frame through which the figure could be seen immediately behind.

<u>Subjects</u> The subjects were four men and eight women undergraduate students between the ages of 19 and 22 who were paid for their participation. None had taken part in illusion studies previously nor had they any knowledge of the purpose of the experiment. They were randomly assigned to one of four groups with the restriction that there be one man and two women in each group.

<u>Procedure</u> Subjects were tested individually in a room with standard flourscent lighting. They were seated at a table one meter in front of the apparatus (and so from the stimulus) and placed their chin in a chin rest. Each of the four groups received the four figures in a different order. They were instructed to adjust the position of the

lower left transversal from "too high" or "too low" experimenter determined pre-setting until it appeared collinear with either the second transversal or with the dot. (See Appendix A for a copy of the instructions used.) Each subject made three settings for each of the four figures. A 90 sec interval was interposed between successive figures.

Results and Discussion

The results of this experiment are shown in Figure 30. The mean and standard deviation for each condition may be seen in Appendix H. A Lindquist Type VI (Lindquist, 1953) analysis of variance of these data (Table 9) showed a non-significant effect of Order ($F(3, 8)=0.004$, n.s.), a significant effect of Angle ($F(1, 8)=42.12$, $p<.001$), and a significant effect of Transversal/Dot ($F(1, 8)=30.46$, $p<.001$). None of the interactions with order was significant. The Angle x Transversal/Dot interaction was significant ($F(1, 8)=21.30$, $p<.01$). The nature of this interaction is clear from Figure 30. The transversal and dot have no differential effect when the angle is 60°, whereas when the angle is 30° a larger illusion is observed when a dot replaces the second transversal. For this smaller angle the second transversal has a damping effect on illusory magnitude. A reason for this is not readily found. It is interesting that Weintraub and Krantz (1971) report a similar finding where a second transversal or a dot is combined with a first transversal forming an angle of either 16.7° or 50.2°. They did not

Figure 30. Mean illusion in millimeters for two different angled figures drawn either with two obliques or one oblique and a dot.

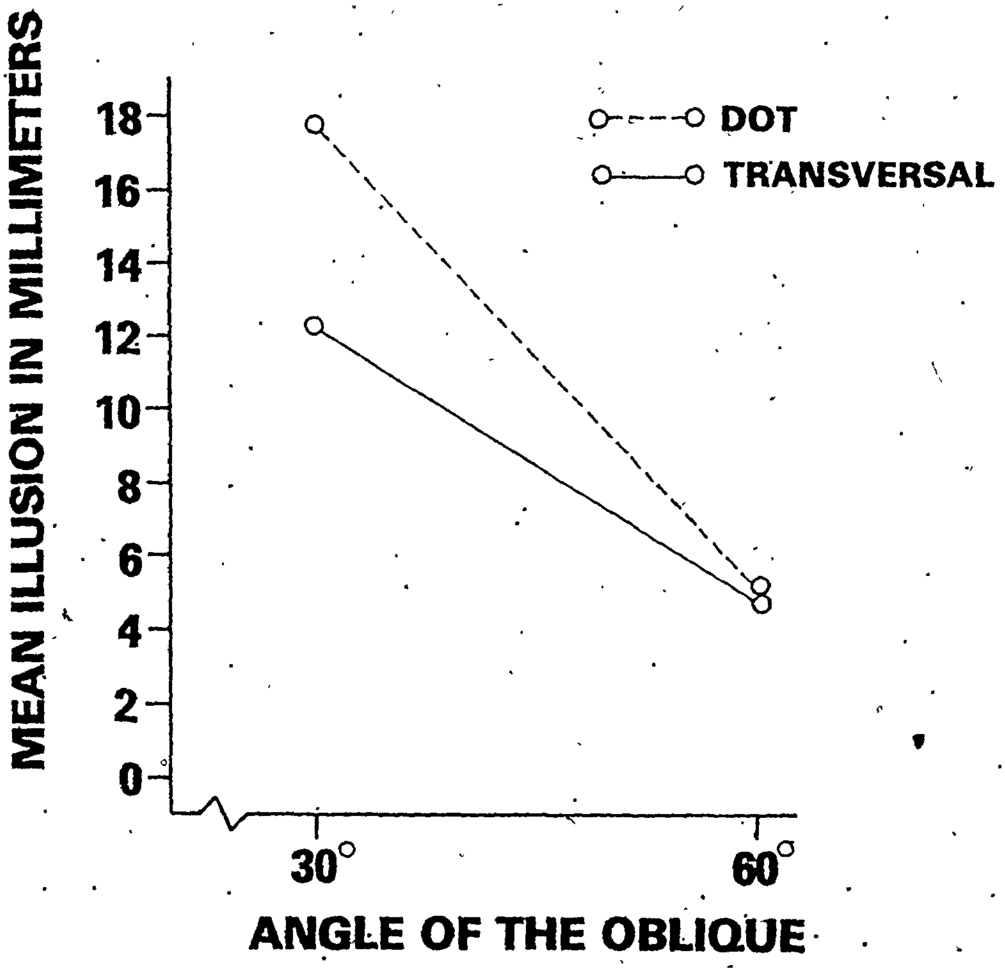

MEAN ILLUSION IN MILLIMETERS
18
16
14
12
10
8
6
4
2
0
DOT
TRANSVERSAL
30°
60°
ANGLE OF THE OBLIQUE

TABLE 9

SUMMARY OF ANALYSIS OF VARIANCE ON THE DATA FOR EXPERIMENT 7.

SOURCE	SS	df	MS	F	p
Between Subjects	545.143	11			
Order	0.788	3	0.263	0.004	
Error	544.355	8	68.044		
Within Subjects	1720.782	36			
Angle	1211.025	1	1211.025	46.127	.001
Order X Angle	28.337	3	9.446	0.360	
Error_1	210.035	8	26.254		
Transversal	103.547	1	103.547	30.464	.001
Order X Transversal	27.085	3	9.028	2.656	
Error_2	27.195	8	3.399		
Angle X Transversal	75.752	1	75.752	21.130	.01
Order X Angle X Transversal	9.124	3	3.041	0.848	
Error_3	28.682	8			
Total	2265.925	47			

statistically assess the observed difference but it would appear from its magnitude and the relatively small standard errors of the means, all of which are shown graphically in their paper, that it would be significant. No explanation of this damping effect is obvious but the effect does not change the general pattern of results and can therefore be ignored for the present purpose.

The results of this experiment combined with those of Experiment 6 support the conclusion that the whole of the illusory effect can be attributed to the linear extrapolation of the perceptual representation of a single transversal. It is obvious that this perceptual representation must be different from the Euclidean one if the illusion is to be accounted for. The next experiment was designed to discover the nature of the differences.

EXPERIMENT 8

As noted in Chapter II, it was Hering in 1861 who first attributed the Poggendorff illusion to the enlargement of acute angles. In recent years psychophysical evidence (Blakemore, Carpenter, & Georgeson, 1970; Bouma & Andriessen, 1968, 1970; Fisher, 1969; Hotopf & Ollerearnshaw, 1972a, a), as well as neurophysical evidence (Burns & Pritchard, 1971) has become available which supports the view that the perceptual representation of an acute angle is indeed larger than its Euclidean counterpart. The difficulty in using these results to explain the Poggendorff illusion is that the magnitude of the enlargement reported is far too small. Hotopf and Ollerearnshaw (1972a), for example, had subjects choose an acute angle from a comparison set to match that made by one of the obliques in a Poggendorff figure which was simultaneously present. They observed apparent enlargements on the order of only 0.5°.

There is a logical difficulty with this method and, indeed, any method where the angle to be compared or reproduced is present while the subject selects another angle which is perceptually equal to it or attempts to draw an angle of matching size. The nature of the difficulty can perhaps best be seen by an example. Suppose the subject is shown a 30° angle and that it is in fact perceptually enlarged by some substantial amount, say 8°. None he is shown a second angle of 38° and he says it is too large for a match, This is exactly what we would expect because this second angle will also be perceptually enlarged to an angle of 45° or so. In fact, the only angle that should appear equal to the perceptual representation of a 30° angle is a second 30° angle. They will both be enlarged by the same amount. From the experimenter's point of view the subject's choice of a matching angle may indicate little or no angular enlargement although the enlargement may be substantial indeed.

In the experiment which follows we have used a different method of estimating angular enlargement which appears to get around this difficulty and does produce values large enough to account for the magnitude of the Poggendorff illusion.

Method

Stimuli Four sets of stimuli were prepared, one for each of the 30°, 45°, 60°, and 75° angles, with each set consisting of 11 cards. Consider the 30° set as an example. The classical Poggendorff was drawn with the transversal intercepting the lower part of the left-hand parallel at an angle of 30° and with a dot on the upper part of the right-hand parallel replacing the second transversal. The transversal and the dot were aligned so that if the transversal were extended upwards it would pass through the center of the dot. Then 10 additional figures were prepared in which the position of the dot and the point of interception of the transversal were identical but in which the angle of the transversal was made smaller in successive steps of 1.5°. The smallest angle in this set, then, was 15°. This same method was used to prepare the 45°, 60°, and 75° sets.

Preliminary experimentation showed that, for all sets, the range of angles used was securely anchored at both ends. For the transversal that formed an angle such that its Euclidean extrapolation would pass through the center of the dot, the classical figure, all subjects judged that it would pass below. Similarly, at the other extreme, all subjects judged that the transversal forming the smallest angle with the parallel would pass above the dot.

All figures were drawn in black ink on 35.5 cm x 28.0 cm white bristol board. The parallels were 18 cm long and 3 cm apart, while the obliques were 3.5 cm long. All lines were 0.5 mm in width and the dot was 2 mm in diameter.

Subjects Subjects were 9 men and 11 women undergraduate students between the ages of 20 and 28 who were paid for their participation. None had taken part in illusion studies previously nor had they any knowledge of the purpose of the experiment. They were randomly assigned to one of four groups of five subjects each with the restriction that there be at least two men and two women in each group.

Procedure Each group was given 110 trials (10 presentations of each of the 11 figures) with one of the stimulus sets. Subjects were tested individually in a room with standard flourescent lighting.

When the subject arrived at the experimental room he was seated at a table, one meter in front of a stimulus card holder. He was shown one of the stimulus cards and instructed that for each similar card he was shown he was to judge whether the transversal, if extended, would pass above or below the dot. "Through" judgments were not permitted. (See Appendix A for a copy of the instructions used.) Before collecting his judgments the subject was shown all the members of the set so that he was familiar with the range. After each run through, the set of cards was shuffled and presented again in a different order. The session with each subject lasted about 30 minutes.

Results and Discussion

For each subject the proportion of "above" and "below" judgments were calculated and from these data an estimate was made of the Euclidean angle that defined the median. These estimates were averaged over subjects within each group and a summary of the results is given in Table 10. It will be noted that the enlargement expressed in degrees is substantial and that the percentage increase, particularly for small angles, is very large indeed.

Some explanation is required of the basis on which, for example, an angle of 30^{o} is taken to be the perceptual equivalent of a Euclidean angle of 21.3^{o}. First, it is a fact that, on the average, subjects choose a Euclidean angle of 21.3^{o} as the one that would pass through the dot. Perceptually, the transversal and the dot lie on a common path although, of course, a Euclidean extrapolation of a 21.3^{o} transversal would pass well above it. But if perceptually the 21.3^{o} angle is enlarged to 30^{o}, then the perceptual path will have a smaller slope and achieve collinearity with the dot, precisely what the physical extrapolation of the Euclidean angle of 30^{o} achieves. Thus, when the Euclidean angle is 21.3^{o}, the perceptual geometry maps on to the Euclidean

TABLE 10

EUCLIDEAN ANGLES AND THEIR PERCEPTUAL EQUIVALENTS FOR EXPERIMENT 8.

