A comparative study of the color zones and the form zones in peripheral vision

A COMPARATIVE STUDY OF THE COLOR ZONES AND THE FORM ZONES IN PERIPHERAL VISION

FREY - 1932

A COMPARATIVE STUDY OF THE COLOR ZONES AND THE FORM ZONES IN PERIPHERAL VISION.

BY

NEWELL WILLIAM FREY

"THESIS SUBMITTED FOR DEGREE OF MASTER OF SCIENCE."

"MASSACHUSETTS STATE COLLEGE, AMHERST."

1932.

CONTENTS

Chapter		Page
I.	INTRODUCTION	1
	A. Statement of the Problem	1
	B. Definition of Terms	1
	C. Limitations of the Study	2
II.	HISTORICAL REVIEW	4
	A. Studies Made in Regard to the Color Sensitivity of the Peripheral Retina	5
	B. Studies Made in Regard to the Form Sensitivity of the Peripheral Retina	12
III.	EXPERIMENTAL RESULTS	17
	A. Changes of Color in Peripheral Vision	17
	Apparatus	17
	Method	18
	Results	19
	Summary of Results	20
	Discussion of Results	29
	Interpretation of Results	30
	Conclusions	32
	B. Relative Extension of the Color Zones	33
	Apparatus	33
	Method	34
	Results	35

Chapter Page

Summary of Results 35
Discussion of Results 36
Interpretation of Results 37
Conclusions 41
C. Changes of Form in Peripheral Vision.. 42
Apparatus 42
Method 42
Results 43
Summary of Results 53
Discussion of Results 55
Interpretation of Results 55
Conclusions 57
D. Relative Extension of the Form Zones . 59
Apparatus 59
Method 59
Results 59
Summary of Results 60
Discussion of Results 68
Interpretation of Results 69
Conclusions 69
IV. GENERAL DISCUSSION 70
A. Graphical Comparison of the Color
and the Form Zones 70
B. General Summary 82
BIBLIOGRAPHY 85
APPENDIX 87

CHAPTER I

INTRODUCTION

A. Statement of the Problem.

The purpose of this thesis is to study the changes of color and form in indirect vision. The following questions show the purpose more exactly:

1. What changes of color tone occur when the stimulus is moved from the outer extremity of the periphery to the fovea?

2. What changes of form occur when the stimulus is moved from the outer extremity of the periphery to the fovea?

3. What are the limits of the different color zones on the retina?

4. What are the limits of the different form zones on the retina?

5. In regard to form and color, which can be distinguished first in indirect vision, and to what extent?

6. What effect does form exert upon color in indirect vision and vice versa?

B. Definition of Terms Used in the Title.

Color Zone--A term used to describe the relative extent of the retinal surface that responds to color stimulation.

Form Zone--A term used to describe the relative extent of the retinal surface that responds to form stimulation.

Peripheral Vision--All that is visible outside the fovea, with the eye focused on a definite point, is said to be in peripheral vision. In this study, peripheral vision is limited to that which is visible on the horopter with one eye blindfolded and the other focused on a single point.

C. Limitations of the Study.

The data obtained in this experiment are limited to those reported by three subjects. Owing to the limited amount of time available on the part of both subject and experimenter, either a few trained subjects could be investigated thoroughly or a great number could be investigated superficially. In order not to sacrifice quality for quantity it was decided to investigate a few subjects thoroughly rather than to study many subjects superficially.

In regard to the number of meridians investigated, only eight were explored. Consequently, in plotting the zones, the number of points on the curve was limited to eight. However, these points come at equal intervals and the resulting figure is fairly representative. In reading the available literature on this subject, the writer finds that the majority of the earlier investigators explored but the four major meridians while others explored eight. With a single exception[1], there is no available reference in the literature where an investigator explored more than eight meridians. Nevertheless, the writer believes that, if one is to plot the color and form zones accurately, as many meridians as possible should be explored.

---

1. Selligman and Beardsley; summarized in "Area of Form Fields", Ferree, Rand and Monroe, Am. J. Ophth., 9, 1926, 101.

CHAPTER II

HISTORICAL REVIEW

The examination of the peripheral retina is an old problem that began over a century ago. The first published account of such an examination appeared in a paper written by Thomas Young which was read before the Royal Society of England in 1800. In this paper Young states the following:[1] "The visual axis being fixed in any direction, I can at the same time see a luminous object placed laterally at a considerable distance from it; but in various directions the angle is very different. Upwards it extends to 50 degrees, inwards to 60, downwards to 70, and outwards to 90 degrees. These internal limits of the field of view nearly correspond with the external limit formed by the different parts of the face, when the eye is directed forwards and slightly downwards, which is its most natural position. ...The whole extent of perfect vision is little more than 10 degrees; or more strictly speaking, the imperfection begins within a degree or two of the visual axis, and at a distance of 5 or 6 degrees becomes nearly stationary, until, at a still greater distance, vision is wholly extinguished. The imperfection is partly owing to the unavoidable aberration of oblique rays,

---

1. Baird, J. W., "Color Sensitivity of the Peripheral Retina", Carnegie Institution of Washington, 1905, p. 7.

but principally to the insensibility of the retina. ...The motion of the eye has a range of about 55 degrees in every direction; so that the field of perfect vision, in succession, is by this motion extended to 110 degrees."

With this as a beginning, the work done on the investigation of the peripheral retina took two main courses. One had to do with the color sensitivity of the peripheral retina and the other with the form sensitivity of the peripheral retina. The work on the former preceded that done on the latter. In fact, it has been but recently that much work has been done on the examination of the form sensitivity of the peripheral retina. The advent of gestalt psychology probably has added more impetus in this direction than any other factor. Founded by Max Wertheimer in 1912 and expounded chiefly by Köhler and Koffka, this new psychology has literally spread like wildfire in the United States. Its influence has been felt by all branches of psychology and experimental psychology has not escaped its flame.

A. Studies Made in Regard to the Color Sensitivity of the Peripheral Retina.

In 1804 Troxler,[1] while performing an experiment to prove that the blind spot is not wholly insensitive to light, accidentally discovered that the peripheral retina adapts itself with relative rapidity to blue. Similar experiments with papers

1. Ibid., p. 7.

of various colors showed that certain tones disappear more rapidly in indirect vision than do others.

Purkinje in 1825, "was the first to observe that sensitivity to light has a wider retinal extension than sensitivity to color, that different colors have zones of different extension, and that colored objects appear in different tones at different parts of the retina. He also discovered the significance of retinal adaptation in color vision; for in the discussion of his experiments he recommends that the eye be closed for a time after each exposure."[1]

In 1865 Aubert[2] made a very thorough study of the visual fields of colors. Using a perimeter, as the apparatus, and different sized colored paper squares mounted on both white and black cards, as the stimuli, Aubert came to the following conclusions:

1. The extension of the color sensitivity and the extension of the brightness sensitivity vary with the brightness of the background. On a white background, red becomes colorless at 16 degrees while on a black background red becomes colorless at 30 degrees. Beyond the limits of the color zones, all colors look white on a black background and black on a white background.

---

1. Ibid, p. 10.

2. Ibid, p. 11-13.

2. The area of a color zone increases with the area of the stimulus but not in a direct ratio. The area of the color zone increases more slowly than that of the stimulus.

3. The color zones do not extend the same distance along each meridian. Rather, they extend the farthest on the nasal side of the retina.

4. Red passes through reddish-yellow and yellowish gray to gray; green becomes yellowish, while yellow and blue undergo no change of tone, decrease in saturation, and finally appear gray.

5. There is but little difference between the extensions of the various color zones.[1]

In 1871, Landolt[2], using a modified Foerster perimeter, and colored papers as stimuli, obtained a much wider area of color sensitivity than any of his predecessors. His zones, in decreasing order, were: blue and yellow, orange, red, yellow-green, blue-green, and violet. He also states that with a sufficiently bright stimulus all color zones are coextensive at the periphery.

---

1. With stimuli mounted upon a black background, the relative extension of the color zones, in decreasing order, are: blue, red, yellow, and green. With stimuli mounted upon a white background the order is green, yellow, blue, and red. Aubert averaged the two, and arrived at the following results: blue, 34°, yellow 33°, green 31° , and red 27°. From these results he drew the above conclusion.

2. *Ibid*, p. 16-17.

About 1881, Bull[1] performed an experiment which shed much light on the much disputed problem. He believed that the final solution would never be reached unless two factors were taken into consideration. The first was that the investigator must use stimuli whose colors do not change in tone in peripheral vision. In his own experiment, Bull claims that he has controlled both of these factors. His four "physiologically pure" colors were a purplish red, a bluish green, a yellow and a blue. His results indicate that blue and yellow are seen farther out on all meridians than red and green; that each pair are practically coextensive; and that color sensitivity extends farther up than down.

Hess,[2] in c. 1889, performed an experiment that was both a continuation and a refinement of that performed by Bull. By means of spectral light, Hess determined the wavelengths of the stable colors, that is, those colors which experience no change of tone in passing across the retina. He found the stable blue to be 471 mm.,[3] yellow 574 mm., and green 495 mm. No spectral red was stable and so he mixed red and violet in sufficient proportions until the desired tone was obtained. With stable stimuli, whose white-values and color-values pre-

---

1. Ibid., p. 22-23.

2. Ibid., p. 27-28.

3. mm. is used here to mean milli microns.

viously had been equalized, Hess proceeded to determine the limits of retinal sensitivity. He found that the retinal limits of red and green coincided and that those of yellow and blue also coincided. He found a considerable wider extension of the yellow-blue zone than of the red-green zone. He also found that an increased saturation of stimulus gave an increased extension of zonal limits; he further demonstrated that the zonal limits are widened by an increase in the area of the color stimulus.

In 1905, Baird investigated the peripheral retina and came to the conclusion that the color zones are variable depending upon the "momentary condition of retinal adaptation, the brightness and saturation of the stimuli employed, the character of the background, the condition of optic refraction, and the magnitude of visual angle of stimulus."[1] Using a Hellpach perimeter where the stimulus was a light coming from a lantern after passing through colored gelatine, he found in five subjects with dark adapted eyes that the fields for blue and yellow are coextensive and larger than the fields for red and green which are also coextensive.

In 1920, Ferree and Rand[2] found that the periphery of the retina is deficient in sensitivity but not blind to blue, red,

---

1. <u>Ibid</u>.

2. Kleitman and Blier - "Color and Form Discrimination in Periphery of Retina", Amer. J. Phys., 1928, V. 85-86, p. 179.

and yellow, and that with stimuli of sufficient intensity the limits of these colors coincide with the limits of light vision. The peripheral blindness for green, however, was absolute.

In 1926, Peter[1] found that the fields for red and green are not coextensive and that the field for red is larger than that for green.

In 1928, Kleitman and Blier[2] found that the visual fields, determined simultaneously for six colors in three subjects, in decreasing order in extension are as follows: blue, red, white, yellow, green-gray. These investigators also discovered that a central or cerebral element affects the extent of the visual field. That is, the fields for blue, red, white, and yellow are larger when the number of colors to be discriminated is smaller. They also found that there is an individual variation in the extension of the fields of vision for different colors.

Summary. There is some agreement in the results of the various investigators. All agree that the region near the fovea of the retina is the keenest in regard to color sensitivity. Furthermore, all agree that the acuteness diminishes from the fovea outward. There is a tendency among the more recent investigators to believe that the extreme fringe of the retina is not totally color-blind. Rather, the more recent

---

1. Ibid., p. 179.

2. Ibid., p. 189-190.

belief is that the retinal extremity is but relatively weak and that, with a sufficiently strong stimulus, it can produce the same sensations as the central and paracentral regions. In addition, three investigators (Bull, Hess and Baird) agree that the color zones of a certain red and a certain green are coextensive and that those of a certain yellow and a certain blue are also coextensive; the latter pair of zones are much wider than the former pair. On the other hand, Peter, and Kleitman and Blier agree that the red color zone is larger than the green color zone.

It is evident from the literature on the subject that a color zone of the retina is a variable. If the data obtained by the different investigators are examined from the point of view of the apparatus used and the conditions under which the experiments were conducted, it is possible to isolate the factors which apparently are the cause of this variability. The writer has attempted such an isolation and has come to the conclusion that a color zone is a variable depending on the following factors: (1) size of stimulus, (2) intensity of stimulus, (3) saturation of stimulus, (4) character of the background, (5) retinal adaptation, (6) lighting conditions, (7) condition of optic refraction, and (8) a cerebral element.

B. Studies Made in Regard to the Form Sensitivity of the Peripheral Retina.

In a comparative study of direct and indirect vision Huech,[1] c. 1840, took actual measurements in determining how far from the fixation point and with what size various objects might be distinguished.

Helmholtz, c. 1867, states "that in indirect vision a straight line is not always, apparently, the shortest distance between two points."[2] He also shows that on the periphery of the visual field objects appear larger and are elongated or compressed with the major axis at right angles with the line of sight.

Fick,[3] c. 1898, found that visual acuity falls off very rapidly at first, slowly afterwards, from the fovea outward in both directions on the horizontal meridian. Discrimination in the periphery was better along the temporal meridian of the visual field than along the nasal one. This work was limited in that only the horizontal meridians, the temporal and nasal, were studied and then with only one subject.