Euclidean Angle	Perceptual Equivalent	Difference (Degrees)	% Enlargement (Difference/Euclidean)
21.3°	30°	8.7°	41%
36.7°	45°	8.3°	23%
52.1°	60°	7.9°	15%
68.5°	75°	6.5°	9%

when that geometry includes an angle of 30°.

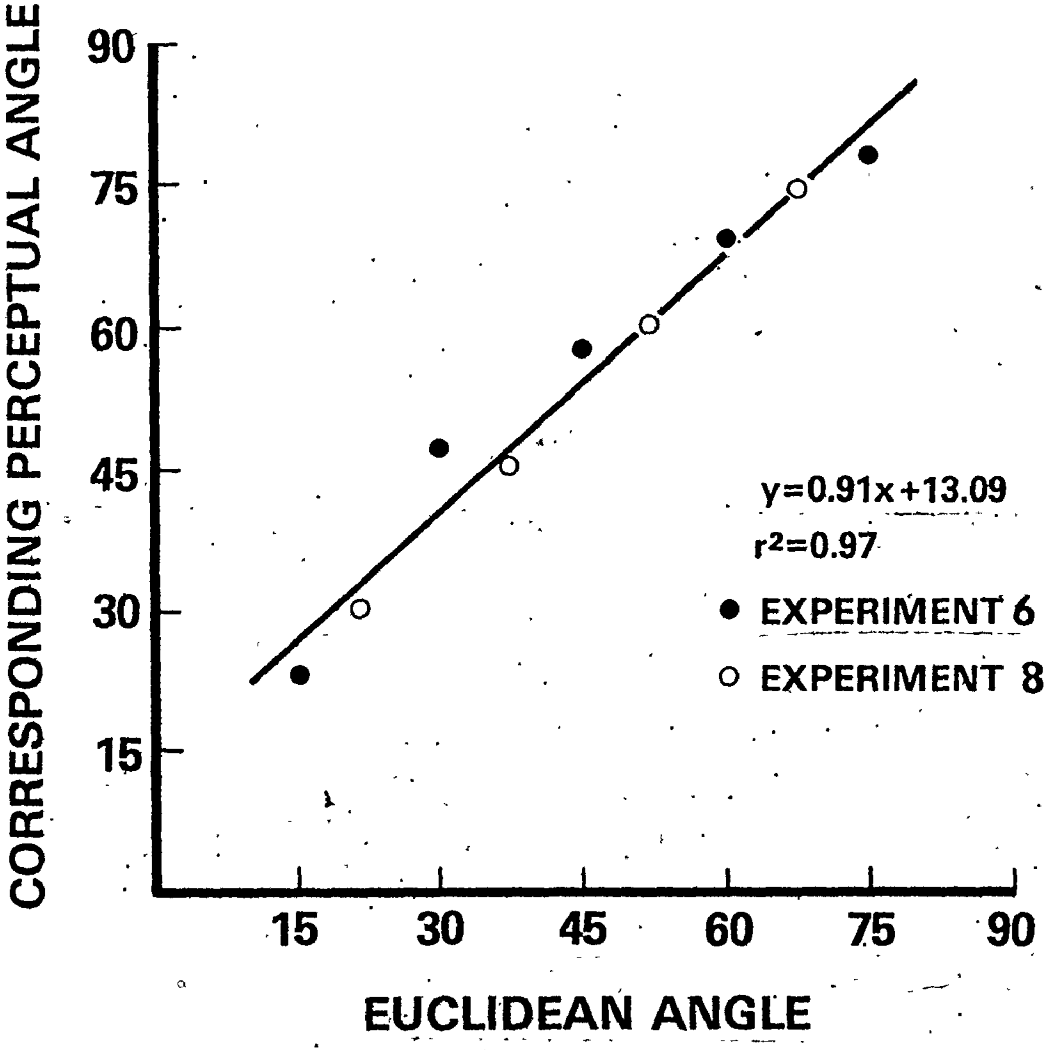
Some confirmation of the validity of these values for angular enlargement may be obtained by comparing them with values estimated from the magnitudes of illusion observed in Experiment 6. These estimates were obtained by extrapolating the least squares lines of best fit on a scale drawing for the data points in Figure 25 until they intercepted the left-hand parallel. A perceptual angle was then calculated trigonometrically and compared with the Euclidean angle that generated the various illusion magnitudes.

These estimates along with those of Experiment 8 are plotted in Figure 31. The linear regression equation was calculated by the method of least squares using all of the data points shown in the figure. Considering the very different ways in which the two sets of data were obtained, the fit seems remarkably good and constitutes, in effect, an across experiment validation of our method of directly estimating subjective angle.

EXPERIMENT 9

The three experiments so far described in this chapter were designed to provide the basis for an empirical model of the perceptual representation of the classical Poggendorff figure and not to test a theory about the cause of the illusory effect. By attributing the whole of the effect to the perceptual enlargement of a single transversal,

Figure 31. Estimates of perceptual angles corresponding to various Euclidean angles.


CORRESPONDING PERCEPTUAL ANGLE
90
75
60
45
30
15
15
30
45
60
75
90
EUCLIDEAN ANGLE
y=0.91x+13.09
r²=0.97
● EXPERIMENT 6
○ EXPERIMENT 8

however, certain theoretical interpretations would seem to be ruled out as possibilities. In particular, any theory such as misapplied constancy (Gregory, 1966) or depth processing (Gillam, 1971) which proposes that the two transversals are perceptually misaligned because the configuration somehow interfers with their being processed as a single line receding in depth, has to be wrong unless it is argued that a dot acts as effectively as a second transversal. It should be noted, however, that although not fully developing this argument, Gillam (1971) does state that the illusory effects are the same when a dot replaces the second transversal.

Of the other proposals most involve angular distortion (see Chapter II). Burns and Pritchard (1971), unlike most proponents of angular enlargement, propose a testable mechanism which produces this effect. They attribute the cortical displacement of contours that form an angle to reciprocal inhibition in the visual system. Since reciprocal inhibition depends upon brightness differences between the contours which form the angle and the background against which they are displayed it should be possible, by shading in the area formed by the acute angle, to eliminate the excitatory-inhibitory relationship and thus the contour displacement. Behaviorally, this should result in the elimination of apparent displacement from collinearity of the transversal segments in the classical Poggendorff figure.

Method

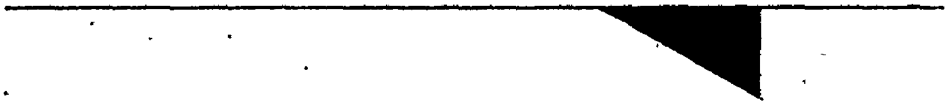
Stimuli The three figures used in this experiment are shown in Figure 32. These figures were produced on white construction paper with black matte graphic tape 1.6 mm in width. The parallel lines were 32 cm long and 3 cm apart. The obliques were 3.5 cm long and intercepted the parallels at an angle of 30°. The shading in the two figures was done with wide black matte tape so that the shaded areas were of the same brightness as the lines.

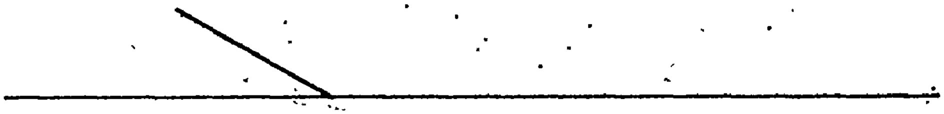
Apparatus The apparatus was the same as that used in Experiment 7.

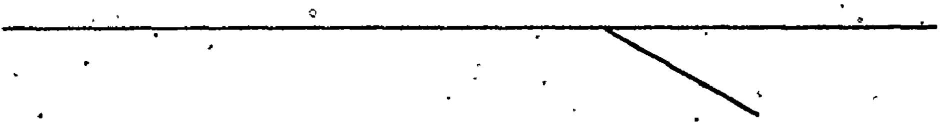
Subjects The subjects were six men and six women undergraduate students between the ages of 18 and 23 who were paid for their participation. None had taken part in illusion studies previously nor had they any knowledge of the purpose of the experiment. They were randomly assigned to one of three groups with the constraint that there be two men and two women in each group.

Procedure Subjects were tested individually in a room with standard flourescent lighting. They were seated one meter in front of the apparatus (and so from the stimulus) and placed their chin in a chin rest. Each of the three groups received all three figures but in a different order. They were instructed that they were to adjust the position of the lower left-hand transversal (or angled edge of the shaded area) from a "too high" or "too low"

Figure 32. The figures used in Experiment 9.







experimenter determined pre-setting until it appeared collinear with the transversal (or angled edge of the shaded area) on the upper right. (See Appendix A for a copy of the instructions used.) Each subject made five settings for each of the three figures. A 90 sec interval was interposed between successive figures.

Results and Discussion

A Lindquist Type I (Lindquist, 1953) analysis of variance of the data (Table 11) showed a significant effect of Figure ($F(2, 18)=44.18$, $p<.001$). The effect of Order was not significant ($F(2, 9)=0.01$, n.s.). Tukey's H.S.D. test showed that the magnitude of illusion for the shaded acute angle figure was significantly smaller than that for either the classical or shaded obtuse angle figures ($p<.01$). These latter two figures did not differ between themselves. The mean illusion magnitudes (mms) associated with each of the figures in the order in which they appear in Figure 31 are: 15.1, 12.8, and 5.1.

The dramatic reduction in illusion magnitude produced by shading in the acute angle would seem to provide strong support for the Burns and Pritchard (1971) view that the apparent misalignment of the transversals in the classical Poggendorff figure is to be understood as due to a "distorted cortical image" brought about by reciprocal inhibition in the visual system. The fact that the shaded obtuse angle figure does not produce a significant decrement

TABLE 11

SUMMARY OF ANALYSIS OF VARIANCE ON THE DATA FOR EXPERIMENT 9.

SOURCE	SS	df	MS	F	p
Between Subjects	482.84	11			
Order	0.84	2	0.42	0.01	
Error	482.00	9	53.56		
Within Subjects	824.11	24			
Figure	658.30	2	329.15	44.18	.001
Order X Figure	31.71	4	7.93	1.06	
Error	134.10	18	7.45		
Total	1306.95	35			

in illusion, as compared with the classical figure, suggests that shading in and of itself is not the significant factor. It is where the shading is placed that is important.

While shading in the area formed by the acute angles does bring about a very substantial reduction in illusion magnitude it could be argued that this is not a crucial test. This is because, in addition to eliminating or reducing the stimulus conditions necessary for inhibitory effects to occur, shading also has the effect of perceptually isolating the acute angles from the parallels and so generates a different figure. It is well known, as documented in Chapter II, that acute angles in the absence of parallels determine, at best, a very small illusion. Some reassurance that this is not the explanation of the small illusion observed with this figure is provided by the large illusion generated by the shaded obtuse angle figure. Here too the acute angles are perceptually isolated from the parallels and yet the illusory effect is large. The fact that this figure generates a somewhat (though not statistically reliable) smaller illusion than the classical figure may be because, on the shaded side, the acute angle has a one edge contour and this may attenuate the inhibitory processes.

The fact that the shaded acute angle figure still produces a significant positive ($t(11)=3.83$, $p<.005$), though reduced illusion remains to be dealt with. Any account is necessarily speculative at this point but it does seem plausible that the brightness differences between the shaded area and the background produce a degree of reciprocal inhibition sufficient to account for the residual illusion. Clearly, further study is needed before any fruitful development of this line of thought is possible.

CHAPTER V

CONCLUSIONS AND DISCUSSION

In this final chapter, the three major conclusions and the experimental findings from which they are drawn are noted and their implications discussed. Statements are limited to those that seem warranted within the restrictions of the experimental data reported. As well, the shortcomings and problems with the research are noted. Finally, lines of further research suggested by the data are mentioned.

CONCLUSIONS

1. The illusory effect produced by the variants and the classical Poggendorff figure is attributable to a single common perceptual process.

   a. The variants and the classical figure all produce an illusion of displacement in the same direction. (Experiments 1, 2, 3, 4, and 5).

   b. The variants and the classical figure respond in the same way to increases in angle size (the magnitude of illusion decreases as angle size increases - Experiment 1), and to increases in the separation between the parallels (the magnitude of illusion increases as the separation increases -

Experiment 2).

c. Individuals respond consistently to the variants and the classical figure. (Experiments 1 and 2)

d. The variation in illusion magnitude observed among the variants is dependent on the particular components retained or omitted, not upon the total amount of the pattern presented. (Experiment 3)

e. The magnitude of illusion decreases with practice and equal or greater positive transfer to the classical figure is obtained from the variants as from the classical figure itself. (Experiments 4 and 5)

2. The perceptual representation of the Poggendorff figure differs from its Euclidean representation.

a. For any angle of interception of the transversal there is a linear increase in the magnitude of the illusion as the separation between the parallels increases. (Experiment 6)

b. A single transversal is all that is required to produce the full illusory effect. (Experiment 7)

c. The angle of interception is perceptually enlarged. (Experiment 8)

3. Angular enlargement due to lateral inhibition in the visual system is involved in generating the illusion. (Experiment 9)

DISCUSSION

The major contribution of this thesis is empirical. In particular the first five experiments are noteworthy in that they serve as a much needed clarification with respect to the variants and the classical figure. It was shown that the systematic removal of line segments from the classical Poggendorff figure produces variants and that these variants produce an illusory effect in the same direction as the classical figure, although substantially smaller in magnitude. Moreover, these experiments demonstrated that figure and stimulus variables interact, they are not independent of each other in determining the magnitude of the illusion. Specifically it was noted that angle size and separation of the parallels have a smaller effect on the acute and oblique figures than they do on the classical and obtuse figures. It appears that many of the discrepant and inconsistent results noted in the historical introduction can be attributed, in part, to varying values of important stimulus variables. For example, Green and Hoyle's (1964) result of no significant misalignment in an oblique only figure is entirely reasonable given the metrics of the situation, a 45° angle of inclination and a 1 cm separation. When standard values are selected a clearer picture can be assembled. Another empirical contribution is the derivation of the model. This is significant in that it clarifies what the perceptual system does when confronted with the classical Poggendorff figure and this is basic for any theory. The main theoretical contribution is the implication of lateral inhibition in generating the illusion.

The Poggendorff illusion has been known and studied for over 100 years, but little progress has been made at understanding how the observed perceptual effects occur. Theories on the cause of the illusion have always been plentiful. Ingenious explanations were often presented by early theorists. These theorists were, however, less ingenious in showing that their explanation accounted for the empirical facts about the illusion. Contemporary theorists have also employed 19th century ideas of what mechanisms might be involved in the Poggendorff. Elsewhere contemporary theorists have adopted explanatory mechanisms from other areas of visual perception. It will be remembered, however, that none of the current theories is able to account for all of the data. The strong point that emerges from the present experiments is that contained in the last experiment which dealt with the process responsible for the illusion. The data strongly implicate lateral inhibition in the visual system.

Burns and Pritchard (1971) demonstrated that the cortical representation of figures containing acute angles undergoes neurological distortion. This distortion results in acute angles being perceptually enlarged. Our own experiments arrived at the same result by entirely different means.

Burns and Pritchard attribute this neurological distortion to lateral inhibition in the visual system. Two things from the present experiments seem to support their position. One is the rebound effect observed at the beginning of the transfer trials after practice. It is conceivable that some sort of physiological adaptation occurs during the practice trials and the 5 minute interval at the end of the practice trials before the start of the transfer trials permits substantial recovery from this adaptation. It is known, for example, that the strength of inhibition depends on the level of excitation of the interacting units and that excitation declines in the face of constant stimulation. The effect of repeated presentations could be to decrease the excitation level and thus the excitatory-inhibitory interactions. The 5 minute interval between trial groups would allow a partial return to the conditions that existed before practice. If, alternatively, the illusion decrement observed with practice were due to some kind of cognitive learning one would not expect the rapid and substantial "forgetting" that is in fact observed.

The other is the result of the shading in of the acute angles. By modifying the figure such that the brightness differences between the contours of the angles and the background were eliminated, and so the excitatory-inhibitory relationship, a significant reduction in illusion magnitude was observed.

The model derived from the experimental data and an interpretation in terms of lateral inhibition, handles the classical figure quite well. In addition several pieces of data can be easily accounted for; for example, the effect of angle of interception. With small angles the contours forming the angle are close together and this maximizes the excitatory-inhibitory relationship; with large angles the illusion will be weak because the contours forming the angles are farther apart. In discussing an observer's assessment of angle based on the projected shape of the cortical image of an angle pattern, Burns and Pritchard (1971) state that maximal perceptual error will occur between 35^{o} to 45^{o} while no error of perception would be expected for a 90^{o} angle.

There are, however, a number of problems that arise when one attempts to account for the illusion generated by the complete Poggendorff and its variants solely in terms of lateral inhibition. As the first five experiments show amputating the figure reduces the illusion magnitude. Herein lies a problem. There is no obvious reason why, for example, in the case of the acute angle figure, the illusion magnitude should be reduced; the angle is still present. In addition, the large illusory effect obtained in the obtuse angle figure cannot be accounted for since lateral inhibition is not expected in the case of angles equalling 90^{o} or more. Further, in the vanishing point figure (Gillam, 1971; Young, 1976) why should we get a reduction in illusory magnitude?

It is not that the causal factor has been eliminated since the acute angles are still present, but rather in this case, the illusory effect is attenuated due to the way the figure is constructed. The total configuration must contribute to the illusion. More is taken into account in our perception of the Poggendorff figure than angle, and a causal explanation cannot be limited to what goes on at the angles. Somehow the total figure is taken into account by the perceptual system. Burmester (1896) recognized this when he argued that the overestimation of acute angles is determined through the form (Gestalt) of the figure. It is not immediately obvious, however, how the perceptual system takes the total configuration into account.

Another piece of data with which an interpretation in terms of lateral inhibition has difficulty concerns the effects of orientation. Why should placing the obliques vertical or horizontal result in a reduction of illusory magnitude? If we accept, however, the notion of orientation specific cells then it is not unreasonable to expect that those cells which respond maximally to vertical or horizontal orientations to predominate, for it is well known that performance is better on a variety of perceptual tasks when the orientations to be judged correspond to "spatial norms" (Appelle, 1972). As well, Robinson (1972) in his discussion of various illusion figures relates the idea of "specifically tuned orientation analysers". This idea is used by Carpenter and Blakemore (1973) to support their model for angular distortion.

While a core physiological process like lateral inhibition may underlie the classical Poggendorff illusion, this is not meant to imply that all aspects of this phenomenon can be explained in sensory or neurophysical terms. For example, consider the reduced illusion observed in the variants. In addition, the residual illusion observed in the shaded acute angle figure has to be explained. These are some of the issues which remain unresolved within the present set of experiments. Clearly further research is needed.

Burns and Pritchard (1971) showed that neural distortion of visual information is involved in the Poggendorff illusion but this cannot be everything. Accordingly, our initial conclusion of a single underlying perceptual process has to be tempered. It may well be that a two factor explanation is required. A promising companion candidate in this regard is depth processing as implicated by Gillam (1971) and Young (1976). An account involving perspective is appealing in that, like lateral inhibition, not only is a well established perceptual principle invoked, but also a link between two bodies of perceptual knowledge is effected. Therefore, it could be argued that a dot (Experiment 7) functions as a very short line. Given that the vanishing point figure reduces the illusion, as does amputating the figure, it is possible that under some circumstances the organization of the figure exercises constraints on the inhibitory effect. Certain other arrangements, i.e., the classical figure; permit a maximal effect. The organization of the figure, therefore, could determine how the figure is perceived (in depth or not) and thus the relative contribution of the different processes. Of course, any statement along this line is necessarily speculative at this time and additional study is needed before any definite statement is possible.

One of the first experiments that should be undertaken as an adjunct to the present studies concerns the residual illusion found in the shaded acute angle figure. As pointed out in the discussion of Experiment 9, brightness differences between the shaded areas and the white background could produce a degree of reciprocal inhibition sufficient to account for the residual illusion and this possibility should be investigated.

As well, the role of perspective should be investigated. Adding perspective cues has been found to reduce the illusion by 30% to 50% from that observed in the classical figure (Gillam, 1971; Young, 1976). If depth processing is involved in generating the illusion then shading in the area formed by the acute angles in a figure to which perspective cues have been added, e.g., a vanishing point figure, should eliminate or at least further reduce the illusion.

One phenomenon that clearly warrants further study in connection with the process involved in the decrement of the illusion with practice, is the significant recovery between the end of practice and the beginning of the transfer trials. This rebound effect is indeed curious and demands attention.

These are some of the problems and questions which were not addressed, which this research indicates should be examined in order to more fully understand the perceptual processes which produce the Poggendorff illusion.

BIBLIOGRAPHY

Anton, B.S. Poggendorff illusion as a function of orientation of transversal and parallel lines. Perceptual and Motor Skills, 1976, 43, 83-90.

Appelle, S. Perception and discrimination as a function of stimulus orientation: The "Oblique Effect" in man and animals. Psychological Bulletin, 1972, 78, 226-278.

Baldwin, J.M. Handbook of psychology. (2nd ed.) New York: Henry Holt & Co., 1890.

Bayer, C.A. An explanation of developmental differences in the successive trials effect of the Poggendorff illusion. Psychonomic Science, 1972, 26, 85-86.

Bean, C.H. The blind have "optical illusions". Journal of Experimental Psychology, 1938, 22, 283-289.

Beery, K.E. Estimation of angles. Perceptual and Motor Skills, 1968, 26, 11-14.

Békésy, G. von Sensory inhibition. Princeton: Princeton University Press, 1967.

Blakemore, C., Carpenter, R.H.S., & Georgeson, M.A. Lateral inhibition between orientation detectors in the human visual system. Nature, 1970, 228, 37-39.

Blix, M. Die sogenannte Poggendorff'sche optische tauschung. Skandinavisches Archiv fur Physiologie, 1902, 13, 193-228.

Boring, E.G. A history of experimental psychology. New York: Appleton-Century, 1929.

Boring, E.G. Sensation and perception in the history of experimental psychology. New York: Appleton, 1942.

Bouma, H. & Andriessen, J.J. Perceived orientation of isolated line segments. Vision Research, 1968, 8, 493-507.

Bouma, H. & Andriessen, J.J. Induced changes in the perceived orientation of line segments. Vision Research, 1970, 10, 333-349.

Brentano, F. Ueber ein optisches Paradoxon. Zeitschrift fuer Psychologie, 1892, 3, 349-358. Cited by M. ~~Blix~~, Die songenannte Poggendorff'sche optische tauschung. Skandinavisches Archiv fur Physiologie, 1902, 13, 193-228.