---

1. R. M. Collier - "Form Perception in Indirect Vision", J. of Comp. Psych., Feb. 1931, V. XI, p. 281.

2. Ibid., p. 281.

3. Kleitman & Blier - "Color and Form Discrimination in Periphery of Retina", Amer. J. Phys., 1928, V. 85-86, p. 185.

Geissler,[1] c. 1926, made a study of "form perception in indirect vision." A modified Soul's self-recording perimeter was used as apparatus and five white forms, i.e., a square, triangle, diamond, sector, and circle, which were mounted on black cardboard and whose areas were about 80 square millimeters each, were used as stimuli. The experiment was carried out in a dark room where the only source of light was a frosted electric light which was fastened above the observer's head. The right eyes of four observers were tested along eight meridians. The results of this experiment showed "a gradual but not uniform increase in per cent of wrong judgments towards the periphery, with few inversions. Of the five forms used the circle was judged correctly more often, and the sector less often, than any other figure. The latter was frequently mistaken for the triangle, although the triangle was also almost equally often confused with the square and the diamond. The fewest errors occurred in the horizontal diameter, the largest number in the vertical."

Kleitman and Blier,[2] c. 1928, found that the fields of vision for form as determined by discrimination of geometrical figures are practically identical for figures of the same size. They found that visual acuity, both for color and form,

---

1. Geissler, L. R. - "Form Perception in Indirect Vision," Psych. Bul., 1926, V. 23, p. 135-136.

2. Kleitman and Blier - "Color and Form Discrimination in Periphery of Retina," Amer. J. Phys., 1928, V. 85-86, p. 178-190.

falls off from the fovea outward, but at an unequal rate in different directions. They also discovered that the manner in which the visual acuity decreases is the same along all meridians explored and would seem to be a personal characteristic (based on only two subjects). In addition, they state that the ability to distinguish form in the periphery of the retina improves with practice.

In 1929, Zigler, Cook, Miller and Wemple[1] found that there were four different fields of apprehension in the visual field in the four major quarters. In the outermost one (figure-less field) the background only is perceived; there is no figure. In the adjacent field (formless figure) an unorganized mass of marks is vaguely seen, and the principal dimensions of the figure may be reported. In the next zone (formlike figure) there is a figure formation which suggests several names in succession, and this figure may manifest different modes of appearance to correspond with the successive arousal of names tentatively accepted. Mutilated figures and alterations of details are not perceived in this region. In the innermost region (clear figure) the details of the figure are accurately perceived.

They also discovered that the four regions are most extensive in the temporal and least so in the superior quarter;

---

1. Zigler, Cook, Miller and Wemple, "The Perception of Form in Peripheral Vision", Amer. J. Psych., 1930, V. 42, p. 246-259.

that the zones for all figures are roughly coextensive; that individual differences appear in the extension of the various fields; that a figure first appears formed but not familiar, then the general class name is suggested, then the specific name (or names) appears, and finally the figure is positively identified and recognized.

Collier,[1] in 1931, performed an experiment on "form perception in indirect vision." The forms that were used were the circle, parallelogram, square, isoseles triangle, equilateral triangle, hexagon and octagon. In order to determine the superiority of a form on the periphery of the visual field, Collier states that any form may be rated by the following criteria: "(1) How well does it retain its identity from the other forms? (2) What is its range based on a standard which may be equally applied to all the forms? (3) What is the length of time required for recognition? (4) Are the observers consistently more certain of this form?"[2]

Using these four criteria, Collier concludes that the triangular configuration is superior in indirect vision. He also concludes that "according to the extent of the field in which the figures may be correctly identified, the forms may be ranged in order from least to greatest as follows: Octogon,

---

1. Collier, R. M., "Form Perception in Indirect Vision", J. Comp. Psych., Feb. 1931, V. 11, p. 281-290.

2. Ibid., p. 288.

Hexagon, Circle, Parallelogram, Square, Isosceles Triangle, Equilateral Triangle;"[1] that the upper vertical meridian is the least efficient (judged by the percentage of right responses); that the degree of uncertainty increases with the time taken for identification.

---

1. Ibid., p. 289.

CHAPTER III

EXPERIMENTAL RESULTS

The observers were H. N. Glick (I), A. H. Holway (II), and the writer (III). Hereafter they shall be referred to by the numerals appearing after their names. When observer number III introspected, the apparatus was operated by observer number II. All the observers possessed normal color vision. Observers numbers II and III were emmetropes, while observer number I, being afflicted with mixed astigmia, was an ametrope. While introspecting, observer number I did not wear his glasses.

A. Changes of Color Tone in Peripheral Vision.

Apparatus. The experiment was carried out in a chamber where the light was constant. This chamber was three feet square with walls of black cloth and ceiling of smooth white cardboard. It was lighted by two forty-watt daylight bulbs which were situated at the two corners in the rear of and above the head of the observer. Each bulb was fitted with a shade which reflected the light to the ceiling, which in turn reflected the light downward to the perimeter.

The apparatus employed was a Schweigger's perimeter. It consisted of two iron posts, one being an upright and the other a curved offset, mounted on an iron stand. At the upper end of the curved offset, a semicircular iron band, which was graduated in degrees, was attached at its center by means of an axis fitted into a bearing. This device enabled the iron band to turn freely through 360 degrees, its complete revolution thus describing a hemisphere about a horizontal axis. At the upper end of the upright a brass eye-rest was attached. This eye-rest was located at the center of the described hemisphere whose radius in this perimeter is 15.5 cm. At the axis of the iron band there was a small white dot on which the eye could be focused.

The stimuli employed consisted of colored paper forms mounted on black cardboard. The forms used were: circle, triangle, capital letter "T", Arabic number "7", rabbit, star, and circle with a segment cut out of it. The main dimensions of each form were 15 mm. The colors employed were a red, green, yellow, and blue.

Method. In these experiments eight meridians were explored, namely, horizontal nasal, horizontal temporal, upper vertical, lower vertical, upper nasal, lower nasal, upper temporal, and lower temporal.[1] The observer sat on the west side of the chamber and the operator on the east side. The right eye of the observer was blindfolded and the left eye was brought

1. Some writers classify these same meridians in the following manner: in, out, up, down, in-up, down-in, up-out, and out-down.

to rest on the eye-rest. The observer focused his left eye on the white dot on the perimeter.[1] The operator placed one of the stimuli in a holder and presented it at the outermost point on the periphery. He was careful, at all times before and after the presentation, to conceal the stimuli from the observer. After the stimulus color had been exposed for a period of approximately three seconds, the observer's report was taken and recorded in a table.[2] The stimulus was moved in ten degrees nearer the fovea for the next sitting. This process was repeated until the stimulus had been moved into the fovea. However, if some noticeable change in color took place in a ten-degree interval, then the stimulus was moved slowly over this space until the exact point of the change was determined. Since there were seven forms and since each meridian was explored three times, the total number of trials on any meridian for any color was twenty-one.

Results. The results of this part of the problem are stated in the eight tables which follow, one table for each explored meridian. Table 1 gives the results obtained in the exploration of the horizontal nasal meridian of the retina;

---

1. It took numerous practice trials on the part of the observer before he was able to keep his eye fixated on this white dot as the stimuli were being presented.

2. A sample of this table is found in the appendix.

Table 2, the horizontal temporal meridian; Table 3, the upper vertical meridian; Table 4, the lower vertical meridian; Table 5, the upper nasal meridian; Table 6, the upper temporal meridian; Table 7, the lower nasal meridian; and Table 8, the lower temporal meridian.

The results, as found in the tables, have been arranged according to stimuli. The upper section of each table contains the sensations reported by each observer (I, II and III) as the red stimulus was moved from the outer extremity of the periphery to the paracentral region. The sensations, as they are recorded, have been abbreviated thusly: Br. for brown, Or. for orange, R. for red, Bl. for blue, Y. for yellow and Gr. for green. In cases where composite colors were reported, the weaker of the two was recorded first; e.g., Bl.-gray means a bluish-gray with the gray predominating. The numbers appearing before the sensations indicate the degree of eccentricity (in degrees) at which the color was reported.

<u>Summary of Results</u>. Under the conditions of this experiment, the results show that all colors appear colorless at the outer limits of the periphery of the retina. They also indicate that the first mode of appearance of a color depends upon the amount of gray in that color.

Table 1.

Horizontal Nasal Meridian of the Retina.

Color of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Color Reported by Observer.
Red	I	85-80 Gray,75-60 Y.-Or., 55-5 R.
	II	90-80 Gray,75 Y.,70-60 Or.,45-5 R.
	III	90-85 Gray,80-60 Or., 55-5 R.
Green	I	85-80 Gray,75-60 Y.,55-5 Gr.
	II	90-85 Gray,80-55 Y.,50-5 Gr.
	III	90-80 Light Gray,75-60 Y.,55-5 Gr.
Yellow	I	85-80 Gray,75-5 Y.
	II	90-85 Light Gray,80-70 Wh,,55-5 Y.
	III	90 Light Gray,85-5 Y.
Blue	I	85 Gray,80-5 Bl.
	II	90-80 Gray,75 Bl.-Gray,70-5 Bl.
	III	90 Bl.-Gray,88-5 Bl.

N.B. Y.-yellow; Or.-orange; R.-red
Gr.-green; Bl.-blue; Wh.-white

Table 2.

Horizontal Temporal Meridian of the Retina.

Color of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Color Reported by Observer.
Red	I	60-50 Gray,45-40 Y.,35-3000r.,25-5 R.
	II	60-55 Gray,50-45 Y.,40-35 Or.,30-5 R.
	III	60 Gray,50-45 Y.,30 Or.,25-5 R.
Green	I	60-55 Gray,50-30 Y.,25-5 Gr.
	II	60-50 Light Gray,45-35 Y.,30-5 Gr.
	III	60-55 Gray, 50-30 Y.,25-5 Gr.
Yellow	I	60-50 Light Gray,45-5 Y.
	II	60-55 Light Gray,50-5 Y.
	III	60-50 Gray,45-5 Y.
Blue	I	60-50GGray,45-5 Bl.
	II	60-55 Gray,50-5 Bl.
	III	60-55 Gray,50-5 Bl.

N.B. Y.-yellow; Or.-orange; R.-red; Gr.-green; Bl.-blue.

Table 3.

Upper Vertical Meridian of the Retina.

Color of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Color Reported by Observer.
Red	I	60-45 Br.,40-30 Or.,25-5 R.
	II	60 Gray,55-35 Or.,30-5 R.
	III	60-30 Or.,25-5 R.
Green	I	60 Gray,55 Bl.,50-30 Y.,25-5 Gr.
	II	60 Gray,55-35 Y.,30-5 Gr.
	III	60 Gray,50-30 Y.,25-5 Gr.
Yellow	I	60 Gray,55-5 Y.
	II	60 Light Gray,55-5 Y.
	III	60 Light Gray,55-5 Y.
Blue	I	60 Gray,55-5 Bl.
	II	60 Bl.-Gray,55-5 Bl.
	III	60-5 Bl.

N.B. Br.-brown; Or.-orange; R.-red
Bl.-blue; Y.-yellow; Gr.-green.

Table 4.

Lower Vertical Meridian of the Retina.

Color of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Color Reported by Observer.
Red	I	40 Br.-Gray,35-30 Br.-Or.,25-5 R.
	II	45 Gray,40-25 Or.,20-5 R.
	III	40 Gray,35-30 Or.,25-5 R.
Green	I	40 Light Gray,35-30 Y.,25-5 Gr.
	II	45 Gray,40-25 Y.,20-5 Gr.
	III	40 Gray,40-25 Y.,20-5 Gr.
Yellow	I	40 Light Gray,35 Whitish,30-5 Y.
	II	45 Light Gray,35-5 Y.
	III	40 Light Gray,35-5 Y.
Blue	I	40-35 Gray,30-5 Bl.
	II	45 Gray,35-5 Bl.
	III	40 Gray,35-5 Bl.

N.B. Y.-yellow; Or.-orange; R.-red; Gr.-green; Bl.-blue.

Table 5.

Upper Nasal Meridian of the Retina.

Color of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Color Reported by Observer.
Red	I	70 Gray,60-40 Or.,35-5 R.
	II	80-75 Gray,70-50 Or.,45-5 R.
	III	90-80 Gray,75-60 Or.,55-5 R.
Green	I	70-65 Gray,60-40 Y.,35-5 Gr.
	II	80-70 Light Gray,65-50 Y.,45-5 Gr.
	III	90-80 Light Gray,75-55 Y.,50-5 Gr.
Yellow	I	70 Gray,69-5 Y.
	II	80-60 Light Gray,55-5 Y.
	III	90-80 Light Gray,75-5 Y.
Blue	I	70-5 Bl.
	II	80 Gray,75 Bl.-Gray,60-5 Bl.
	III	90 Gray,85-5 Bl.

N.B. Y.-yellow; Or.-orange; R.-red; Gr.-green; Bl.-blue.

Table 6.

Upper Temporal Meridian of the Retina.

Color of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Color Reported by Observer.
Red	I	50 Gray,40-30 Or.,25-5 R.
	II	50 Gray,45-40 Y.- Gray,35 Or.,25-5 R.
	III	55-45 Gray,40-30 Y.-Or.,25-5 R.
Green	I	50-45 Gray,40-30 Y.,25-5 Gr.
	II	50-40 Gray,35-40 Y.-Gray,25-5 Gr.
	III	55-50 Gray,45-30 Gray-Y.,25-5 Gr.
Yellow	I	50 Gray,45-5 Y.
	II	50-45 Light Gray,35-5 Y.
	III	55-50 Light Gray,45-5 Y.
Blue	I	50 Gray,45-5 Bl.
	II	50 Bl.-Gray,45-5 Bl.
	III	55 Gray,50-5 Bl.

N.B. Y.-yellow; Or.-orange; R.-red; Gr.-green; Bl.-blue.

Table 7.

Lower Nasal Meridian of the Retina.

Color of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Color Reported by Observer.
Red	I	50 Gray,45-30 Or.-Y.,25-5 R.
	II	50 Gray,45-30 Or.,25-5 R.
	III	50 Gray,40 Gray-Or.,30-5 R.
Green	I	50-45 Gray,40-30 Y.,25-5 Gr.
	II	50-40 Light Gray,35-30 Y.,25-5 Gr.
	III	50-40 Gray,35 Y.,30-5 Gr.
Yellow	I	50 Light Gray,40-5 Y.
	II	50 Light Gray,40-5 Y.
	III	50 Light Gray,40-5 Y.
Blue	I	50 Gray,45-5 Bl.
	II	50-45 Gray,40-5 Bl.
	III	50 Gray,45-5 Bl.

N.B. Y.-yellow; Or.-orange; R.-red; Gr.-green; Bl.-blue.

Table 8.

Lower Temporal Meridian of the Retina.

Color of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Color Reported by Observer.
Red	I	45 Gray, 40 Y., 35-30 Or., 25-5 R.
	II	60-50 Gray, 45-40 Or., 35-5 R.
	III	50 Gray, 45 Y.-Or., 40-35Or., 30-5 R.
Green	I	45 Gray, 40-30 Y., 25-5 Gr.
	II	60-50 Light Gray, 45 Y.-Gr., 30-5 Gr.
	III	50-40 Light Gray, 35 Y.-Gr., 25-5 Gr.
Yellow	I	45 Light Gray, 40-5 Y.
	II	60-50 Light Gray, 45-5 Y.
	III	50-45 Light Gray, 40-5 Y.
Blue	I	45 Gray, 40-5 Bl.
	II	60-55 Gray, 50 Bl.-Gray, 45-5 Bl.
	III	50 Gray, 45-5 Bl.

N.B. Y.-yellow; Or.-orange; R.-red; Gr.-green; Bl.-blue.

When the stimuli were brought in far enough to appear colored, the changes in color tone were as follows:

1. Green first appeared a yellow, then greenish, and finally green.

2. Red first appeared yellowish orange (with a single exception), then orange and finally red.

3. Yellow first appeared yellowish and then increased in saturation.

4. Blue first appeared bluish and then increased in saturation.

5. Blue first appeared bluish and then increased in saturation.

Discussion of Results. The results of the investigation of the changes in color in indirect vision agree with the testimony of previous investigators, with the following exceptions. Woinow[1] and Klug[2] contend that yellow appears green in indirect vision. The results of this investigation do not confirm such a contention. Hellpach[3] maintains that there is an absence of the sensation of yellow upon the periphery. Here again the results of this experiment do not substantiate such a statement.

---

1. Baird, J. W., "Color Sensitivity of the Peripheral Retina," 1905, p. 14.

2. Ibid., p. 20.

3. Ibid., p. 32.

<u>Interpretation of Results</u>. The fact that all colors, under normal conditions of luminosity, appear colorless at the outer limits of the periphery of the retina can be explained adequately by either the Hering theory or the Ladd-Franklin theory. The Hering theory conceives the retinal surface to contain three pairs of photochemical substances; a white-black, a blue-yellow, and a green-red. These pairs of photochemical substances are unevenly distributed over the whole retina in a rather uniform way. There is very little distribution of red-green and yellow-blue substances over the extreme peripheral regions of the retina. Consequently, under normal conditions of luminosity, because of the preponderance of the white-black substance over both the blue-yellow and red-green substances, only shades of gray are perceived in the extreme peripheral regions. The Ladd-Franklin theory would attempt an explanation of the fact that all colors, under normal conditions of luminosity appear colorless in the extreme peripheral region of the retina by assuming that this region is still in its primitive form. This would mean that the outermost portion of the peripheral retina contains only the rods. These rods are capable of arousing only the achromatic sensations. This approximates the conditions as they are in the periphery of the retina. Cajal[1] has proved that

1. Ladd-Franklin, "Colour and Colour Theories", 1929, p. 126.

the extreme periphery of the retina contains rods almost exclusively with the exception of a few stray cones, the cones being capable of arousing chromatic sensations only.

The changes of color in peripheral vision can be interpreted in the light of either the Hering theory, Ladd-Franklin theory, or a modified form of the Helmholtz theory. The Helmholtz theory assumes that in direct vision a stimulus affects all three forms of visual substance but in an unequal degree. Thus a red light stimulates the red-sensing substance most intensively, the green sensing substance less intensively, and the blue sensing substance least intensively. The curve which represents the intensity of the excitation of this red-sensing substance would have its peak in the red and would slope off gradually toward the blue. However, in indirect vision Fick[1] believes that the intensity of excitation of a color-sensing substance is different than in direct vision. He believes that the curves tend to flatten out and the results are straight lines. This would mean that all three color-sensing substances are excited equally by all stimuli. Thus the changes in color in peripheral vision can be explained by assuming that any colored stimuli excites the three visual substances with equal intensity.

The Hering theory, in explaining these changes of color

---

1. Baird, "Color Sensitivity of the Peripheral Retina", 1905, p. 39.

in indirect vision, assumes that each pair of photochemical substances has a different distribution over the retina. The distribution is such that the white-black substance is found over all parts of the retina in practically equal quantities. The yellow-blue substance is concentrated about the central and paracentral vision and decreases in quantity as it approaches the periphery. The same is true of the green-red substance. It, however, decreases more rapidly as it approaches the periphery than does the blue-yellow substance. The changes in color in indirect vision are because of the greater amount of blue-yellow substance.

The Ladd-Franklin theory would explain these changes in color by assuming that the peripheral part of the retina is still in both the first and second stages of its development. Any change in color would be a regression to its more primitive form. The primitive stage of the retina originally contained rods only. But it has progressed enough so that the normal primitive stage of the retina now contains a few cones. The second stage contains cones which can differentiate between yellow and blue waves. The third stage can differentiate between yellow and blue, and also between red and green.

Conclusions. On the basis of this experiment, one may conceive the retinal surface to contain three photochemical substances. At the outer limits of the periphery there is a gray producing substance. Next there is a substance which differentiates between yellow and blue. Finally, there is a substance in the central and paracentral region that differentiates between blue, yellow, red and green.

B. The Relative Extension of the Color Zones.

Apparatus. The apparatus used in these experiments was the same as that used in the two preceding experiments, and the experiment was carried out under the same conditions (p. 17 ff.). The colored paper used in making the colored forms was obtained from the Stoelting Company and was presumably equated for both brilliance[1] and saturation.[2] Later, after a thorough investigation of the literature and after considerable data had been collected, it was discovered that the colors were not equated for brilliance and saturation. Immediate steps were taken to remedy this situation. Samples of the colored paper were sent to the Bureau of Standards, Washington, D. C. to be analyzed. It was the writer's belief that this variable factor, that is, equated stimuli for brilliance and

---

1. By brilliance is meant "that attribute of any color in respect of which it may be classed as equivalent to some member of a series of grays ranging between black and white." Report of Committee on Colorimetry for 1920-21, L. T. Troland, Chairman, J.O.S.A. and R.S.I., Aug., 1922, 6, 527-96.

2. By saturation is meant "that attribute of all colors possessing a hue, which determines their degree of difference from a gray of the same brilliance." Ibid.

saturation, which was thought to have been taken care of previously, could now be best accounted for by definitely specifying the attributes of the colored stimuli.

The analysis obtained by the Bureau of Standards definitely provided such a specification. The following are their results:[1]

SAMPLE	HUE	VALUE	CHROMA
Red	7 R	3.5	15
Yellow	9 Y	8.0	9
Green	10 G	6.0	6
Blue	6 PB	4.5	12

Method. In these experiments the stimuli were presented in the same manner as in the two preceding experiments. However, after the first trial, the approximate limits of the color zones were known and in the second and third trials it was not necessary to begin at the periphery. The procedure in the second and third trials consisted of presenting the stimuli approximately at the outer limits of the color zones and then moving the stimuli slowly inward until the exact points, at which the corresponding colors appeared, were determined. Each stimulus was presented three times. Since

---

1. These results are based upon a comparison of the colored paper used in this experiment with an accepted standard, in this case, the Munsell standard. In the Munsell system value is synonomous with brilliance as defined by the Committee on Colorimetry and chroma according to the Munsell system is synonomous with saturation as defined by the Committee on Colorimetry.

there were seven forms, the total number of trials for each color was twenty-one. The relative extent of each color zone was taken as the average of these twenty-one trials.

Results. The same eight half-meridians were explored in these experiments as in the two preceding experiments. They were, namely, the horizontal temporal meridian of the retina, the horizontal nasal, the upper vertical, the lower vertical, the upper temporal, the lower temporal, the upper nasal, and the lower nasal. The results are contained in table 9a. The upper section of table 9a contains the outer limits of the color zones along the horizontal temporal meridian of the retina for observers numbers I, II and III. The next section is along the horizontal nasal meridian and the next along the upper vertical meridian, etc.

Summary of Results. The results of this experiment show definitely that the horizontal nasal meridian of the retina is most sensitive to color and that the upper vertical meridian of the retina is least sensitive to color. If the meridians of the retina were arranged in decreasing order according to the relative extension of the color zones, the results of this experiment indicate that they would be as follows: horizontal nasal, upper nasal, upper vertical, horizontal temporal, upper temporal, lower temporal, lower nasal, and lower vertical. The results show that the green and red zones are practically coextensive and smaller than the blue and yellow

Table 9a.

Meridian[1]	Observer	Degree of Eccentricity Red	Green	Yellow	Blue
Hor. Temporal	I	20.7	23.6	40	43.4
	II	27	25.5	46	48.3
	III	23	24	44	50
Hor. Nasal	I	53.3	53	72.3	76
	II	43	44	65	67
	III	53	50	82	87
Upper Vertical	I	26	25	50.7	52
	II	30.4	29.5	51	53
	III	23.2	20	54.3	57
Lower Vertical	I	22.5	20.4	27	26.1
	II	18.3	17	31.5	33
	III	20.8	17.5	30	32
Upper Nasal	I	33	31	69	70
	II	42	40	53	55
	III	51	46	76	84.5
Lower Nasal	I	23.8	21.5	37.2	40.3
	II	20	22	35	35
	III	32	26	40	43
Upper Temporal	I	21.8	22	42.5	42.5
	II	23.5	24	33	41
	III	24	22.6	42	47
Lower Temporal	I	23	25.4	36	39.2
	II	30.2	26	40.1	41.5
	III	29	22.6	36.5	42

1. Meridians of the retina.

zones, also practically coextensive. They also show that there are individual differences in zonal extensions.

Discussion of Results. The investigation of the relative extent of the color zones has yielded results which are in harmony with those obtained by such investigators as Baird,[1] Bull,[2] and Hess,[3] in that all find the zones for blue and yellow coextensive and larger than those for green and red which are also coextensive. Peter[4] found that the red zone is larger than that of green. Kleitman and Blier[5] conclude that the red zone is larger than those of both yellow and green. The results of this experiment do not substantiate the findings of the last three investigators. The fact that all investigators found the horizontal nasal meridian of the retina the most sensitive to color is confirmed by the results of this investigation. The fact that the lower vertical meridian of the retina was proved by the reports of all three observers to be the least sensitive to color has been stated by other investigators.

---

1. Baird, "Color Sensitivity of the Peripheral Retina", 1905.

2. Ibid., p. 22-23.

3. Ibid., p. 27-28.

4. Kleitman and Blier, "Color and Form Discrimination in Periphery of Retina", Amer. J. Phys., 1928, V. 85-86, p. 179.

5. Ibid.

Interpretation of Results. Any attempt on the part of the writer to explain color vision and its accompanying phenomena would, in all probability, lead into many difficulties. The writer only hopes to mention the possibilities of an interpretation of the data in the light of the prevailing theories.

The first possibility of an interpretation in physiological terms would be one in which the whole retinal surface is to be conceived as uniform. Any peculiarities in color-tone are explained by the physical structure of the eye and the spatial arrangement of its parts. The peripheral part of the retinal surface contains the same color sensing substance as the central region. However, owing to defective refraction of oblique rays of light and owing to the fact that the plane of the pupil is not perpendicular to the path of the incident light, it does not receive so bright and so exact an image as the central region does. In other words, what little light does strike the peripheral retina is imperfectly focused and consequently constitutes a weaker physiological stimulus.

The second possibility would be to conceive of the retina as not being uniform. The peripheral retina in this case would not be constituted of the same chemical substance as the central region. Any transition in color tone would thus be explained by the difference in chemical constitution of the peripheral region and the central region of the retina.

A third possibility would be a combination of the first two mentioned. Transitions in color tone would be explained here by differences in chemical consitition plus the fact that the peripheral region of the retina receives a weaker physiological stimulus than the central region.

The first mentioned possibility seems inadequate for explaining color vision. It assumes essentially that color vision depends upon the amount and quality of the light that strikes the color sensing substance--in other words, it depends upon the strength of the stimulus. On this assumption, it would be expected that the same sensations would be aroused by setting the stimulus at a definite point on the periphery of the retina and then varying the intensity of the stimulus as would be aroused by moving a stimulus of constant intensity across the retina. The facts of the case indicate that this is not so. Consequently, the first possibility as an explanation of color vision is eliminated. Since the third possibility also implies the same explanation, in part, as the first, it too is eliminated as a means of interpretation. This leaves only one other possibility--with the exception of one which depends upon a cerebral element which is so vague that it seems hardly worth mentioning.

The point of view which assumes that the retinal surface contains an uneven distribution of chemical substance seems, by the process of elimination, to be the one by which color vision can be explained. In the hands of different theorists this point of view has appeared in different forms.