Burmester, E. Beitrag zur experimentellen Bestimmung geometrisch-optischer Taeuschungen. Zeitschrift fur Psychologie und Physiologie de Sinnes, 1896, 12, 355-394.

Burns, B.D. & Pritchard, R. Geometrical illusions and the response of neurones in the cat's visual cortex to angle patterns. Journal of Physiology, 1971, 213, 599-616.

Caelli, T.M., Finlay, D.C., & Hall, A.C. Lie transformation groups and the Poggendorff illusion. Australian Journal of Psychology, 1975, 27, 177-186.

Cameron, E.H. & Steele, W.M. The Poggendorff illusion. Psychological Review Monograph Supplement, 1905, 7, 83-111.

Carpenter, R.H.S. & Blakemore, C. Interactions between orientations in human vision. Experimental Brain Research, 1973, 18, 287-303

Carr, H.A. An introduction to space perception. New York: Longmans, Green, 1935.

Carter, D.J. & Pollack, R.H. The great illusion controversy: A glimpse. Perceptual and Motor Skills, 1968, 27, 705-706.

Chiang, C. A new theory to explain geometrical illusions produced by crossing lines. Perception & Psychophysics, 1968, 3, 174-176.

Coren, S. The influence of optical aberrations on the magnitude of the Poggendorff illusion. Perception & Psychophysics, 1969, 6, 185-186.

Coren, S. Lateral inhibition and geometrical illusions. Quarterly Journal of Experimental Psychology, 1970, 22, 274-278.

Coren, S. & Girgus, J.S. Illusion decrement in intersecting line figures. Psychonomic Science, 1972, 26, 108-110.

Coren, S., Girgus, J.S., Erlichman, H., & Hakstian, A.R. An empirical taxonomy of visual illusions. Perception & Psychophysics, 1976, 20, 129-137.

Croft, W.B. Optical illusions. Nature, 1892, 47, 78.

Cumming, G.D. A criticism of the diffraction theory of some geometrical illusions. Perception & Psychophysics, 1968, 4, 375-376.

Curthoys, I., Wenderoth, P., & Harris, J. The effects of the motion path and the length of the variable segment in the Poggendorff illusion without parallels. Perception & Psychophysics, 1975, 17, 358-362.

Day, R.H. On the stereoscopic observation of geometric illusions. Perceptual and Motor Skills, 1961, 13, 247-258.

Day, R.H. The oblique line illusion: The Poggenodrff effect without parallels. Quarterly Journal of Experimental Psychology, 1973a, 25, 535-541.

Day, R.H. The Poggendorff illusion with obtuse and acute angles. Perception & Psychophysics, 1973b, 14, 590-596.

Day, R.H. The Poggendorff illusion: Apparent displacement of the oblique lines. Australian Journal of Psychology, 1974, 26, 49-59.

Day, R.H. & Dickinson, R.G. The components of the Poggendorff illusion. British Journal of Psychology, 1976, 64, 537-552.

Delboeuf, J. Notes sur certaines illusions d'optique. Bulletins de l'acad. roy. de Belg. 2me S., 1865, 19, 195. Cited by von Kries in H. Helmholtz, Handbuch der physiologischen Optik III, (1910). Trans. by J. P.G. Southall (Ed.) Helmholtz's treatise on physiological optics. New York: Dover Publications, 1962.

Dresslar, F.B. A new illusion for touch and an explanation for the illusion of displacement of certain cross lines in vision. American Journal of Psychology, 1893-95, 6, 275-276.

Einthoven, W. Eine einfache physiologische Erklarung fur verschildene geometrisch-optische Tauschungen. Pfluger's Archiv fur Physiologie, 1898, 71, 1-43. (Abstract)

Eriksson, E.S. A field theory of visual illusions. British Journal of Psychology, 1970, 61, 451-466.

Evans, C.R. & Marsden, R.P. A study of the effect of perfect retinal stabilization on some well-known visual illusions, using the after-image as a method of compensating for eye movements. British Journal of Physiological Optics, 1966, 23, 242-248.

Farne, M. On the Poggendorff illusion: A note to Cumming's criticism of Chung Chiang's theory. Perception & Psychophysics, 1970, 8, 112.

Filehne, W. Die geometrisch-optischen Tauschungen als Nachwirkungen der im korperlichen Sehen erwarbenen Erfahrung. Zeitschrift fur Psychologie und Physiologie der Sinnesorgane, 1898, 17, 15-61. Cited by A.H. Pierce, Studies in auditory and visual space perception. New York: Longmans, Green, & Co., 1901.

Finlay, D.C. & Caelli, K. The Poggendorff illusion and estimates of transverse extent. Perceptual and Motor Skills, 1975, 41, 143-148.

Fisher, G.H. A tactile Poggendorff illusion. Nature, 1966, 212, 105-106.

Fisher, G.H. Illusions and size-constancy. American Journal of Psychology, 1968, 81, 2-21.

Fisher, G.H. An experimental study of angular subtension. Quarterly Journal of Experimantal Psychology, 1969, 21, 356-366.

Fisher, G.H. An experimental and theoretical appraisal of the perspective and size-constancy theories of illusions. Quarterly Journal of Experimental Psychology, 1970, 22, 631-652.

Fisher, G.H. & Lucas, A. Illusions in concrete situations: I. Introduction and demonstrations. Ergonomics, 1969, 12, 11-24.

Foster, T. In Knowledge, 1881, 1, 10. Cited by A.H. Pierce, Studies in auditory and visual space perception. New York: Longmans, Green, & Co., 1901.

Ganz, L. Mechanisms of the figural aftereffects. Psychological Review, 1966, 73, 128-150.

Gardner, R.W. Cognitive controls of attention deployment as determinants of visual illusions. Journal of Abnormal and Social Psychology, 1961, 62, 120-127.

Gillam, B. A depth processing theory of the Poggendorff illusion. Perception & Psychophysics, 1971, 10, 211-216.

Goldstein, M.B. & Weintraub, D.J. The parallel-less Poggendorff: Virtual contours put the illusion down but not out. Perception & Psychophysics, 1972, 11, 353-355.

Green, R.T. & Hoyle, E.M. The Poggendorff illusion as a constancy phenomenon. Nature, 1963, 200, 611-612.

Green, R.T. & Hoyle, E.M. The influence of spatial orientation on the Poggendorff illusion. Acta Psychologica, 1964, 22, 348-366.

Gregory, A.H. Visual illusions: Peripheral or central? Nature, 1968, 220, 827-828.

Gregory, R.L. Distortion of visual space as inappropriate constancy scaling. Nature, 1963, 199, 678-680.

Gregory, R.L. Visual illusions. In B.M. Foss (Ed.), New horizons in psychology. Baltimore: Penguin Books, 1966.

Gregory, R.L. Visual illusions. Scientific American, 1968, 219, 66-76.

Gregory, R.L. Cognitive contours. Nature, 1972, 238, 51-52.

Gregory, R.L. The confounded eye. In R.L. Gregory & E.H. Gombrich (Eds), Illusions in nature and art. London: Duckworth, 1973.

Gregory, R.L. Concepts and mechanisms of perception. London: Duckworth, 1974.

Gregory, R.L. & Gombrich, E.H. (Eds.) Illusions in nature and art. London: Duckworth, 1973.

Gregory, R.L. & Harris, J.P. Illusion destruction by appropriate scaling. Perception, 1975, 4, 203-220.

Hasserodt, W. Gesichtspunkte zu einer experimentellen Analyse geometrischoptischer Tauschungen. Arch. f. d. ges. Psychol., 1913, 28, 336-347. (Abstract)

Helmholtz, H. von Handbuch der physiologischen Optik III, (1866:1910). Trans. by J.P.C. Southall (Ed.), Helmholtz's treatise on physiological optics. New York: Dover Publications, 1962.

Hering, E. Beitrage zur Physiologie. Leipzig: Engelmann, 1861. Cited by J.O. Robinson, The psychology of visual illusions. London: Hutchinson University Library, 1972.

Hill, A.L. Poggendorff illusion: Effects of intelligence, viewing distance, and space between the vertical lines. Psychonomic Science, 1971, 25, 71-72.

Hotopf, W.H.N. The size-constancy theory of visual illusions. British Journal of Psychology, 1966, 57, 307-318.

Hotopf, W.H.N. & Ollerearnshaw, C. The regression to right angles tendency and the Poggendorff illusion. I. British Journal of Psychology, 1972a, 63, 359-367.

Hotopf, W.H.N. & Ollerearnshaw, C. The regression to right angles tendency and the Poggendorff illusion. II. British Journal of Psychology, 1972b, 63, 369-379.

Hotopf, W.H.N., Ollerearnshaw, C., & Brown, S. The regression to right angles tendency and the Poggendorff illusion. III. British Journal of Psychology, 1974, 65, 213-231.

Hotopf, W.H.N. & Robertson, S.H. The regression to right angles tendency, lateral inhibition, and the transversals in the Zollner and Poggendorff illusions. Perception & Psychophysics, 1975, 18, 453-459.

Houck, R.L. & Mefferd, R.B. The Poggendorff illusion: A neurophysiologically based hypothesis. American Journal of Psychology, 1973, 86, 283-309.

Hubel, D.H. & Wiesel, T.N. Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. Journal of Physiology, 1962, 160, 106-154.

Imai, S. Experiments on Poggendorff illusion. Journal of Social Sciences and Humanities of Toyko Metroplitan University, 1973, 90, 1-39. Cited by R.H. Day, The Poggendorff illusion with obtuse and acute angles. Perception & Psychophysics, 1973b, 14, 590-596.

Jastrow, J. Studies from the laboratory of experimental psychology of the University of Wisconsin. II. A study of Zollner's figure and other related illusions. American Journal of Psychology, 1891-92, 4, 381-398.

Johannsen, D.E. Early history of perceptual illusions. Journal of the History of the Behavioral Sciences, 1971, 7, 127-140.

Judd, C. A study of geometrical illusions. Psychological Review, 1899, 6, 241-261.

Julesz, B. Foundations of cyclopean perception. Chicago: Chicago University Press, 1971.

Kobayashi, T. Analytical study of displacement in visual perception, I. Japanese Psychological Research, 1956, 3, 37-44.

Kohler, W. & Wallach, H. Figural aftereffects: An investigation of visual processes. Proceedings of the American Philosophical Society, 1944, 88, 269-357.

Krantz, D.H. & Weintraub, D.J. Factors affecting perceived orientation of the Poggendorff transversal. *Perception & Psychophysics*, 1973, *14*, 511-517.

Kuhn, T.S. Historical structure of scientific discovery. *Science*, 1962, *136*, 760-764.

Kundt, A. Untersuchungen uber Augenmaass und opt. Tauschungen. *Pogg. Ann.*, 1863, Bd. *CXX.S.*, 118. Cited by M. Blix, Die sogenannte Poggendorff'sche optische Tauschung. *Skandinavisches Archiv fur Physiologie*, 1902, *13*, 193-228.

Ladd, G.T, & Woodworth, R.S. *Elements of physiological psychology*. New York: Charles Scriber's Sons, 1911.

Leibowitz, H.W. & Gwozdecki, J. The magnitude of the Poggendorff illusion as a function of age. *Child Development*, 1967, *38*, 573-580.

Leibowitz, H.W. & Toffey, S. The effect of rotation and tilt on the magnitude of the Poggendorff illusion. *Vision Research*, 1966, *6*, 101-103.

Letourneau, J.E. The Poggendorff illusion among mental retardates. *Perceptual and Motor Skills*, 1972, *35*, 535-538.

Letourneau, J.E. & Lavoie, G. The Poggendorff illusion among paranoid and simple schizophrenic patients. *American Journal of Optometry and Archives of American Academy of Optometry*, 1973, *50*, 994-948.

Lewis, R.T. Optical illusions. *Nature*, 1892, *47*, 31.

Lindquist, E.F. *Design and analysis of experiments in psychology and education*. Boston: Houghton Mifflin, 1953.

Lucas, A. & Fisher, G.H. Illusions in concrete situations: II Experimental studies of the Poggendorff illusion. *Ergonomics*, 1969, *12*, 395-402.

Luckiesh, M. *Visual illusions: Their causes, characteristics and applications*. New York: Dover, 1922:1965.

Mach, E. *The analysis of sensation*. New York: Dover, 1898:1959.

Mallenby, T.W. Effect of discussion on reduction of magnitude of Poggendorff illusion. *Perceptual and Motor Skills*, 1974, 39, 787-791.

Murch, G.M. *Visual and auditory perception*. Indianapolis: The Bobbs-Merrill Co., Inc.; 1973.

Novak, S. Effects of free inspection and fixation on the magnitude of the Poggendorff illusion. *Perceptual and Motor Skills*, 1966, *23*, 663-670.

Obonai, T. Experimentelle Untersuchungen uber den Aufbau des Sehraumes. *Archiv fur die gesamte Psychologie*, 1931, *82*, 308-328. Cited by T. Oyama, Japanese studies on the so-called geometrical-optical illusions. *Psychologia*, 1960, *3*, 7-20.

Ogasawara, J. The deflection of the line laid obliquely to another line: III. The factor of angle. Paper presented at the 20th Annual Meeting of the Japanese Psychological Association. Cited by T. Oyama, Japanese studies on the so-called geometrical-optical illusions. *Psychologica*, 1960, *3*, 7-20.

Ohwaki, S. On the destruction of geometrical illusions in stereoscopic observation. *Tohoku Psychologica Folia*, 1960, *29*, 24-36.

Over, R. Explanations of geometrical illusions. Psychological Bulletin, 1968, 70, 545-562.

Parrish, M., Lundy, R.M., & Leibowitz, H.W. Hypnoptic age regression and magnitudes of the Ponzo and Poggendorff illusions. Science, 1968, 159, 1375-1376.

Pasnak, R. & Ahr, P. Tactual Poggendorff illusion in blind and blindfolded subjects. Perceptual and Motor Skills, 1970, 31, 151-154.

Perry, C. & Chisholm, W. Hypnotic age regression and the Ponzo and Poggendorff illusions. International Journal of Clinical and Experimental Hypnosis, 1973, 21, 192-204. (Abstract)

Pierce, A.H. Geometrical optical illusions. Science, 1898, 8, 814-829.

Pierce, A.H. Studies in auditory and visual space perception. New York: Longmans, Green, & Co., 1901.

Piaget, J. The mechanisms of perception. London: Routledge & Paul, 1969.

Pratt, M.B. The visual estimation of angles. Journal of Experimental Psychology, 1926, 9, 132-140.

Pressey, A.W. Group differences on the Poggendorff illusion. Canadian Psychologist, 1965, 6, 224.

Pressey, A.W. Field dependence and susceptibility to the Poggendorff illusion. Perceptual and Motor Skills, 1967, 24, 309-310.

Pressey, A.W. An extension of assimilation theory to illusions of size, area, and direction. Perception & Psychophysics, 1971, 9, 172-176.

Pressey, A.W., Bayer, C.A., & Kelm, H. The Poggendorff illusion in schizophrenic patients. Schizophrenia, 1969, 1, 88-94.

Pressey, A.W. & Dewar, M.J. A reversed Poggendorff illusion. Psychonomic Science, 1970, 20, 227-228.

Pressey. A.W. & den Heyer, K. Observations on Chiang's "new" theory of geometrical illusions. Perception & Psychophysics, 1968, 4, 313-314.

Pressey, A.W. & Koffman, G. Figural aftereffects, illusions and the dimensions of field dependence. Psychonomic Science, 1968, 10, 279-280.

Pressey, A.W. & Sweeney, O. A variation of the Poggendorff illusion. Percpetual and Motor Skills, 1969, 28, 883-886.

Pressey, A.W. & Sweeney, O. Age change in the Poggendorff illusion as measured by a method of production. Psychonomic Science, 1970, 19, 99-100.

Pressey, A.W. & Sweeney, O. Acute angles and the Poggendorff illusion. Quarterly Journal of Experimental Psychology, 1972a, 24, 169-174.

Pressey, A.W. & Sweeney, O. Some puzzling results on the Poggendorff illusion. Perception & Psychophysics, 1972b, 12, 433-437.

Quina-Holland, K. Spatial distortions within the Poggendorff figure and its variants: A parametric analysis. Perception & Psychophysics, 1977, 21, 118-124.

Restle, F. Illusions of bent line. Perception & Psychophysics, 1969, 5, 273-274.

Richmond, W.D. In *Knowledge*, 1881, *1*, 57. Cited by A.H. Pierce, *Studies in auditory and visual space perception*. New York: Longmans, Green, & Co., 1901.

Rivers, W.H.R. Observations on the senses of the Todas. *British Journal of Psychology*, 1905, *1*, 321-396.

Robertson, A. Studies from the psychological laboratory of the University of California: VI. "Geometric-optical" illusions in touch. *Psychological Review*, 1902, *9*, 549-569.

Robinson, J.O. Retinal inhibition in visual distortion. *British Journal of Psychology*, 1968, *59*, 29-36.

Robinson, J.O. *The psychology of visual illusion*. London: Hutchinson University Library, 1972.

Rock, I. *An introduction to perception*. New York: Macmillan, 1975.

Sanford, E.C.A. *A course in experimental psychology. Part 1: Sensation and perception*. Boston: Heath, 1901.

Schiller, P. & Wiener, M. Binocular and stereoscopic viewing of geometric illusions. *Perceptual and Motor Skills*, 1962, *15*, 739-747.

Segall, M.H., Campbell, D.T., & Herskovits, M.J. *The influence of culture on visual perception*. Indianapolis: Bobbs-Merrill, 1966.

Springbett, B.M. Some stereoscopic phenomena and their implications. *British Journal of Psychology*, 1961, *52*, 105-109.

Spitz, H.H., Goettler, D.R., & Dively, S.L. A comparison of retardates and normals on the Poggendorff and Oppel-Kundt illusions. *Developmental Psychology*, 1970, *3*, 58-65.

Tausch, R. Optische Tauschungen als artifizielle Effekte der Gestaltungprozesse von Grossen-und Formenkonstanz in der naturlichen Raumevahrenehung. Psychologische Forschung, 1954, 24, 299-348. (Abstract)

Thiery, A. Uber geometrisch-optische Tauschungen. Philosophische Studien, 1896, 12, 67-126.

Tichý, G. Ueber eine vermeintliche optische Tauschung. Zsch. f. Psychol., 1912, 60, 267-279. (Abstract)

Tinker, M.A. Susceptibility to optical illusions: Specific or general. Journal of Experimental Psychology, 1938, 22, 593-598.

Titchener, E.B. Experimental psychology: A manual of laboratory practice. New York: Macmillan, 1901.

Tolansky, S. Optical illusions. New York: Pergamon, 1964.

Tong, L. & Weintraub, D.J. Contour displacement and tracking errors. Probing 'twixt Poggendorff parallels. Perception & Psychophysics, 1974, 15, 258-268.

Velinsky, P. St. Explication physiologique de l'illusion de Poggendorff. Annee Psychologique, 1925, 26, 107-116. (Abstract)

Vurpillot, E. L'influence de la signification du material sur l'illusion de Poggendorff. Annee Psychologique, 1957, 57, 339-357. (Abstract)

Walker, E.H. A mathematical theory of optical illusions and figural aftereffects. Perception & Psychophysics, 1973, 13, 467-486.

Warden, C.J. & Boars, J. The Muller-Lyer illusion in the Ring Dove, Turtur Risorius. Journal of Comparative and Physiological Psychology, 1929, 9, 275-292.

Weintraub, D.J. & Krantz, D.H. The Poggendorff illusion: Amputations, rotations, and other perturbations. Perception & Psychophysics, 1971, 10, 257-264.

Weintraub, D.J. & Tong, L. Assessing Poggendorff effects via collinearity, perpendicularity, parallelism, and Oppel (distance) experiments. Perception & Psychophysics, 1974, 16, 213-221.

Weintraub, D.J. & Virsu, V. The misperception of angles: Estimating the vertex of converging line segments. Perception & Psychophysics, 1971, 9, 5-8.

Wilson, A.E. & Pressey, A.W. The role of apparent distance in the Poggendorff illusion. Perception & Psychophysics, 1976, 20, 309-316.

Wohlwill, J.F. Developmental studies in perception. Psychological Bulletin, 1960, 57, 249-288.

Woodworth, R.S. Psychology: A study of mental life. New York: Henry Holt & Co., 1921.

Wundt, W. Grundzugen der physiologischen Psychologie. 1874. Cited by M. Blix, Die sogenannte Poggendorff'sche optische tauschung. Skandinavisches Archiv fur Physiologie, 1902, 13, 193-228.

Wundt, W. Die geometrisch-optischin Tauschungen. Abhandlungen der mathematisch physischen Classe der Koeniglischen Sacohsischen Gesellschaft der Wissenschaften, 1898, 42, 53-178.

Young, A. Perspective variants of the Poggendorff illusion. Unpublished M.A. thesis, McMaster University, 1976.

Zajac, J.L. Some investigations on the so-called "geometrico optical illusions." Acta Psychologica, 1957, 13, 140-150.

Zusne, L. Optical illusions: Output of publications. Perceptual and Motor Skills, 1968, 27, 175-177.

Zusne, L. Visual perception of form. New York: Academic Press, 1970.

APPENDIX A

Instructions used in Experiments 1, 2, 3, and 6.

This is an experiment to see how accurately people can make visual judgments concerning straight lines. During this experiment you must always keep your writing hand and your pencil on the yellow dot in front of you until I give you the signal to make a response. Here are some examples of the kind of figures you are going to see (experimenter draws a subset of the figures on the blackboard). Now, what will happen is this. I will give the signal "TURN" and you will turn the first page of your booklet. Facing you will be a figure of the kind I have just shown you. You may inspect this figure for 10 seconds. After this time is up I will say "NOW". Then I want you to pick up your hand from the yellow dot and with your pencil make a well-defined mark on the right hand parallel line which appears to you to be collinear with the oblique line you are given. By collinear I mean that a ruler can be laid across the two lines and the line you have drawn is the extension of the one you are given. When you have finished making your response turn the page, replace your hand with the pencil in it on the yellow dot and wait for the signal to begin the next trial. Do you all understand the instructions? (The experimenter generally explained the task again using slightly different wording.)

During this experiment you may not make any arm movements with your pencil before you make your response, nor may you tilt your head during the inspection period. You may make only one response per stimulus figure and you must make a response on every trial. Try to be as accurate in your judgments as possible. Are there any questions?

Instructions used in Experiments 4 and 5.