Helmholtz assumed that there were three photochemical substances in the retina. One responded to red, one to green and one to blue-violet. The color that was perceived depended upon the amount that each of these substances was stimulated. The relative amount that each of these photochemical substances was stimulated depended upon the wavelength of the stimulus. A long wavelength like that of orange stimulated the red substance to a large extent, the green substance to a small extent, and the blue-violet to a very small extent. In the case of a short wavelength like that of blue, the blue-violet substance was decomposed the most, the green slightly and the red very slightly. White light, according to Helmholtz decomposed all the photochemical substances at the same time.

Hering conceived the retina to contain three pairs of photochemical substances: a white-black, a blue-yellow, and a red-green. The perception of red, yellow and white was caused by a decomposition of the photochemical substances, while the perception of green, blue and black depended upon the building up of the photochemical substances. According to Hering, each substance under all conditions of stimulation tended to maintain its equilibrium. Thus every process of decomposition induced a corresponding building up process. By this maintenance of equilibrium, Hering accounted for after images and contrast phenomena.

Ladd-Franklin conceived the visual substance of the eye to be the product of a progressive development. Originally, that is, in its primitive form, the photochemical substance was decomposed by all sorts of light and the result was that only shades of gray were perceived. Only the rods contained this substance. Later, probably with the development of the rods in the central region into cones, the photochemical substance was affected by long waves in one way and by short waves in a different way. Long waves now produced yellow and short waves produced blue. This differentiation occurred only in the cones. The cones slowly developed outward and eventually the yellow producing substance in the cones located in the central region differentiated further and now were able to be decomposed by erythrogenic (red-producing) and chlorogenic (green-producing) rays of light. The normal retina thus contains photochemical substance in all three stages of development. Its distribution over the retina is such that the less highly developed substance increases with the increase of distance from the center.

Forbes explained color vision by basing it upon interference phenomena in light. These interference effects are seen in the coloring of insects' wings and scales, in thin films of oil, and in soap bubbles. He assumed that <u>maxima</u> of "standing waves" are set up in the cones by the reflection of part of the light back toward the front of the eye. The color of the light, that is, the wavelength, determined the position of these standing waves. Forbes also assumed that there is a membrane across the cone at the point where one of these standing waves will come. As in the Hering theory, Forbes also assumed three pairs of photochemical substances located in the cones. In the red-green cone the membrane will come at the point for the yellow maxima. Red waves will go beyond the membrane and increase the normal action of the cone. Green waves will go below the membrane and inhibit its normal action. The same phenomena occur in the yellow-blue cone. The membrane is at the maxima for the green, yellow increasing and blue inhibiting the normal action of the cone.

Conclusions. Under the conditions of this experiment and with the results obtained, the central region of the retina may be conceived to have an abundance of sensitive cones which have developed so that they may differentiate among red, green, yellow and blue colors. The region, next to the central region, may be conceived to have sensitive cones less in number, and these cones have developed only far enough to differentiate between blue and yellow colors. The extreme peripheral region of the retina is so undeveloped that it contains very few sensitive cones, and vision here is limited to rod vision, a condition where only achromatic colors are discernible.

C. Changes of Form in Peripheral Vision.

Apparatus. The apparatus used in this part of the problem was exactly the same as that used in the preceding experiment (p. 17 ff.). It consisted of a Schweigger's perimeter and colored paper forms mounted on black cardboard. The experiment was carried out under exactly the same conditions in a chamber where the light was held constant. The forms used were a triangle, circle, Arabic numeral 7, capital letter T, star, rabbit and circle with segment cut out of it. The triangle was equilateral and each side was 15 mm. The circle was 15 mm. in diameter. The long vertical part of the "7" was 15 mm., the horizontal part was 13 mm. and the short vertical part was 3 mm. The vertical part of the letter "T" was 13 mm. and the horizontal part was 15 mm. The size of the five pointed star was such that it could be inscribed in a circle with a diameter of 16 mm. The length of the rabbit from the tip of its nose to the end of its tail was 16 mm. The diameter of the circle with a segment cut out of it was 15 mm. The segment had a central angle of 45 degrees. Each form was duplicated in four colors, namely, red, green, yellow and blue.

Method. Each form was first presented at the outermost point in the periphery and moved inward in 10-degree intervals. At each interval the observer described what he perceived. In addition to this, an objective scale was used. This scale ranged from one to five. One represented the perception of the background only; two, the vague perception of an unorganized mass of marks; three, the perception of a figure formation which suggested several names in succession; four, the perception of a figure which could be identified; and five, the perception of a clear definite figure, the details of which could be accurately perceived. The observer first gave an explicit description of his perception and then ranked it according to the scale. The ranks were recorded in a table and the introspective reports were kept on sheets of paper.

Results. Eight meridians were investigated. The results of these investigations are recorded in the eight following tables. Table 9 contains statements regarding the changes that occurred when the stimulus was moved along the horizontal nasal meridian of the retina from the outer extremity of the periphery to the paracentral region. Table 10 was along the horizontal temporal meridian; table 11, the upper vertical meridian; table 12, the lower vertical meridian; table 13, the upper nasal meridian; table 14, the lower nasal meridian; table 15, the upper temporal meridian; and table 16, the lower temporal meridian.

Table 9 Horizontal Nasal Meridian of the Retina

Form of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Form Reported by Observer.
Circle	I	90(1),80(2),75(3),65-20(4),19-5(5).
	II	90(1),85(2),70(3),65-20(4),19-5(5).
	III	90(1),80(2),65(3),60-20(4),19-5(5).
Triangle	I	90(1),80(2),70(3),60-20(4),15-5(5).
	II	90(1),85(2),70(3),60-20(4),15-5(5).
	III	90(1),80(2),65(3),55-25(4),20-5(5).
"T"	I	90(1),80(2),70(3),60-25(4),20-5(5).
	II	90(1),85(2),70(3),60-25(4),20-5(5).
	III	90(1),80(2),65(3),55-25(4),20-5(5).
"7"	I	90(1),80(2),70(3),60-25(4),20-5(5).
	II	90(1),85(2),70(3),50-25(4),20-5(5).
	III	90(1),80(2),65(3),50-25(4),20-5(5).
Rabbit	I	90(1),80(2),70(3),55-25(4),20-5(5).
	II	90(1),85(2),70(3),50-25(4),20-5(5).
	III	90(1),80(2),65(3),50-25(4),20-5(5).
Star	I	90(1),80(2),70(3),60-25(4),20-5(5).
	II	90(1),85(2),70(3),50-25(4),20-5(5).
	III	90(1),80(2),65(3),50-25(4),20-5(5).
Circle with segment cut out	I	90(1),85(2),70(3),55-25(4),20-5(5).
	II	90(1),85(2),70(3),50-25(4),20-5(5).
	III	90(1),80(2),65(3),50-25(4),20-5(5).

N.B. (1)-perception of ground only.
(2)-perception of vague figure.
(3)-perception of potential form.
(4)-identification of form.
(5)-clear identification of form.

Table 10. Horizontal Temporal Meridian of the Retina.

Form of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Form Reported by Observer.
Circle	I	60(2),55(3),50-20(4),15-5(5).
	II	60(2),55-40(3),35-15(4),10-5(5).
	III	60(2),55(3),50-25(4),20-5(5).
Triangle	I	60(2),55(3),50-20(4),15-5(5).
	II	60(2),55(3),25-20(4),15-5(5).
	III	60(2),55(3),50-25(4),20-5(5).
"T"	I	60(2),50(3),40-20(4),15-5(5).
	II	60(2),50-30(3),25-15(4),10-5(5).
	III	60(2),50(3),40-25(4),20-5(5).
"7"	I	60(2),50(3),40-20(4),15-5(5).
	II	60(2),50-25(3),20-15(4),10-5(5).
	III	60(2),50(3),45-25(4),20-5(5).
Rabbit	I	60(2),50(3),40-20(4),15-5(5).
	II	60(2),55-25(3),20-15(4),10-5(5).
	III	60(2),50(3),40-25(4),20-5(5).
Star	I	60(2),50(3),45-20(4),15-5(5).
	II	60(2),50-30(3),25-15(4),10-5(5).
	III	60(2),55(3),50-25(4),20-5(5).
Circle with segment cut out	I	60(2),50(3),40-20(4),15-5(5).
	II	60(2),50-25(3),20-15(4),10-5(5).
	III	60(2),55-25(3),40-25(4),10-5(5).

N.B. (2)-perception of vague figure.
(3)-perception of potential form.
(4)-identification of form.
(5)-clear identification of form.

Table 11. Upper Vertical Meridian of the Retina.

Form of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Form Reported by Observer.
Circle	I	60(2),50(3),45-15(4),14-5(5).
	II	55(2),50(3),35-15(4),14-5(5).
	III	60(2),50(3),30-15(4),14-5(5).
Triangle	I	60(2),45(3),40-20(4),15-5(5),
	II	55(2),45(3),30-20(4),15-5(5).
	III	60(2),45(3),30-20(4),15-5(5).
"T"	I	60(2),45(3),40-20(4),15-5(5).
	II	55(2),45(3),30-20(4),15-5(5).
	III	60(2),40(3),25-20(4),15-5(5).
"7"	I	60(2),50(3),35-20(4),15-5(5).
	II	60(2),50(3),20-15(4),14-5(5).
	III	60(2),50(3),20-15(4),14-5(5).
Rabbit	I	60(2),40(3),35-20(4),15-5(5).
	II	55(2),40(3),25-20(4),15-5(5).
	III	60(2),40(3),39-20(4),15-5(5).
Star	I	60(2),40(3),39-20(4),15-5(5).
	II	55(2),40(3),30-20(4),15-5(5).
	III	60(2),40(3),30-20(4),15-5(5).
Circle with segment cut out	I	60(2),40(3),35-20(4),15-5(5).
	II	60(2),40(3),20-15(4),14-5(5).
	III	60(2),40(3),30-20(4),15-5(5).

N.B. (2)-perception of vague figure.
(3)-perception of potential form.
(4)-identification of form.
(5)-clear identification of form.

Table 12. Lower Vertical Meridian of the Retina.

Form of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Form Reported by Observer.
Circle	I	40(2),30(3),29-15(4),10-5(5).
	II	40(2),30(3),29-20(4),15-5(5).
	III	40(2),30(3),29-20(4),15-5(5).
Triangle	I	40(2),30(3),29-20(4),15-5(5).
	II	40(2),30(3),29-20(4),15-5(5).
	III	40(2),30(3),29-20(4),15-5(5).
"T"	I	40(2),30(3),29-20(4),15-5(5).
	II	40(2),30(3),25-20(4),15-5(5).
	III	40(2),30(3),20-15(4),14-5(5).
"7"	I	40(2),30(3),25-15(4),14-5(5).
	II	40(2),30(3),20-15(4),14-5(5).
	III	40(2),30(3),20-15(4),14-5(5).
Rabbit	I	40(2),30(3),25-15(4),14-5(5).
	II	40(2),30(3),20-15(4),14-5(5).
	III	40(2),30(3),20-15(4),14-5(5).
Star	I	40(2),30(3),25-15(4),14-5(5).
	II	40(2),30(3),20-15(4),14-5(5).
	III	40(2),30(3),20-15(4),14-5(5).
Circle with segment cut out	I	40(2),30(3),25-15(4),14-5(5).
	II	40(2),30(3),20-15(4),14-5(5).
	III	40(2),30(3),20-15(4),14-5(5).

N.B. (2)-perception of vague figure.
(3)-perception of potential form.
(4)-identification of form.
(5)-clear identification of form.

Table 13 Upper Nasal Meridian of the Retina.

Form of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Form Reported by Observer.
Circle	I	75(1),70(2),55(3),40-20(4),15-5(5).
	II	80(1),75(2),65(3),45-20(4),15-5(5).
	III	90-75(1),70(2),60(3),40-20(4),15-5(5).
Triangle	I	75(1),65(2),50(3),35-20(4),15-5(5).
	II	80(1),75(2),70(3),45-20(4),15-5(5).
	III	90(1),70(2),50(3),40-20(4),15-5(5).
"T"	I	75(1),70(2),55(3),35-20(4),15-5(5).
	II	80(1),70(2),65(3),35-20(4),15-5(5).
	III	90(1),70(2),30(3),35-20(4),15-5(5).
"7"	I	75(1),70(2),50(3),30-20(4),15-5(5).
	II	80(1),70(2),55(3),40-20(4),15-5(5),
	III	90(1),70(2),50(3),30-20(4),15-5(5).
Rabbit	I	75(1),70(2),45(3),30-20(4),15-5(5).
	II	80(1),70(2),55(3),35-20(4),15-5(5).
	III	90(1),70(2),50(3),30-20(4),15-5(5).
Star	I	75(1),70(2),45(3),30-20(4),15-5(5).
	II	80(1),70(2),50(3),40-20(4),15-5(5).
	III	90(1),70(2),50(3),40-20(4),15-5(5).
Circle with segment cut out	I	75(1),70(2),55(3),30-20(4),15-5(5).
	II	80(1),70(2),55(3),35-20(4),15-5(5).
	III	90(1),70(2),55(3),30-20(4),15-5(5).

N.B. (1)-perception of ground only.
(2)-perception of vague figure.
(3)-perception of potential form.
(4)-identification of form.
(5)-clear identification of form.

Table 14. Lower Nasal Meridian of the Retina.