This is an experiment to see how accurately people can make visual judgments concerning straight lines. On each trial I will set the oblique line on the left (experimenter points to left hand oblique) to some position either obviously too high or too low the point where it would intersect the straight extension of this oblique on the right. Your task is to adjust the position of this left hand line, either moving it up or down as the case might be (experimenter demonstrates how the hand held switch works) and set it at the point where it appears to you to be collinear with the line on the right. By collinear I mean that a ruler can be laid across the two lines and the one on the left appears to be the straight extension of the one on the right. You may only move the left hand line in one direction on each trial so be careful that you don't overshoot the place you want to put it. You will have 50 (15) trials on this figure followed by a 5 minute break and then 25 (50) trials on a slightly different figure. (This section was worded somewhat differently for subjects who received both practice and transfer trials on the classical figure.)

Now this is a repetitive task and people often become tired and bored while doing it. I would like you to pay close attention to the task and try to be as accurate in your judgments as possible. Do you have any questions?

Instructions used in Experiment 7.

This is an experiment to see how accurately people can make visual judgments concerning straight lines. On each trial I will set the oblique line on the left (experimenter points to left hand transversal) to some position either obviously too high or too low the point where it would intersect the straight extension of the oblique or dot on the right. Your task is to adjust the position of this left hand line, either moving it up or down as the case might be (experimenter demonstrates how the hand held switch works) and set it at the point where it appears to you to be collinear with either a second line or with a dot on the right. By collinear I mean that a ruler can be laid across the two lines or through the dot and the one on the left appears to be the straight extension of the line or dot on the right. You may only move the left hand line in one direction on each trial so be careful that you don't overshoot the place you want to put it. You will have three trials on each of four different figures.

I would like you to pay close attention to the task and try to be as accurate in your judgments as possible. Do you have any questions?

Instructions used in Experiment 8.

This is an experiment to see how accurately people can make visual judgments concerning straight lines. On each trial I will show you a figure consisting of an oblique line. two vertical parallel lines, and a dot (experimenter points to features of the figure). Your task is to decide whether the oblique line on the left, if extended, would pass above or below the dot on the right hand parallel line, no "through" judgments are permitted. You may only make one response per figure and you must make a response for every figure. I am going to show you a large number of figures. Some judgments will be easier than others (experimenter shows all members of the set so that the subject is familiar with the range).

I would like you to pay close attention to the task and try to be as accurate in your judgments as possible. Do you have any questions?

Instructions used in Experiment 9.

This is an experiment to see how accurately people can make visual judgments concerning straight lines. On each trial I will set the oblique line or angled edge on the left (experimenter points to left hand oblique and angled edge) to some position either obviously too high or too low the point where it would intersect the straight extension of this oblique or angled edge on the right. Your task is to adjust the position of this left hand line or angled edge, either moving it up or down as the case might be (experimenter demonstrates how the hand held switch works) and set it at the point where it appears to you to be collinear with a second line or angled edge on the right. By collinear I mean that a ruler can be laid across the two lines or angled edges and the one on the left appears to be the straight extension of the one on the right. You may only move the left hand line or angled edge in one direction on each trial so be careful that you don't overshoot the place you want to put it. You will have five trials on each of three different figures.

I would like you to pay close attention to the task and try to be as accurate in your judgments as possible. Do you have any questions?

APPENDIX B

PRODUCT MOMENT CORRELATION COEFFICIENTS BETWEEN AVERAGE ERRORS FOR THE FOUR STIMULUS FIGURES.

	Complete	Obtuse Angle	Acute Angle	Oblique
Complete	1.000	0.728**	0.776***	0.850***
Obtuse Angle		1.000	0.709*	0.882****
Acute Angle			1.000	0.842***
Oblique				1.000

* $p < .025$
** $p < .01$
*** $p < .005$
**** $p < .0005$

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER SUBJECT PER ANGLE PER FIGURE, ALL DATA WERE COLLECTED BY THE METHOD OF PRODUCTION.

	Complete Figure					Obtuse Angle Figure				
	15°	30°	45°	60°	75°	15°	30°	45°	60°	75°
Subject										
1	4.17	2.83	0.83	2.67	0.83	-2.67	-0.50	1.33	2.50	0.17
2	22.83	18.17	5.67	3.50	1.17	9.33	12.00	11.67	6.00	1.50
3	-5.67	3.50	5.00	2.83	0.67	7.50	5.00	3.00	2.00	1.67
4	-3.00	7.00	5.83	3.50	1.00	18.50	11.50	3.00	3.33	-1.50
5	34.50	8.67	2.33	-0.50	-0.33	0.00	1.33	1.83	1.00	0.17
6	4.50	1.00	2.00	0.33	0.33	-4.33	2.83	1.17	0.67	0.50
7	13.00	8.50	8.83	6.83	2.50	16.17	11.33	8.83	8.50	2.33
8	46.50	24.66	11.50	5.67	2.00	-1.67	24.00	7.83	5.33	1.67
9	46.17	25.33	15.67	9.00	3.50	45.00	13.67	9.67	8.83	2.17
10	20.33	4.67	3.33	4.66	0.17	14.83	8.50	4.33	1.33	-0.50
Mean	18.33	10.43	6.10	3.85	1.18	10.27	8.97	5.22	3.95	0.82
Standard Deviation	18.18	8.55	4.43	2.71	1.11	14.02	6.86	3.62	2.88	1.19

(CONTINUED)

	Acute Angle Figure					Oblique Figure				
	15°	30°	45°	60°	75°	15°	30°	45°	60°	75°
Subject										
1	1.00	-0.17	2.50	1.50	-0.17	-4.33	-2.33	0.67	1.83	0.83
2	20.50	16.50	13.00	4.83	1.17	9.83	3.33	5.83	4.00	1.00
3	-18.17	-3.16	0.33	0.83	0.33	4.33	2.00	2.00	0.83	0.50
4	-10.17	2.00	-0.67	-2.67	-0.33	-9.00	0.00	2.00	1.67	0.67
5	10.33	3.50	1.17	-0.83	-0.83	1.83	0.33	0.50	-0.67	0.00
6	-6.83	-6.50	-1.50	3.00	0.00	-10.50	-0.67	-1.67	0.50	0.00
7	-8.50	8.33	6.33	1.17	0.83	4.50	4.00	3.33	2.50	2.17
8	7.17	0.33	5.00	1.83	-0.67	11.67	4.50	4.33	4.17	0.00
9	40.17	15.67	13.00	7.67	1.83	40.33	11.00	10.67	6.83	2.33
10	15.00	0.83	2.83	3.00	-0.83	5.67	0.00	2.33	0.50	-1.17
Mean	5.05	3.73	4.20	2.03	0.13	5.43	2.22	3.00	2.22	0.63
Standard Deviation	16.48	7.19	4.95	2.73	0.86	13.60	3.59	3.23	2.12	1.00

APPENDIX C

PRODUCT MOMENT CORRELATION COEFFICIENTS BETWEEN AVERAGE ERRORS FOR THE FOUR STIMULUS FIGURES.

	Complete	Obtuse Angle	Acute Angle	Oblique
Complete	1.000	0.796****	0.745***	0.636**
Obtuse Angle		1.000	0.476	0.783****
Acute Angle			1.000	0.554*
Oblique				1.000

*	$p < .05$
**	$p < .025$
***	$p < .01$
****	$p \leq .005$

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER SUBJECT PER SEPARATION PER FIGURE. ALL DATA WERE COLLECTED BY THE METHOD OF PRODUCTION.

	Complete Figure					Obtuse Angle Figure				
	1cm	2cm	3cm	4cm	5cm	1cm	2cm	3cm	4cm	5cm
Subject										
1	1.50	2.33	5.67	9.33	14.17	1.67	5.00	7.67	6.00	9.33
2	4.67	10.00	21.00	23.67	36.67	2.67	2.83	15.50	12.67	21.00
3	3.67	7.00	7.67	23.50	23.50	3.50	4.83	14.67	8.50	12.33
4	3.50	7.67	16.50	28.33	31.67	6.67	13.00	11.00	19.50	26.50
5	2.17	6.33	11.67	23.17	24.83	1.83	8.50	8.83	12.67	17.83
6	6.67	10.17	18.00	35.50	43.00	3.83	6.33	13.83	27.00	32.33
7	3.33	8.33	12.67	16.17	23.67	1.67	7.67	6.33	15.67	15.00
8	6.67	8.83	9.67	23.83	13.83	0.83	4.83	15.17	12.33	18.17
9	1.50	9.00	16.33	23.67	31.67	0.00	2.67	8.33	4.83	21.83
10	2.50	6.33	12.83	21.67	20.50	2.33	4.67	11.17	11.33	21.00
Mean	3.62	7.60	13.20	22.88	26.35	2.50	6.03	11.25	13.05	19.53
Standard Deviation	1.79	2.18	4.55	6.51	8.93	1.76	2.93	3.21	6.20	6.36

(CONTINUED)

	Acute Angle Figure					Oblique Figure				
	1cm	2cm	3cm	4cm	5cm	1cm	2cm	3cm	4cm	5cm
Subject										
1.	0.33	2.33	3.33	8.67	1.33	0.67	2.33	0.50	-0.83	-9.50
2	2.67	6.33	13.83	21.17	28.33	-0.67	-2.17	2.67	-0.50	10.67
3	0.67	2.33	4.67	13.67	25.50	-1.83	0.00	5.50	8.83	11.00
4	1.50	4.00	2.17	3.33	10.67	-1.00	0.00	8.00	5.17	10.33
5	5.67	4.67	4.83	10.17	13.67	0.33	2.50	5.50	6.17	13.83
6	1.50	10.17	19.67	26.67	31.00	1.67	0.83	8.00	9.17	23.67
7	2.33	7.67	7.00	15.83	13.17	-0.33	0.50	1.33	4.50	1.17
8	0.33	4.67	7.00	9.50	20.50	0.33	-1.33	1.00	7.50	8.50
9	-2.67	5.67	6.50	10.50	24.83	-1.50	1.17	2.00	-4.17	7.33
10	0.50	3.67	8.67	13.83	25.83	-0.17	-0.17	6.00	10.50	5.00
Mean	1.28	5.15	7.77	13.33	19.48	-0.25	0.37	4.05	4.63	8.20
Standard Deviation	2.02	2.31	5.01	6.34	8.94	1.00	1.38	2.73	4.66	8.14

APPENDIX D

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER SUBJECT PER FIGURE. ALL DATA WERE COLLECTED BY THE METHOD OF PRODUCTION.

Subject	Complete Figure	Obtuse Angle Figure	½ Obtuse Angle Figure	¼ Obtuse Angle Figure
1	9.6	9.1	8.7	5.1
2	15.6	8.0	9.0	9.6
3	15.6	5.6	8.8	7.8
4	12.6	11.4	9.3	10.3
5	22.0	15.8	18.2	18.5
6	21.4	17.7	14.8	16.7
7	20.5	16.7	16.5	19.7
8	18.5	11.7	12.5	14.4
9	13.9	8.6	9.3	7.8
10	15.9	6.0	4.9	9.8
11	21.3	18.9	20.4	19.9
Mean	17.0	11.8	12.0	12.7
Standard Deviation	4.1	4.8	4.8	5.3

THE RESULTS OF TUKEY'S HSD TEST FOR SIGNIFICANT DIFFERENCES BETWEEN THE TOTALS OF THE CONDITIONS.

	Complete Figure	¼ Obtuse Angle Figure	½ Obtuse Angle Figure	Obtuse Angle Figure
Complete Figure		**	**	**
¼ Obtuse Angle Figure				
½ Obtuse Angle Figure				
Obtuse Angle Figure				

** $p < .01$

APPENDIX E

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER BLOCK OF FIVE TRIALS PER SUBJECT FOR THE COMPLETE FIGURE. ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

Practice Trial Blocks	1	2	3	4	5	6	7	8	9	10
Subject										
1	9.7	6.8	7.7	7.7	8.5	7.6	6.8	7.1	5.6	6.1
2	10.3	8.9	7.8	8.0	8.1	6.4	7.9	6.9	6.3	6.2
3	11.9	10.4	9.1	8.8	8.9	8.1	7.9	6.8	6.5	6.6
4	13.3	11.9	11.7	11.4	10.1	9.1	7.4	7.7	7.7	7.3
5	12.0	9.9	10.3	8.0	7.4	7.9	7.8	6.5	6.1	6.7
6	12.4	10.3	7.0	7.5	6.9	6.1	4.7	5.9	4.2	4.6
7	18.4	14.5	12.8	11.6	11.2	9.3	9.9	9.3	8.7	8.1
8	12.7	11.3	11.1	10.5	10.5	10.4	10.7	10.0	9.0	10.7
9	13.6	11.1	9.1	8.8	9.0	7.2	6.3	6.4	5.3	6.1
10	13.5	14.6	14.2	13.0	12.1	14.1	12.9	10.3	9.5	9.3
Mean	12.8	11.0	10.1	9.5	9.3	8.6	8.2	7.7	6.9	7.2
Standard Deviation	2.4	2.4	2.4	1.9	1.7	2.3	2.4	1.6	1.8	1.8

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER BLOCK OF FIVE TRIALS PER SUBJECT FOR THE OBTUSE ANGLE FIGURE. ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

Practice Trial Block	1	2	3	4	5	6	7	8	9	10
Subject										
11	7.7	7.2	7.5	5.5	5.9	5.4	5.0	5.3	4.7	3.8
12	9.9	7.3	7.4	7.3	7.4	7.3	7.4	6.6	5.8	5.1
13	9.3	8.0	8.2	6.7	6.5	6.4	6.5	6.6	6.2	6.0
14	14.0	12.6	12.7	11.2	11.5	11.4	11.6	10.5	9.2	9.2
15	8.8	7.7	7.8	7.7	7.4	4.3	4.4	4.9	5.1	4.3
16	6.7	7.3	6.8	6.1	4.9	5.8	4.8	5.4	5.5	4.6
17	10.1	6.9	6.5	6.6	5.1	2.6	3.2	2.3	1.1	1.3
18	9.6	8.7	9.1	9.3	8.3	8.7	7.0	5.3	4.5	4.9
19	9.4	9.2	9.1	9.2	9.3	9.1	8.9	7.8	8.1	6.3
20	9.7	6.5	6.6	6.8	4.8	4.0	4.6	4.7	4.2	3.7
Mean	9.2	8.1	8.2	7.6	7.1	6.5	6.3	5.9	5.4	4.9
Standard Deviation	1.9	1.8	1.8	1.8	2.2	2.7	2.5	2.2	2.2	2.1

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER BLOCK OF FIVE TRIALS PER SUBJECT FOR THE ACUTE ANGLE FIGURE: ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

Practice Trial Blocks	1	2	3	4	5	6	7	8	9	10
Subject										
21	6.4	5.8	4.7	5.3	4.6	4.5	4.4	3.6	3.8	2.7
22	3.6	1.8	2.5	1.2	1.0	0.2	0.1	0.6	0.4	1.0
23	13.3	10.1	8.6	9.2	9.2	8.5	7.4	6.9	6.6	6.6
24	6.5	4.9	4.7	2.1	2.9	3.9	3.6	3.3	2.6	2.9
25	7.9	5.5	4.4	4.4	4.8	4.5	5.1	5.1	4.9	5.5
26	9.8	10.0	8.7	7.0	7.7	6.6	7.7	6.1	5.5	4.7
27	7.5	6.7	6.8	6.8	6.9	5.7	5.1	6.1	5.0	6.0
28	2.0	1.2	1.9	-0.7	0.4	1.5	0.0	-0.1	1.9	1.4
29	3.1	3.2	2.6	2.5	2.4	2.7	3.5	3.6	3.2	2.8
30	1.7	4.3	0.8	3.3	3.5	3.4	3.3	4.3	2.9	2.2
Mean	6.2	5.4	4.6	4.1	4.3	4.2	4.0	4.0	3.7	3.6
Standard Deviation	3.7	3.0	2.8	3.0	2.9	2.4	2.6	2.3	1.9	2.0

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER BLOCK OF FIVE TRIALS PER SUBJECT FOR THE OBLIQUE FIGURE. ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

Practice Trial Block	1	2	3	4	5	6	7	8	9	10
Subject										
31	9.1	8.1	6.2	6.2	8.0	6.3	5.1	6.4	5.8	5.3
32	10.7	9.5	8.6	6.7	6.6	6.6	5.4	6.7	7.0	4.7
33	6.2	5.3	5.1	4.7	4.6	3.9	3.9	4.0	3.5	3.6
34	1.1	0.7	0.1	0.0	-2.1	0.1	-2.2	-1.7	-1.4	-0.2
35	3.5	0.2	0.9	2.4	3.6	2.9	1.2	1.6	2.0	1.9
36	8.9	7.8	7.7	7.2	7.7	7.6	6.2	6.5	6.8	6.2
37	4.0	3.0	1.7	3.2	2.2	3.2	2.4	3.0	2.4	1.6
38	3.9	2.5	1.5	1.8	1.8	1.7	1.9	1.8	1.7	1.1
39	5.2	3.4	3.9	3.3	2.4	2.7	2.1	2.4	2.5	1.4
40	2.1	1.1	0.3	3.7	5.2	3.5	4.5	4.7	3.6	4.4
Mean	5.5	4.2	3.6	3.9	4.0	3.9	3.1	3.5	3.4	3.0
Standard Deviation	3.2	3.3	3.2	2.3	3.1	2.3	2.5	2.7	2.6	2.1

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER BLOCK OF FIVE TRIALS PER SUBJECT FOR THE COMPLETE FIGURE (TRANSFER TRIALS ON THE COMPLETE POGGENDORFF FIGURE). ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

Transfer Trial Block	1	2	3	4	5
Subject					
1	5.3	6.2	5.1	4.9	4.8
2	8.2	7.2	7.0	7.1	6.3
3	10.7	8.7	7.3	6.9	6.8
4	10.0	8.9	8.2	8.5	7.4
5	8.6	7.4	8.0	7.6	6.9
6	8.2	6.4	6.6	7.2	6.2
7	12.2	10.6	9.1	9.1	8.3
8	11.2	10.8	11.1	10.8	10.5
9	11.6	9.4	9.6	8.0	6.0
10	12.4	11.7	11.8	12.6	12.8
Mean	9.8	8.7	8.4	8.3	7.6
Standard Deviation	2.3	1.9	2.1	2.2	2.4

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER BLOCK OF FIVE TRIALS PER SUBJECT FOR THE OBTUSE ANGLE FIGURE (TRANSFER TRIALS ON THE COMPLETE POGGENDORFF FIGURE). ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

Transfer Trial Block	1	2	3	4	5
Subject					
11	9.7	9.7	8.4	8.8	8.5
12	10.4	9.9	8.4	7.5	6.1
13	10.1	8.5	7.0	7.1	6.1
14	13.5	12.8	12.8	12.6	11.3
15	8.4	7.7	6.4	6.6	7.3
16	5.5	6.3	6.2	3.6	2.2
17	4.9	4.7	3.5	3.7	1.7
18	9.3	8.0	7.9	7.1	6.6
19	11.8	11.5	8.3	7.5	7.5
20	7.1	4.5	3.8	5.0	4.6
Mean	9.1	8.4	7.3	7.0	6.2
Standard Deviation	2.7	2.7	2.6	2.6	2.9

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER BLOCK OF FIVE TRIALS PER SUBJECT FOR THE ACUTE ANGLE FIGURE (TRANSFER TRIALS ON THE COMPLETE POGGENDORFF FIGURE). ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

Transfer Trial Block	1	2	3	4	5
Subject					
21	2.6	2.2	1.5	1.9	1.5
22	7.2	6.7	5.9	5.9	5.1
23	12.3	11.4	11.2	9.5	9.0
24	8.3	6.2	6.3	5.3	5.5
25	6.2	6.7	5.6	5.1	5.1
26	7.6	5.8	5.6	4.1	4.3
27	7.6	7.3	8.3	7.6	6.7
28	7.5	7.9	6.8	6.4	6.3
29	8.7	7.7	7.6	8.0	7.6
30	11.3	9.0	9.5	8.6	8.8
Mean	7.9	7.1	6.8	6.2	6.0
Standard Deviation	2.7	2.4	2.6	2.3	2.2

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER BLOCK OF FIVE TRIALS PER SUBJECT FOR THE OBLIQUE FIGURE (TRANSFER TRIALS ON THE COMPLETE POGGENDORFF FIGURE). ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

Transfer Trial Block	1	2	3	4	5
Subject					
31	11.5	8.5	7.7	6.4	7.3
32	8.0	7.4	6.8	6.4	5.8
33	8.9	8.0	6.9	7.5	6.0
34	8.8	8.0	6.6	5.0	4.5
35	0.7	2.5	2.3	2.9	2.8
36	12.7	10.0	8.8	7.6	6.3
37	7.3	5.5	5.3	5.0	5.3
38	5.8	5.4	4.0	3.0	2.2
39	4.6	4.5	4.5	4.0	4.2
40	9.8	8.8	9.4	7.0	7.2
Mean	7.8	6.9	6.2	5.4	5.2
Standard Deviation	3.5	2.3	2.2	1.7	1.7

APPENDIX F

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER BLOCK OF FIVE TRIALS PER SUBJECT FOR THE COMPLETE FIGURE. ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

Practice Trial Block	1	2	3
Subject			
1	14.5	10.5	10.8
2	10.9	8.5	7.4
3	11.8	10.1	9.7
4	9.9	8.6	8.3
5	7.9	5.9	3.2
6	15.9	13.3	12.5
7	12.2	11.3	10.0
8	9.3	8.5	8.0
9	10.4	9.4	8.8
10	9.8	9.4	7.6
Mean	11.3	9.6	8.6
Standard Deviation	2.4	2.0	2.5

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER BLOCK OF FIVE TRIALS PER SUBJECT FOR THE OBLIQUE FIGURE. ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

Practice Trial Block	1	2	3
Subject			
11	2.2	2.1	1.6
12	3.3	2.3	3.4
13	4.1	3.1	1.2
14	7.5	5.7	4.7
15	4.8	2.3	2.2
16	5.0	5.3	5.0
17	7.0	6.2	3.2
18	3.3	2.7	2.3
19	2.2	2.8	1.5
20	5.9	4.6	2.9
Mean	4.5	3.7	2.8
Standard Deviation	1.9	1.6	1.3

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER BLOCK OF FIVE TRIALS PER SUBJECT FOR THE COMPLETE FIGURE (TRANSFER TRIALS ON THE COMPLETE POGGENDORFF FIGURE). ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