Form of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Form Reported by Observer.
Circle	I	45(2),40(3),35-15(4),10-5(5).
	II	50(2),40(3),35-20(4),10-5(5).
	III	50(2),45(3),20-15(4),14-5(5).
Triangle	I	45(2),40(3),35-20(4),15-5(5).
	II	50(2),40(3),25-20(4),15-5(5).
	III	50(2),40(3),20-15(4),14-5(5).
"T"	I	45(2),40(3),30-20(4),15-5(5).
	II	50(2),40(3),20-15(4),14-5(5).
	III	50(2),40(3),20-15(4),14-5(5).
"7"	I	45(2),40(3),35-20(4),15-5(5).
	II	50(2),40(3),25-20(4),15-5(5).
	III	50(2),40(3),20-15(4),14-5(5).
Rabbit	I	45(2),40(3),30-20(4),15-5(5).
	II	50(2),40(3),25-20(4),15-5(5).
	III	50(2),40(3),20-15(4),14-5(5).
Star	I	45(2),40(3),25-15(4),14-5(5).
	II	50(2),40(3),20-15(4),14-5(5).
	III	50(2),40(3),20-15(4),14-5(5).
Circle with segment cut out	I	45(2),40(3),30-20(4),15-5(5).
	II	50(2),40(3),20-15(4),14-5(5).
	III	50(2),40(3),20-15(4),14-5(5).

N.B. (2)-perception of vague figure.
(3)-perception of potential form.
(4)-identification of form.
(5)-clear identification of form.

Table 15. Upper Temporal Meridian of the Retina.

Form of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Form Reported by Observer.
Circle	I	50(2),45(3),44-20(4),15-5(5).
	II	50(2),45(3),40-20(4),15-5(5).
	III	50(2),45(3),40-20(4),15-5(5).
Triangle	I	50(2),45(3),44-20(4),15-5(5).
	II	50(2),45(3),35-20(4),15-5(5).
	III	50(2),45(3),35-20(4),15-5(5).
"T"	I	50(2),40(3),30-20(4),15-5(5).
	II	50(2),35(3),25-20(4),15-5(5).
	III	50(2),40(3),30-20(4),15-5(5).
"7"	I	50(2),40(3),35-20(4),15-5(5).
	II	50(2),40(3),30-20(4),15-5(5).
	III	50(2),45(3),30-20(4),15-5(5).
Rabbit	I	50(2),40(3),35-20(4),15-5(5).
	II	50(2),40(3),30-20(4),15-5(5),
	III	50(2),40(3),30-20(4),15-5(5).
Star	I	50(2),45(3),40-20(4),15-5(5).
	II	50(2),40(3),30-20(4),15-5(5).
	III	50(2),40(3),30-20(4),15-5(5).
Circle with segment cut out	I	50(2),40(3),35-20(4),15-5(5).
	II	50(2),45(3),30-20(4),15-5(5).
	III	50(2),40(3),30-20(4),15-5(5).

N.B. (2)-perception of vague figure.
(3)-perception of potential form.
(4)-identification of form.
(5)-clear identification of form.

Table 16. Lower Temporal Meridian of the Retina.

Form of Stimulus.	Numeral of Observer.	Degree of Eccentricity of Stimulus; and Form Reported by Observer.
Circle	I	45(2),40(3),35-20(4),15-5(5).
	II	60(2),40(3),20-15(4),14-5(5).
	III	50(2),40(3),20-15(4),14-5(5),
Triangle	I	50(2),40(3),35-20(4),15-5(5).
	II	60(2),40(3),15-11(4),10-5(5).
	III	50(2),40(3),20-15(4),14-5(5).
"T"	I	50(2),40(3),35-20(4),15-5(5).
	II	60(2),40(3),15-11(4),10-5(5).
	III	50(2),40(3),20-15(4),10-5(5).
"7"	I	50(2),40(3),35-20(4),15-5(5).
	II	60(2),40(3),15-11(4),10-5(5).
	III	50(2),40(3),20-15(4),14-5(5).
Rabbit	I	50(2),40(3),30-20(4),15-5(5).
	II	60(2),40(3), 15-11(4),10-5(5).
	III	50(2),40(3),20-15(4),14-5(5).
Star	I	50(2),40(3),35-20(4),15-5(5).
	II	60(2),40(3),15-11(4),10-5(5).
	III	50(2),40(3),20-15(4),14-5(5).
Circle with segment cut out	I	50(2),40(3),35-20(4),15-5(5).
	II	60(2),40(3),15-11(4),10-5(5).
	III	50(2),40(3),15-11(4),10-5(5).

N.B. (2)-perception of vague figure.
(3)-perception of potential form.
(4)-identification of form.
(5)-clear identification of form.

The statements in the tables have been arranged according to stimuli. The first section contains the results of the three observers (I, II and III) as the circle was moved from the edge of the periphery to the paracentral region. The next section contains the results for the triangle, etc.

In moving the stimulus over the retina it was evident from the descriptions given by the observers that the changes in form corresponded to the general scale[1] which had been improvised. In the tables the changes of form are recorded according to this scale. Number (1) signifies the perception of background only. In the explicit descriptions given by the observers, this was expressed by some such statement, "I perceive a grayish blotch." Number (2) means the perception of an unorganized mass of marks. Number (3) stands for the perception of a potential form which arouses successive names according to its mode of appearance. Number (4) indicates the perception of the correct form, that is, there is a one to one relationship between the response and the stimulus. Number (5) signifies the accurate perception of minute details, that is, there is a one to one relationship between the stimulus and the perception. The numbers appearing before the numerals

---

1. The idea of using such a scale was obtained from the experiment by Zigler, Cook, Miller and Wemple on "The Perception of Form in Peripheral Vision." They found that there were four fields of apprehension. These four fields were used in the "general scale", and in addition a fifth was added.

designate the degree of eccentricity (in degrees) of the stimulus, wheneach judgment was reported.

In addition to these general changes of form in peripheral vision there were specific changes which occurred, especially in region III. The circle with a segment cut out of it always appeared as a full circle in this region. The number "7" was frequently described as a "T". The rabbit was called a goose, a tree, and it was often said that it resembled some kind of an animal. In this region, the star was often mistaken for the rabbit or the triangle. The circle and triangle did not arouse any names but were described as being disk-like and triangular-like.

<u>Summary of Results</u>. In moving certain forms across the retina, from the periphery inward, they appeared to pass through the following phases:

1. The circle first appeared as light, undifferentiated from the background, (only the ground was perceived); next as a vague figure, then as a potential form (disk-like), then as a circle and finally as a clear and distinct disk.

2. The triangle originally was perceived as light, then as a vague figure, next as a potential form (triangular-like), subsequently as a triangle and lastly as a triangle, the details of which were clearly and accurately apprehended.

3. First the rabbit came into view as a blotch of light,

next as a vague figure, then as a potential form (goose, tree, some kind of an animal, etc.), then as a rabbit and finally as a distinct rabbit.

4. The Arabic number "7" first became discernible as light, then as a vague figure, next as a potential form (frequently "T"-like), subsequently as the number "7", and lastly as a well defined "7".

5. The capital letter "T" originally became ostensible as light, subsequently as a vague figure, later as a potential form ("T"-like), then as a "T", and finally a clearly defined "T".

6. The star first revealed itself as a blotch of light, next as a vague figure, then as a potential form (a few times as a rabbit, a few times as a triangle, but mostly as star-like), subsequently as a star and lastly as a well defined star, the details of which could be accurately perceived.

7. The circle with a segment cut out of it manifested itself originally as light, then as a vague figure, then as a potential form (practically always disk-like), next as a circle with a segment cut out of it, and finally as a clearly defined circle with a segment cut out of it.

In the potential form region the circle with a segment cut out of it invariably appeared like a complete disk. (In this region the number "7" frequently appeared like the letter "T").

Discussion of Results. The results of these experiments seem to substantiate those obtained by Zigler,[1] Cook, Miller and Wemple. That there are four definite phases or fields of apprehension through which a form goes is evident from the results of both experiments. However, the findings of this experiment indicate that Zigler's "field of clear vision" can be divided into two sections; namely, a field of identification, that is, a field where the image can be named correctly, and a field of clear vision, that is, a field where the minute details in the form are recognized. The fact that visual acuity decreases from the fovea outward--a fact which all previous investigators agree upon--has been confirmed by this experiment.

The writer believes that the results obtained with the circle having a segment cut out of it and with the number "7" show definitely thatthe Law of Pregnancy and the Law of Closure hold for indirect vision as well as direct vision. In Zigler's article, mention is made of the results agreeing with the gestalt ideas of Kohler and Koffka. However, no definite statements were made to show clearly what was meant.

Interpretation of Results. Since sensitivity to form decreases from the fovea toward the periphery of the retina

---

1. Zigler, Cook, Miller and Wemple, "Perception of Form in Peripheral Vision", Amer. J. Psych., 1930, V. 42, p. 246-259.

and since sensitivity to color likewise decreases from the fovea outward, it would seem logical to assume that the decrease is due to the same thing--namely, a thinning out of the cones. If this decrease in form and color sensitivity from the fovea outward is due to a thinning out of the cones in the periphery, then it would seem that, by increasing the intensity of the stimulus, the deficiency of a thinning out of the cones would be compensated for, and the result would be that color and form could be distinguished over the entire retina. Evidence has been obtained by such investigators as Landolt, Baird, Ferree and Rand to prove this for color. The writer tried intensifying a colored form (in a very superficial way) and found that the sensitivity to color was increased while that to form was not increased. However, the writer states this only as a suggestion. Further research along such lines might prove whether or not form is dependent upon the cones of the retina.

Physical factors might be brought in to account for the facts of the changes of form in peripheral vision. Here defective refraction of oblique rays of light can be blamed for the facts of form discrimination in the periphery of the retina. As the stimulus is moved from the fovea outward, there is first perfect refraction of light; that is, when the stimulus is in direct line with the fovea of the retina. But as the stimulus is moved farther and farther toward the periphery there occurs more and more defective refraction of light with the result that the image formed on the retina suffers accordingly.

The fact that the circle with a segment cut out of it always appeared first as a complete circle can be explained best by a concept of <u>Gestalt</u> psychology--namely, the Law of Closure. According to this law, in every process, which issues at all in an end situation, the mode of distribution of energy shifts in the direction of a minimum of <u>gestalt</u> energy. Thus the perception of the circle with a segment cut out of it shifts in the direction of a minimum of <u>gestalt</u> energy with the result that it is perceived as a complete circle.

The fact that the number "7" frequently appeared as the letter "T" can be explained by another concept of <u>Gestalt</u> psychology--namely, the Law of Pregnancy. This law, of which the Law of Closure is a special case, states that <u>Gestalten</u> tend to complete or emphasize their natural form. The more "natural" way for a "7" to appear would be to have it balanced with the horizontal line extending an equal distance on the other side of the vertical. If such is done, the result is a letter

<u>Conclusions</u>. Under the conditions of this experiment, the results indicate that the experiences of all forms in moving across the retina pass through five phases. They also indicate--on the basis of these changes--that we might conceive

the retina to contain an abundance of cones sensitive to form in the central and paracentral regions, and fewer and fewer cones as the periphery is approached.

The findings of this experiment show that the Law of Pregnancy and the Law of Closure hold for indirect vision.

D. The Relative Extension of the Form Zones.

Apparatus. The apparatus for these experiments was the same as that used in the preceding experiment, (p. 17 ff.). A Schweigger's perimeter was employed and colored paper forms mounted on black cardboard were used as stimuli. The forms used were: triangle, star, rabbit, letter "T", number "7", circle, and circle with segment cut out of it. The main dimensions of the stimuli were fifteen millimeters.

Method. The experiment was carried out under the same conditions as the preceding experiment (p. 17 ff.). The moving method was used in presenting the stimuli. Each stimulus was first presented at the outermost point on the periphery and slowly moved inward until the point was reached at which the stimulus appeared to take on a vague form. It was next moved slowly inward until it appeared as a potential form. This was continued until the form was identified and still farther until it was clearly identified. In this way the limits of the five fields of apprehension were recorded. Each meridian was explored three times.

Results. The same eight half-meridians were explored in these experiments as in the three preceding experiments. Tables 17-23 contain the limits of the five fields of apprehension (in degrees) for each form employed. Table 17 represents the results obtained for the circle. Table 18 contains the results obtained for the triangle, table 19 for the number "7", table 20 for the letter "T", table 21 for the rabbit, table 22 for the star, and table 23 for the circle with a segment cut out of it. The results, as recorded in the tables, are arranged according to meridians. The upper section of each table contains the results of observers I, II and III along the horizontal temporal meridian of the retina for, first, the figure-less field, second, the form-less field, third, the form-like field, fourth, the identification field, and fifth, the clear identification field. The next section contains the results for the horizontal nasal meridian of the retina, the next for the lower nasal meridian, etc. The numbers appearing in each column signify the degree of eccentricity of the stimulus (in degrees) when it was reported. The results in the tables are the average of the readings obtained with each stimulus.

Summary of Results. The results of this experiment indicate that four of the five fields of apprehension for a certain triangle, circle, rabbit, star, letter "T", number "7", and circle with a segment cut out of it are "practically"[1] coextensive

---

1. By "practically" is meant that the limits of any two zones do not differ from one another any more than two trials with the same form differ from one another.

Table 17.

Form Employed--Circle

Meridian[1]	Observer	Figureless Field	Formless Field	Formlike Field	Identification	Clear Identification
Hor. Temporal	I	--	60	55	46	11
	II	--	60	55	33.5	10
	III	--	60	55	50	12
Hor. Nasal	I	90	80	75	65	18
	II	90	85	70	62	16
	III	90	80	65	60	16
Upper Nasal	I	75	70	54	37	14
	II	80	72	65	45	15
	III	90	70	60	40	10
Lower Nasal	I	--	45	40	35	10
	II	--	50	40	28	10
	III	--	50	41	20	14
Lower Vertical	I	--	40	30	27	10
	II	--	40	30	27	12
	III	--	40	30	28	12
Upper Vertical	I	--	60	50	43	12
	II	--	55	50	33	15
	III	--	60	50	28	14
Upper Temporal	I	--	50	45	42	14
	II	--	50	45	40	15
	III	--	50	45	38	14
Lower Temporal	I	--	45	40	37	12
	II	--	60	40	15	10
	III	--	50	40	19	10

1. Meridians of the retina.

Table 18.

Form Employed--Triangle

Meridian[1]	Observer	Figureless Field	Formless Field	Formlike Field	Identification	Clear Identification
Hor. Temporal	I	--	60	55	46	12
	II	--	60	51	22	13
	III	--	60	55	48	12
Hor. Nasal	I	90	80	70	60	15
	II	90	85	70	50	14
	III	90	80	65	55	16
Upper Nasal	I	70	63	50	31	14
	II	80	74	70	45	16
	III	90	70	50	38	15
Lower Nasal	I	--	45	40	35	14
	II	--	50	40	24	14
	III	--	50	40	18	14
Lower Vertical	I	--	40	30	27	12
	II	--	40	31	25	15
	III	--	40	30	22	12
Upper Vertical	I	--	60	45	40	15
	II	--	56	42	28	13
	III	--	60	45	25	14
Upper Temporal	I	--	50	45	42	14
	II	--	50	45	35	14
	III	--	50	45	35	14
Lower Temporal	I	--	50	40	35	12
	II	--	60	40	14	10
	III	--	50	40	18	10

1. Meridians of the retina.

Table 19

Form Employed--"7"

Meridian[1]	Observer	Figureless Field	Formless Field	Formlike Field	Identification	Clear Identification
Hor. Temporal	I	--	60	50	43	12
	II	--	60	50	18	10
	III	--	60	50	44	12
Hor. Nasal	I	90	80	70	55	16
	II	90	85	70	48	16
	III	90	80	65	48	16
Upper Nasal	I	75	70	50	27	14
	II	80	70	55	37.5	16
	III	90	70	50	30	15
Lower Nasal	I	--	45	40	32	14
	II	--	50	40	22	14
	III	--	50	40	15.5	14
Lower Vertical	I	--	40	30	22	12
	II	--	40	30	18	12
	III	--	40	30	18	12
Upper Vertical	I	--	60	50	34	14
	II	--	60	48	19	14
	III	--	60	50	20	15
Upper Temporal	I	--	50	40	35	14
	II	--	50	40	30	14
	III	--	50	45	30	14
Lower Temporal	I	--	50	40	34	12
	II	--	60	40	12	10
	III	--	50	40	15	10

1. Meridians of the retina.

Table 20.

Form Employed--"T"

Meridian[1]	Observer	Figure-less Field	Form-less Field	Form-like Field	Identification	Clear Identification
Hor. Temporal	I	--	60	50	40	12
	II	--	60	50	25	10
	III	--	60	50	38	12
Hor. Nasal	I	90	80	70	58	16
	II	90	85	70	50	18
	III	90	80	65	52	16
Upper Nasal	I	75	70	55	31	14
	II	80	70	62	35	16.5
	III	90	70	60	32	15
Lower Nasal	I	--	45	40	30	14
	II	--	50	40	20	14
	III	--	50	40	17	14
Lower Vertical	I	--	40	30	25	12
	II	--	40	30	20	12
	III	--	40	30	18	12
Upper Vertical	I	--	60	45	37	14
	II	--	58	42	21	13
	III	--	60	40	23	14
Upper Temporal	I	--	50	40	30	14
	II	--	50	35	25	14
	III	--	50	40	28	14
Lower Temporal	I	--	50	40	35	12
	II	--	60	40	12	10
	III	--	50	40	17	10

1. Meridians of the retina.

Table 21.

Form Employed--Rabbit

Meridian[1]	Observer	Figure-less Field	Form-less Field	Form-like Field	Identification	Clear Identification
Hor. Temporal	I	--	60	50	40	12
	II	--	60	52	19	10
	III	--	60	50	37	13
Hor. Nasal	I	90	80	70	55	16
	II	90	85	70	48	16
	III	90	80	65	50	16
Upper Nasal	I	75	70	42	28	14
	II	80	70	55	32.5	18
	III	90	70	50	30	16
Lower Nasal	I	--	45	40	30	14
	II	--	50	40	22	14
	III	--	50	40	16	14
Lower Vertical	I	--	40	30	24	12
	II	--	40	30	20	12
	III	--	40	30	20	12
Upper Vertical	I	--	60	40	34	14
	II	--	55	40	23	13
	III	--	60	40	20	14
Upper Temporal	I	--	50	40	32	14
	II	--	50	40	28	12
	III	--	50	40	28	14
Lower Temporal	I	--	50	40	30	12
	II	--	60	40	13.5	10
	III	--	50	40	15.5	10

1. Meridians of the retina.

Table 22.

Form Employed--Star

Meridian[1]	Observer	Figureless Field	Formless Field	Formlike Field	Identification	Clear Identification
Hor. Temporal	I	--	60	50	40	12
	II	--	60	50	23	10
	III	--	60	50	47	12
Hor. Nasal	I	90	80	70	56	18
	II	90	85	70	50	16
	III	90	80	65	50	16
Upper Nasal	I	75	70	45	29	14
	II	80	70	48	36	18
	III	90	70	50	30	15
Lower Nasal	I	--	45	40	33	14
	II	--	50	40	24	14
	III	--	50	40	18	14
Lower Vertical	I	--	40	30	25	12
	II	--	40	30	20	12
	III	--	40	30	20	12
Upper Vertical	I	--	60	40	38	13
	II	--	55	40	27.5	14
	III	--	60	40	28	14
Upper Temporal	I	--	50	40	40	14
	II	--	50	37	28	12
	III	--	50	40	28	14
Lower Temporal	I	--	50	40	35	12
	II	--	60	40	13.5	10
	III	--	50	38	16	10

1. Meridians of the retina.

Table 23.

Form Employed--Circle(segmented)

Meridian[1]	Observer	Figure-less Field	Form-less Field	Form-like Field	Identification	Clear Identification
Hor. Temporal	I	--	60	50	40	10
	II	--	60	50	19	10
	III	--	60	50	40	12
Hor. Nasal	I	90	85	70	53	18
	II	90	85	70	48	16
	III	90	80	65	50	18
Upper Nasal	I	75	70	52	28.5	14
	II	80	70	55	33.7	16
	III	90	70	55	28	14
Lower Nasal	I	--	45	40	30	15
	II	--	50	40	20	14
	III	--	50	40	15.5	14
Lower Vertical	I	--	40	30	24	12
	II	--	40	30	20	12
	III	--	40	30	20	12
Upper Vertical	I	--	60	40	30	12
	II	--	60	40	19	13
	III	--	60	40	28	14
Upper Temporal	I	--	50	40	35	14
	II	--	50	45	30	13
	III	--	50	40	28	14
Lower Temporal	I	--	50	40	35	12
	II	--	60	40	14.5	10
	III	--	50	40	14	9

1. Meridians of the retina.

sive. The other zone--namely, the identification zone--varies among these seven forms. The circle has the widest identification zone. The triangle has the second largest identification zone. The other five forms have identification zones that are "practically" coextensive. Visual discrimination of form is keenest along the horizontal nasal meridian of the retina and is dullest along the lower vertical meridian of the retina. There are individual variations in zonal extensions.

Discussion of Results. The results of this experiment seem to agree with those obtained by Zigler[1] and others in that both sets find four of the fields of apprehension coextensive. The fact that in this experiment five zones were distinguished instead of four, as was the case with Zigler, would tend to make the two experiments slightly incompatible. The results of this experiment agree with those of Geissler[2] in that both indicate that the circle is the most superior form in indirect vision. Collier,[3] however, stated that the triangle is the most superior form in indirect vision.

---

1. Zigler, Cook, Miller and Wemple, "The Perception of Form in Peripheral Vision", Amer. J. Psych., 1930, V. 42, p. 246-259.

2. Geissler, L. R., "Form Perception in Indirect Vision", Psych. Bul., 1926, V. 23, p. 135-136.

3. Collier, R. M., "Form Perception in Indirect Vision", J. Comp. Psych., Feb. 1931, V. 11, p. 281-290.

Interpretation of Results. The writer believes that the facts of form discrimination in indirect vision can best be explained by a physiological interpretation. In this case, one would conceive the retina to have an abundance of cones in the central and paracentral regions. As the periphery is approached, however, these cones thin out until there are only a few in the extreme portions of the retina. The zones then would represent, physiologically, the number of cones in that region.

Conclusions. Under the conditions of this experiment and with the results obtained, the central region of the retina may be conceived to have enough cones so that the "image" of a form may be perceived clearly and accurately. The next region, that is, toward the periphery, may be conceived to contain enough cones to identify the image of a form on the retina. The next region contains enough cones to suggest a form. The next region contains only enough cones to form a vague "image" and the outermost region contains so few cones that only the ground can be perceived.

CHAPTER IV

GENERAL DISCUSSION

A. Graphical Comparison of the Color Zones and the Form Zones.

The limits of the color zones, under the conditions of this experiment, have been determined (p. 33 ff.). The limits for the form zones, under the same experimental conditions, have been determined also (p. 59 ff.). The results of both experiments can be represented graphically. To do this, it is necessary to assume that the axis of the hemisphere, generated by the curved band on the perimeter, passes through the geometrical center of the retina. With this center as the origin, the limits of the color zones for the horizontal temporal and nasal meridians of the retina can be plotted along the X-axis of the graph and the upper and lower vertical meridians of the retina can be plotted along the Y-axis of the graph. The limits of the color zones for the upper nasal meridian of the retina and the lower temporal meridian of the retina can be plotted along the line x-y = 0. The limits of the upper temporal and lower nasal can be plotted along the line x - y = 0. The results of the above mentioned experiments are plotted in this manner:

Figure I shows the color zones of observer number I. The data appearing with the figure were taken from table 9a. The figure shows that the blue and yellow zones are nearly coextensive. It also shows that the green and red zones are practically coextensive. The blue and yellow zones appear more extensive than do the green and red zones.

Figure 2 represents the identification zones of observer number I for the seven forms employed in the experiment on "The Relative Extension of the Form Zones", p. 59 ff. The data for this figure were taken from tables 17-23. This figure seems to indicate that the seven zones are more or less coextensive. If there is any predominant form, the figure indicates that it might be the circle, (with the triangle second).

Figure 3 represents the color zones of observer number I with the identification zone superimposed upon them. This identification zone was obtained by taking the average extension of the seven forms along each meridian. The figure shows that form may be discriminated before color (green and red) along all meridians except the lower temporal meridian of the visual field. In other words, if a red or green stimulus is moved from the periphery inward, its form will be distinguished before its color.

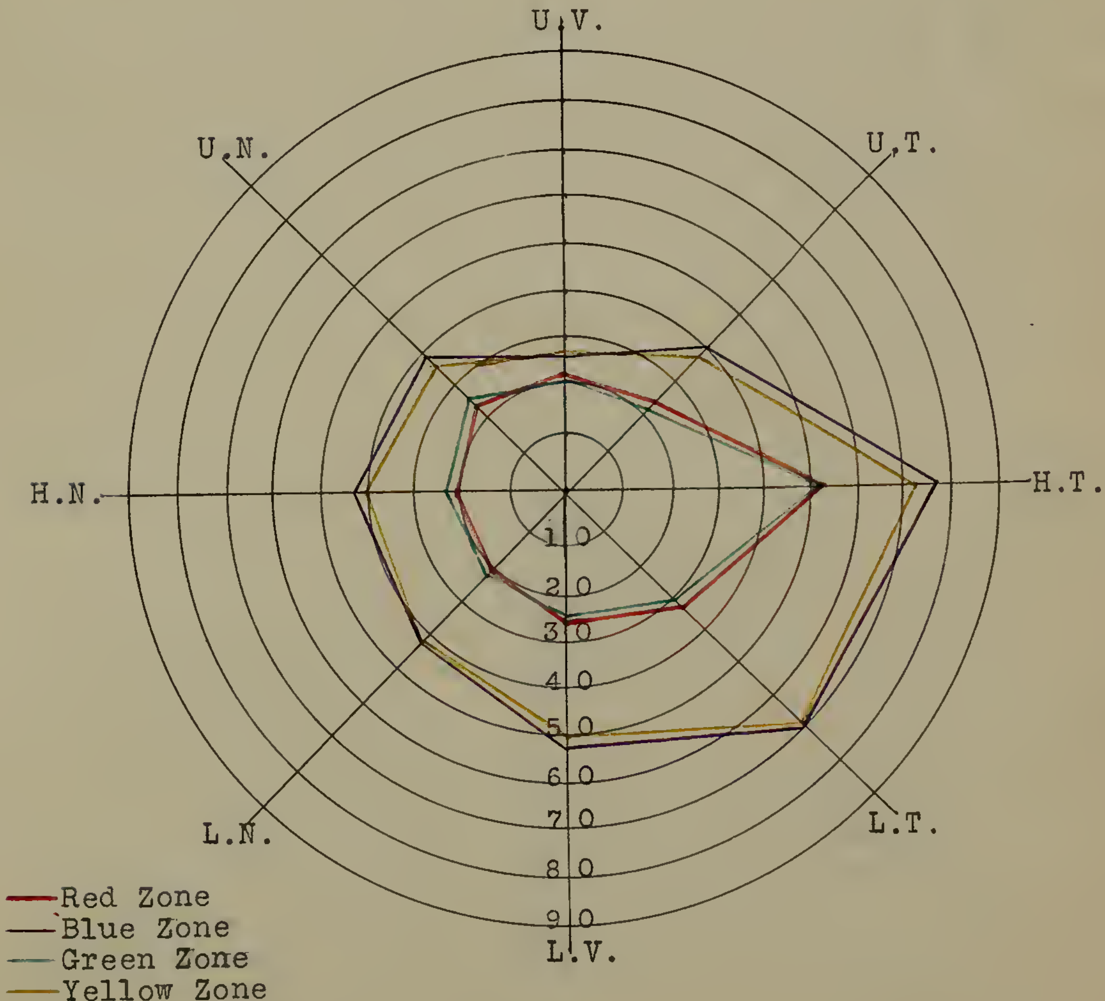
Figure 4 shows the color zones of observer number II. The data for this figure were obtained from table 9a. The resulting figure shows that the blue and yellow zones which are coextensive are more extensive than the green and red zones,

I Meridian	Red	Green	Yellow	Blue
Hor. Temporal	53	53	72.3	76
Hor. Nasal	20.7	23.6	40	43.4
Lower Nasal	21.8	22	42.5	42.5
Upper Nasal	23	25.4	36	39.2
Lower Vertical	26	25	50.7	52
Upper Vertical	22.5	20.4	27	26.1
Lower Temporal	33	31	69	70
Upper Temporal	23.8	21.5	37.2	40.3

1. Meridians of the visual field.

Figure 1.