Transfer Trial Block	1	2	3	4	5	6	7	8	9	10
Subject										
1	14.1	11.9	10.0	10.2	10.2	10.1	9.8	10.1	9.7	9.1
2	7.7	6.6	4.6	3.8	3.7	4.2	2.6	2.8	3.0	4.1
3	10.8	10.7	10.3	9.5	10.1	10.2	8.6	9.2	7.5	6.8
4	8.8	8.3	8.7	7.7	8.2	8.0	8.1	7.5	7.9	7.9
5	4.2	2.3	2.3	1.0	1.3	2.0	3.0	2.9	2.6	1.8
6	13.4	13.4	12.7	12.6	11.5	11.3	11.6	10.9	10.5	10.8
7	14.3	11.9	12.2	11.6	11.9	11.1	10.6	10.7	10.1	10.2
8	9.0	8.3	8.1	8.1	8.0	8.2	7.4	7.8	7.6	5.6
9	11.1	10.1	8.6	9.0	9.1	8.9	8.7	8.7	8.7	8.4
10	9.8	8.1	9.0	8.7	7.9	6.8	6.3	6.2	7.0	5.9
Mean	10.3	9.2	8.7	8.2	8.2	8.1	7.7	7.7	7.5	7.1
Standard Deviation	3.2	3.2	3.2	3.5	3.4	3.0	3.0	2.9	2.7	2.8

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER BLOCK OF FIVE TRIALS PER SUBJECT FOR THE OBLIQUE FIGURE (TRANSFER TRIALS ON THE COMPLETE POGGENDORFF FIGURE). ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

Transfer Trial Block	1	2	3	4	5	6	7	8	9	10
Subject										
11	4.5	3.2	3.5	2.5	1.8	2.7	2.8	2.7	2.5	2.5
12	7.8	7.7	7.3	6.8	6.7	6.8	7.0	6.5	6.6	5.6
13	5.5	4.9	4.4	4.0	2.8	2.6	2.4	1.2	1.7	1.6
14	10.8	9.9	9.6	9.0	8.9	9.1	9.2	8.7	7.5	8.0
15	8.4	8.6	8.3	8.0	7.8	8.0	8.2	7.5	7.7	7.6
16	6.7	5.2	3.8	3.8	3.8	3.7	3.2	2.9	4.0	3.0
17	5.2	3.9	3.7	2.9	3.8	3.6	3.1	3.2	3.2	2.0
18	2.2	2.5	2.3	3.4	1.5	2.3	1.0	0.2	2.5	0.0
19	3.6	3.6	4.1	4.2	3.9	2.9	3.0	2.3	1.3	2.0
20	8.7	8.9	9.0	8.9	8.9	7.8	8.5	8.8	8.9	8.7
Mean	6.3	5.8	5.6	5.4	5.0	5.0	4.8	4.4	4.6	4.1
Standard Deviation	2.6	2.7	2.7	2.6	2.8	2.7	3.0	3.2	2.8	3.1

APPENDIX G

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER SUBJECT PER ANGLE PER SEPARATION. ALL DATA WERE COLLECTED BY THE METHOD OF PRODUCTION.

	1 cm					2 cm				
	15°	30°	45°	60°	75°	15°	30°	45°	60°	75°
Subject										
1	9.17	4.50	1.83	1.67	0.17	29.00	11.67	5.50	1.33	-0.67
2	10.83	1.00	0.50	0.33	-0.50	29.00	8.67	4.33	1.00	-0.50
3	11.67	8.00	2.83	1.17	-0.17	41.50	13.50	8.83	2.83	1.17
4	18.00	8.83	4.67	1.50	0.50	50.00	20.67	9.33	5.00	0.83
5	13.00	5.33	1.83	0.83	0.00	31.83	10.83	3.50	1.33	-1.17
6	3.33	2.17	1.00	0.83	0.00	6.50	5.50	1.67	1.67	0.00
7	20.83	4.33	3.50	1.67	0.67	38.00	20.80	7.83	5.00	2.00
8	13.50	9.33	3.50	2.50	0.83	44.33	15.67	8.50	3.83	0.67
9	6.50	3.83	2.00	1.00	-1.17	21.00	12.00	3.83	1.00	0.17
10	11.83	5.67	2.67	2.00	0.00	28.83	11.83	8.33	3.66	1.50
11	17.33	5.33	2.00	0.83	0.00	42.80	12.33	6.17	2.00	-0.33
12	6.67	2.67	2.50	0.67	0.33	18.33	6.83	4.50	3.00	0.83
Mean	11.89	5.08	2.40	1.25	0.06	31.76	12.53	6.03	2.64	0.46
Standard Deviation	5.12	2.60	1.14	0.63	0.53	12.45	4.76	2.51	1.47	0.84

(CONTINUED)

	3cm					4cm				
	15°	30°	45°	60°	75°	15°	30°	45°	60°	75°
Subject										
1	44.17	14.33	8.67	2.83	0.33	62.17	24.17	11.33	4.83	0.17
2	35.50	14.17	5.50	1.67	0.17	37.33	20.33	11.83	5.33	-0.50
3	66.33	22.50	10.33	7.00	1.33	79.00	33.33	14.67	8.33	3.17
4	76.33	36.00	15.50	8.67	2.00	99.33	45.33	24.67	12.67	4.50
5	51.17	13.00	5.83	3.67	0.67	51.50	17.50	6.67	3.83	0.17
6	15.17	7.50	4.67	2.50	-0.17	24.33	8.33	9.67	3.50	0.50
7	67.67	32.67	12.17	7.33	3.00	92.50	42.50	24.50	11.67	4.00
8	74.00	21.83	12.67	6.17	1.67	70.67	39.83	20.50	10.83	1.67
9	43.83	12.67	6.17	1.50	-1.67	38.67	24.67	8.33	4.50	-0.83
10	20.50	16.67	12.50	7.67	2.50	29.00	28.17	18.33	11.17	5.17
11	41.33	21.17	9.00	2.83	0.83	71.67	30.67	17.33	4.17	0.17
12	28.67	8.33	6.33	4.00	1.17	21.00	12.00	7.50	6.50	2.67
Mean	47.06	18.40	9.11	4.65	0.99	56.43	27.24	14.63	7.28	1.74
Standard Deviation	20.54	8.89	3.52	2.55	1.27	26.73	11.74	6.43	3.45	2.09

(CONTINUED)

	5cm				
Subject	15°	30°	45°	60°	75°
1	76.17	38.00	14.33	6.17	1.33
2	38.17	25.67	13.00	4.00	-0.17
3	95.00	44.67	19.50	11.67	3.83
4	116.83	62.33	31.83	16.00	5.00
5	72.33	22.83	8.17	4.83	0.50
6	25.50	14.50	6.67	3.17	2.00
7	127.67	64.50	30.17	13.67	4.67
8	102.50	53.17	24.17	14.00	4.50
9	39.50	22.83	12.17	3.33	-0.83
10	38.00	29.00	17.17	13.17	6.50
11	84.33	55.00	20.17	7.67	2.17
12	21.67	14.83	7.00	6.83	2.67
Mean	69.81	37.28	17.03	8.71	2.68
Standard Deviation	36.60	18.18	8.49	4.69	2.26

APPENDIX H

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER ORDER PER SUBJECT PER TRANSVERSAL/DOT PER ANGLE. ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

		30°		60°	
	Subject	Dot	Trans.	Dot	Trans.
Order 1	1	20.5	19.7	2.8	2.8
	2	14.7	9.0	3.2	4.2
	3	15.0	15.0	5.3	6.7
Order 2	4	9.8	6.8	3.2	3.2
	5	30.8	19.5	8.0	8.5
	6	14.5	6.3	5.0	4.3
Order 3	7	16.2	9.8	2.5	1.3
	8	29.3	18.5	8.8	7.8
	9	13.0	7.3	3.8	0.7
Order 4	10	21.2	13.0	5.8	5.0
	11	14.3	14.5	5.2	5.3
	12	13.8	8.3	8.8	7.5
Mean		17.76	12.31	5.20	4.78
Standard Deviation		6.51	5.06	2.28	2.52

APPENDIX I

SUMMARY OF PROPORTION OF "ABOVE" JUDGMENTS PER SUBJECT PER SIZE STEP PER STANDARD ANGLE. ALL DATA WERE COLLECTED BY THE METHOD OF CONSTANT STIMULI.

	Subject	Std	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0
	1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.0	1.0	1.0
	2	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0
30°	3	0.0	0.0	0.0	0.0	0.0	0.4	0.6	1.0	1.0	1.0	1.0
	4	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.9	1.0	1.0	1.0
	5	0.0	0.0	0.0	0.0	0.0	0.2	0.6	1.0	1.0	1.0	1.0
	6	0.0	0.0	0.0	0.0	0.0	0.3	0.5	0.6	1.0	1.0	1.0
	7	0.0	0.0	0.0	0.0	0.3	0.8	1.0	1.0	1.0	1.0	1.0
45°	8	0.0	0.0	0.0	0.0	0.1	0.6	0.8	1.0	1.0	1.0	1.0
	9	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.7	1.0	1.0	1.0
	10	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.9	1.0	1.0	1.0
	11	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.0	1.0	1.0
	12	0.0	0.0	0.0	0.0	0.0	0.3	0.8	1.0	1.0	1.0	1.0
60°	13	0.0	0.0	0.0	0.0	0.1	0.5	0.9	1.0	1.0	1.0	1.0
	14	0.0	0.0	0.0	0.0	0.1	0.3	0.8	1.0	1.0	1.0	1.0
	15	0.0	0.0	0.0	0.2	0.6	0.9	1.0	1.0	1.0	1.0	1.0
	16	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.0	1.0	1.0	1.0
	17	0.0	0.0	0.0	0.0	0.7	1.0	1.0	1.0	1.0	1.0	1.0
75°	18	0.0	0.0	0.0	0.0	0.5	0.8	1.0	1.0	1.0	1.0	1.0
	19	0.0	0.0	0.1	0.4	0.8	1.0	1.0	1.0	1.0	1.0	1.0
	20	0.0	0.0	0.0	0.0	0.3	0.9	1.0	1.0	1.0	1.0	1.0

SUMMARY OF PERCEPTUAL ANGLE PER SUBJECT PER STANDARD ANGLE. ALL DATA WERE COLLECTED BY THE METHOD OF CONSTANT STIMULI.

Subject	30° Std	Subject	45° Std	Subject	60° Std	Subject	75° Std
1	20.25	6	36.00	11	50.25	16	65.75
2	21.75	7	38.40	12	51.90	17	69.40
3	21.75	8	37.80	13	52.50	18	69.00
4	21.50	9	36.40	14	51.90	19	70.10
5	21.40	10	35.35	15	54.35	20	68.50
Mean	21.33		36.79		52.18		68.55
Standard Deviation	0.62		1.27		1.47		1.67
Difference	8.67		8.21		7.82		6.45

APPENDIX J

SUMMARY OF AVERAGE ERROR IN MILLIMETERS PER ORDER PER SUBJECT PER FIGURE. ALL DATA WERE COLLECTED BY THE METHOD OF AVERAGE ERROR.

	Subject	Classical Figure	Shaded Obtuse Angle Figure	Shaded Acute Angle Figure
Order 1	1	19.8	19.2	9.4
	2	14.3	12.0	6.9
	3	7.4	5.4	2.3
	4	15.1	11.9	6.0
Order 2	5	16.9	15.2	-2.2
	6	24.8	15.0	12.2
	7	13.7	10.7	2.2
	8	11.2	10.4	1.9
Order 3	9	9.0	9.6	4.7
	10	11.8	14.5	6.4
	11	21.1	17.4	11.1
	12	16.5	11.7	0.4
Mean		15.1	12.8	5.1
Standard Deviation		5.1	3.7	4.4

THE RESULTS OF TUKEY'S HSD TEST FOR SIGNIFICANT DIFFERENCES BETWEEN THE TOTALS OF THE CONDITIONS:

	Classical Figure	Shaded Obtuse Angle Figure	Shaded Acute Angle Figure
Classical Figure			**
Shaded Obtuse Angle Figure			**
Shaded Acute Angle Figure			

** $p < .01$.