Color Zones of Left Eye of Observer Number I.

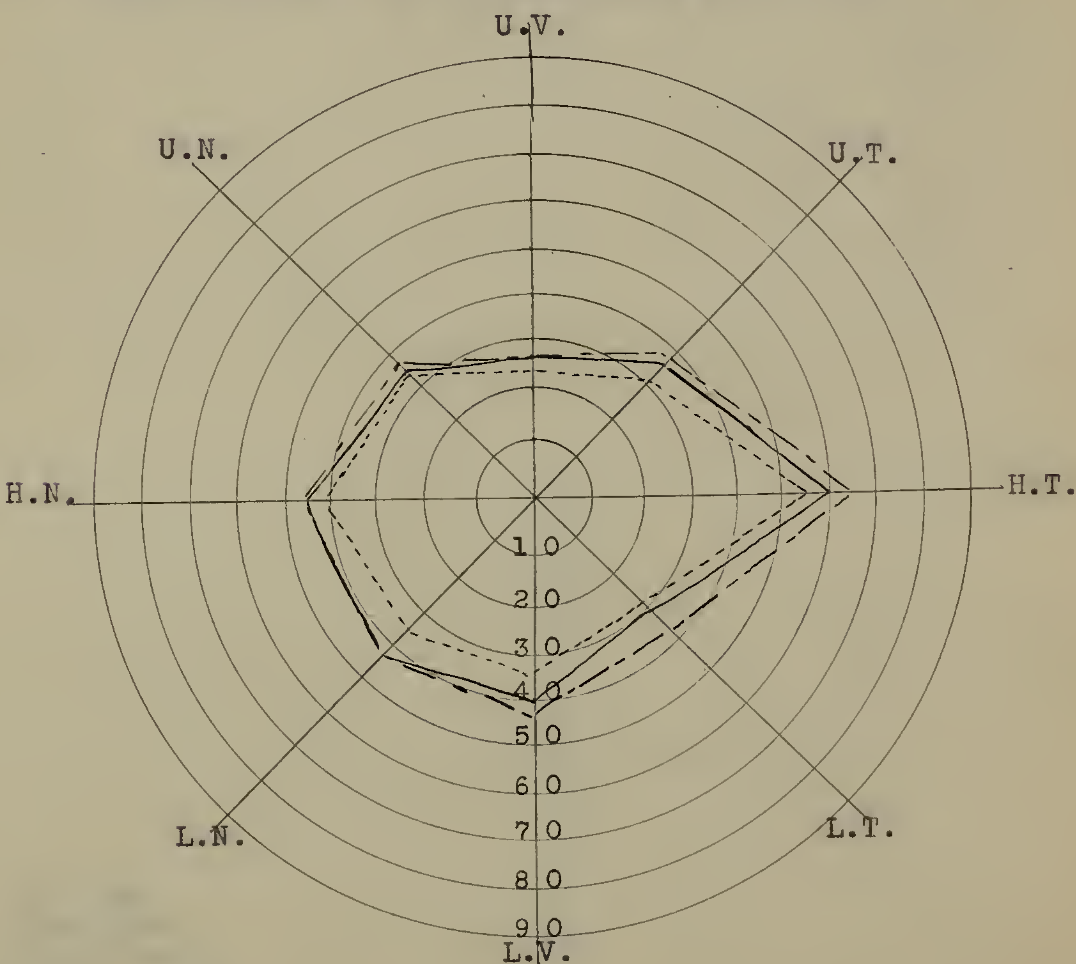


Meridian[1]	Circle	Star	Triangle	"T"	"7"	Rabbit	Circle (segmented)
Hor. Temporal	65	56	60	58	55	55	53
Hor. Nasal	46	40	46	40	43	40	40
Lower Nasal	42	40	42	30	35	32	35
Upper Nasal	37	35	35	35	34	30	35
Lower Vertical	43	38	40	37	34	34	30
Upper Vertical	27	25	27	25	22	24	24
Lower Temporal	37	29	31	31	27	28	28.5
Upper Temporal	37	33	35	31	29	28	30

1. Meridians of the visual field.

Figure 2.

Identification Zones of Left Eye of Observer Number I.

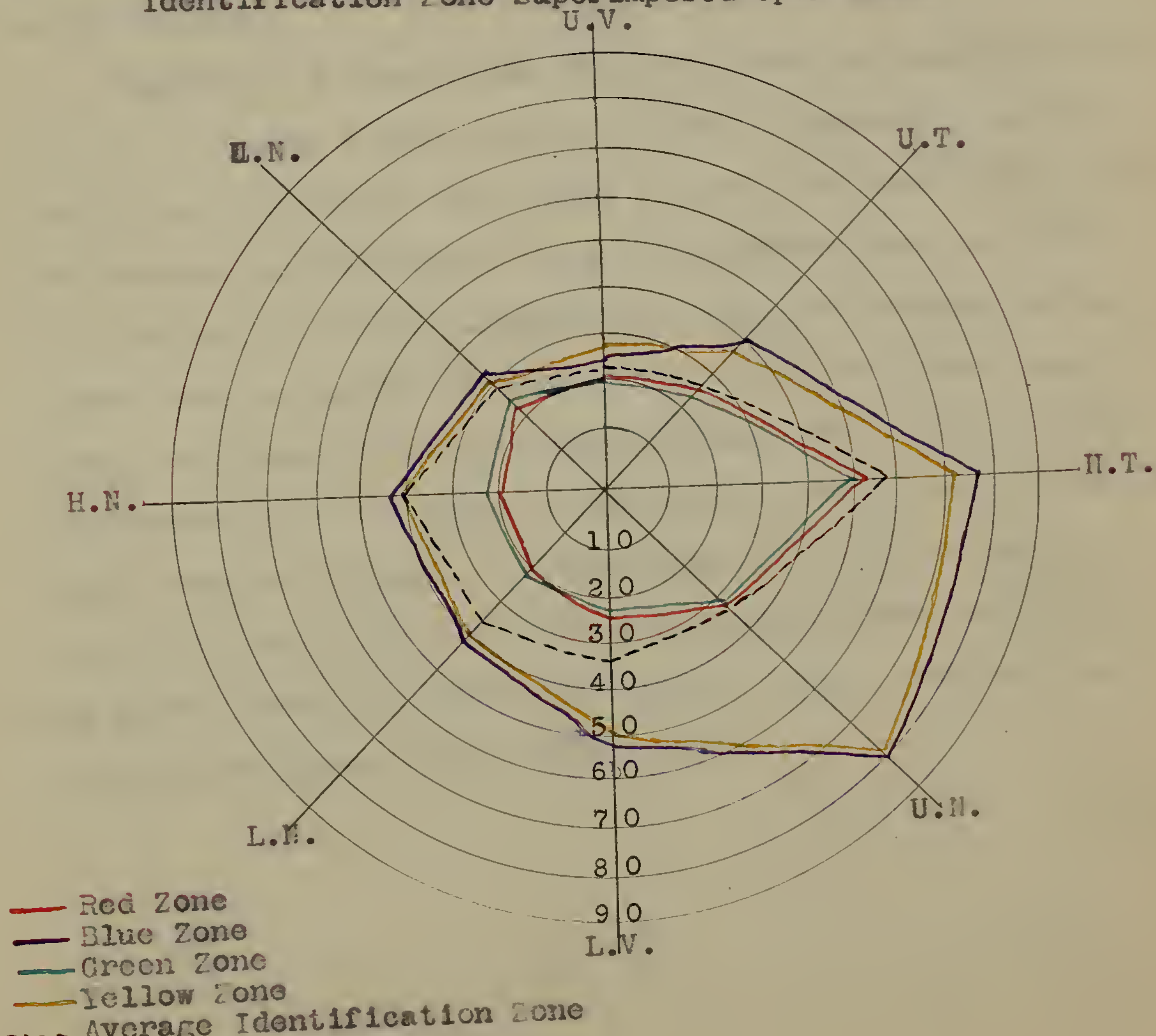


Meridian[1]	Average of all forms.
Hor. Nasal	42
Hor. Temporal	57.4
Lower Temporal	30.2
Upper Temporal	32
Upper Vertical	25
Lower Vertical	36.5
Lower Nasal	36.5
Upper Nasal	34.5

1. Meridians of the visual field.

Figure 3.

Color Zones of Left Eye of Observer Number I with Average Identification Zone Superimposed Upon Them.



also coextensive.

Figure 5 represents the identification zones of observer number II. The data used here were obtained from tables 17-23. The figure seems to indicate that the seven zones are nearly coextensive. The zones for the circle and triangle seem to be more extensive than any of the others.

Figure 6 gives the color zones with the identification zone superimposed upon them. The figure shows that form may be discriminated before color (green and red) in a few scattered regions.

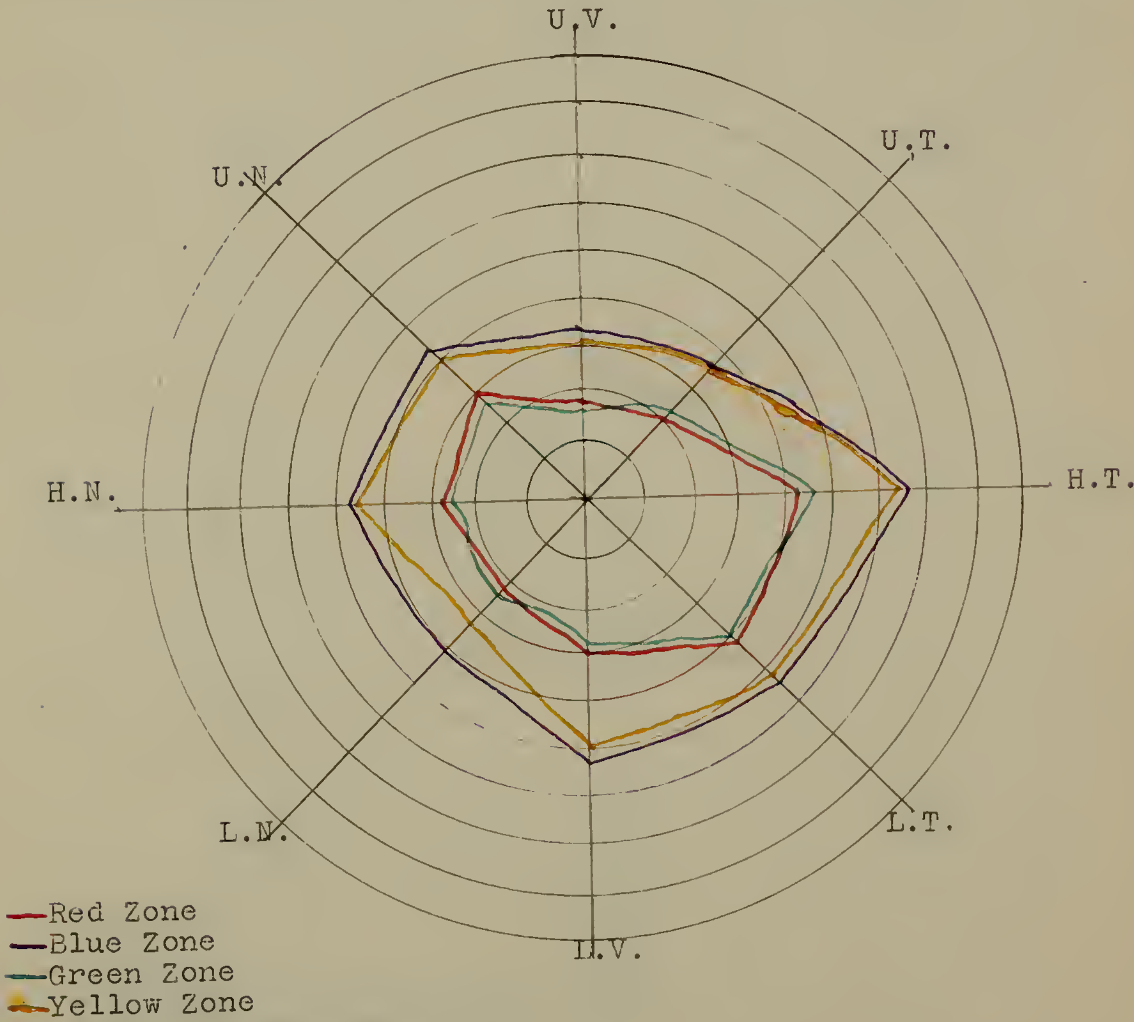
Figures 7, 8 and 9 show the same zones for observer number III. Figure 7 shows the form zones; figure 8 shows the identification zones; and figure 9 shows the color zones with the average identification zone superimposed upon it. The blue and yellow zones indicate that they are coextensive and larger than the green and red zones, which are also coextensive. The identification zones indicate that they are almost coextensive with the zones of the circle and triangle a little larger than the others. A comparison of the color and form zones show that form may be discriminated before color (red and green) along the horizontal nasal, lower nasal and lower vertical meridians of the visual field.

Meridian[1]	Red	Green	Yellow	Blue
Hor. Nasal	27	25.5	46	48.3
Hor. Temporal	43	44	65	67
Upper Vertical	18.3	17	31.5	33
Lower Vertical	30.4	29.5	51	53
Upper Nasal	30.2	26	40.1	41.5
Lower Nasal	23.5	24	33	41
Upper Temporal	20	22	35	35
Lower Temporal	42	40	53	55

1. Meridians of the visual field.

Figure 4.

Color Zones of Left Eye of Observer Number II.

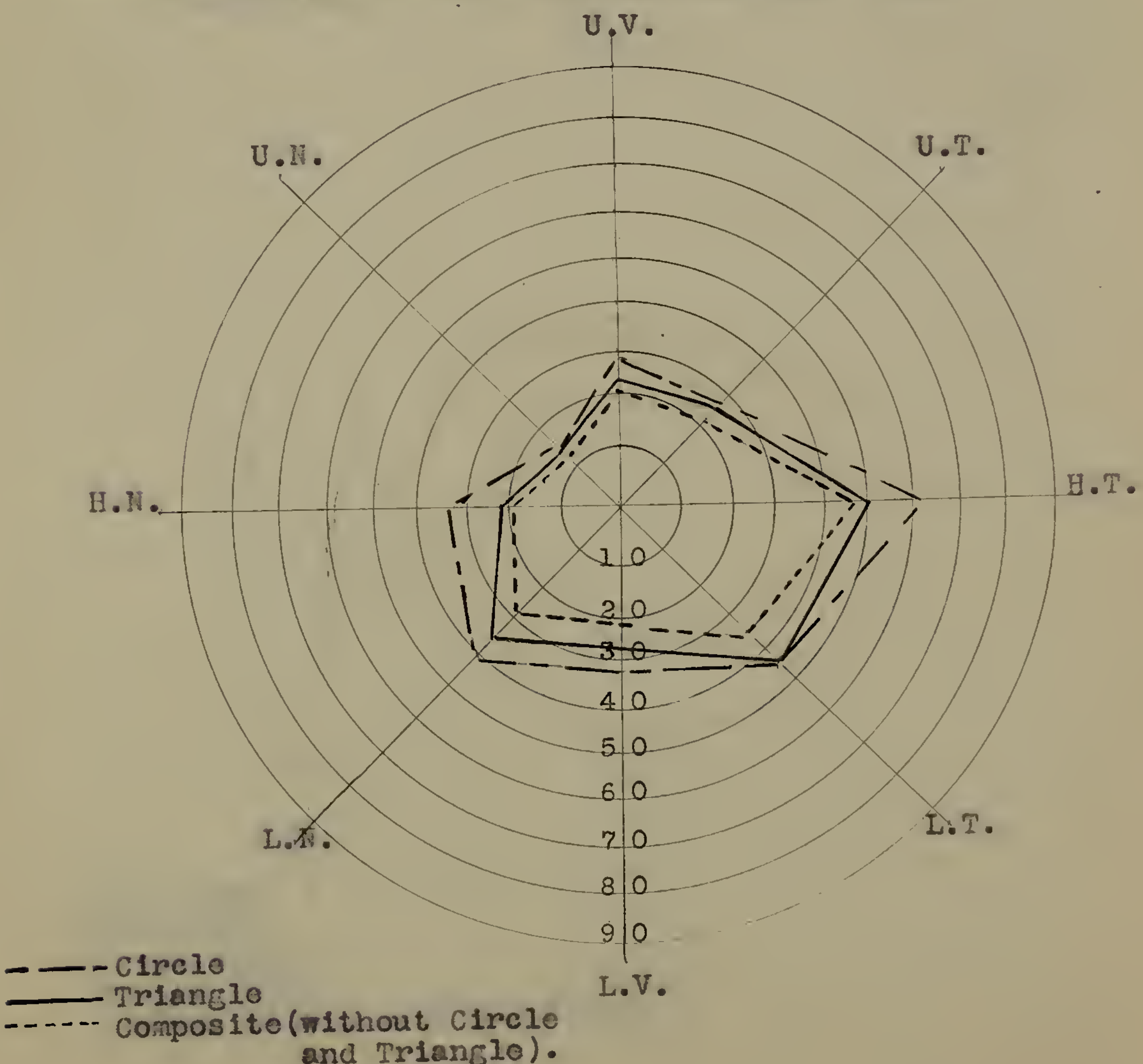


Meridian[1]	Circle	Star	Triangle	"T"	"7"	Rabbit	Circle (segmented)
Hor. Temporal	62	50	50	50	48	48	48
Hor. Nasal	33.5	23	22	25	18	19	19
Lower Nasal	40	28	35	25	30	28	30
Upper Nasal	15	13.5	14	12	12	13.5	14.5
Lower Vertical	33	27.5	28	21	19	23	19
Upper Vertical	28	20	25	20	17	20	20
Lower Temporal	45	36	45	35	37.5	32.5	33.7
Upper Temporal	28	24	24	20	22	22	20

1. Meridians of the visual field.

Figure 5.

Identification Zones of Left Eye of Observer Number II.

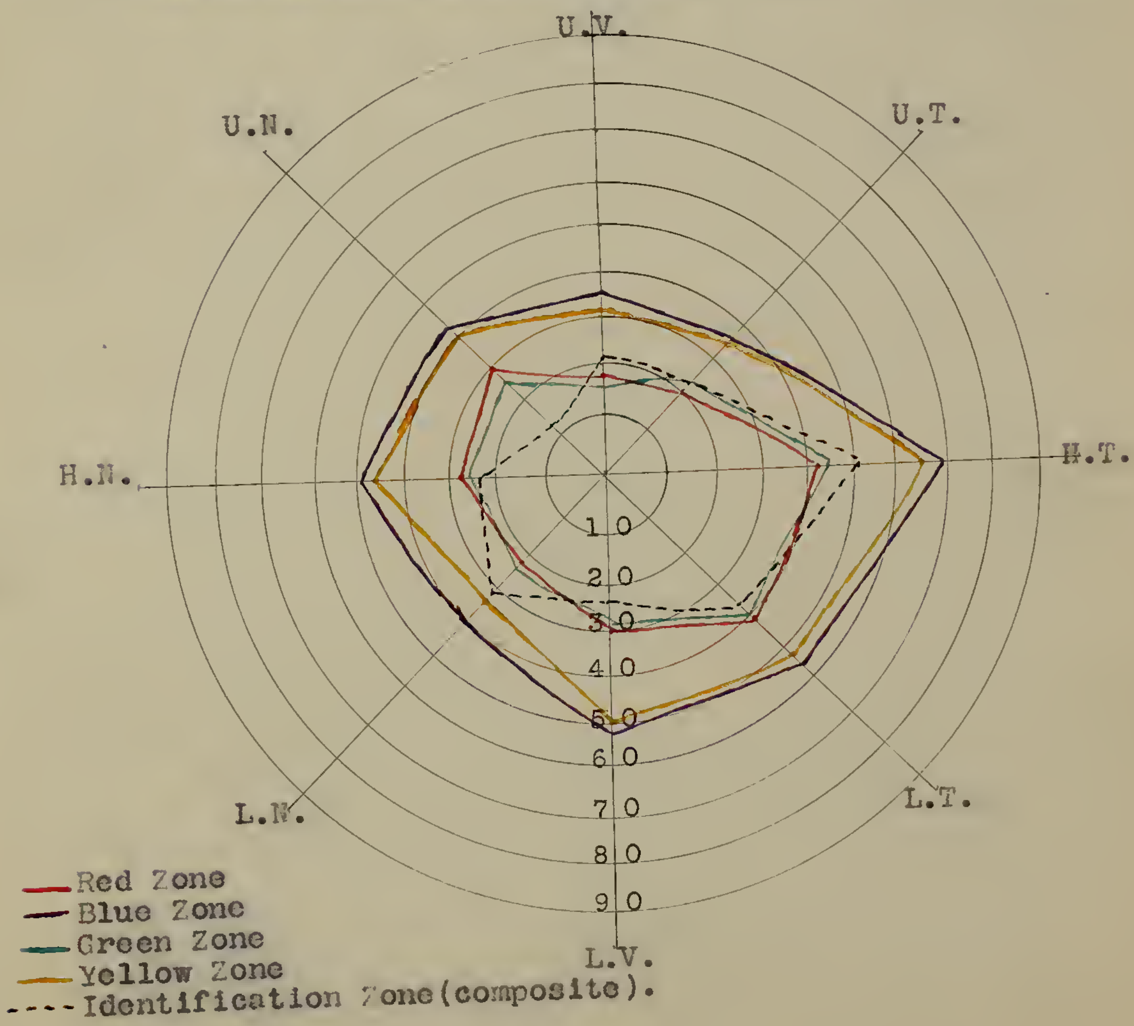


Meridian[1]	Average of all forms.
Hor. Nasal	23
Hor. Temporal	51
Lower Temporal	37.7
Upper Temporal	23
Upper Vertical	21.7
Lower Vertical	24.3
Lower Nasal	31
Upper Nasal	13.6

1. Meridians of the visual field.

Figure 6.

Color Zones of Left Eye of Observer Number II with Average Identification Zone Superimposed Upon Them.

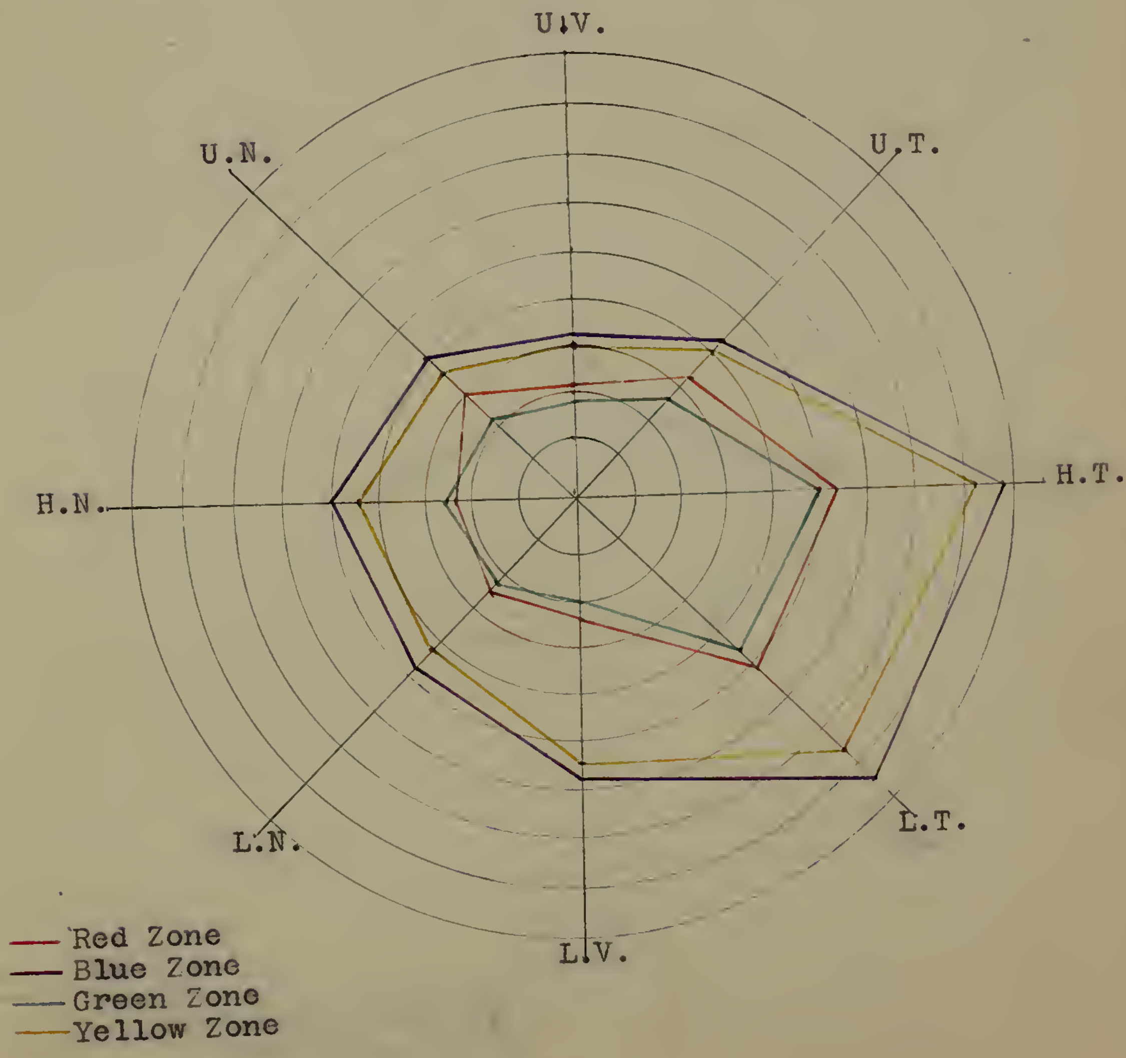


Meridian[1]	Red	Green	Yellow	Blue
Hor. Nasal	23	24	44	50
Hor. Temporal	53	50	82	87
Upper Vertical	208	17.5	30	32
Lower Vertical	232	20	54.3	57
Upper Nasal	29	22.6	36.5	42
Lower Nasal	24	22.6	42	47
Upper Temporal	32	26	40	43
Lower Temporal	51	46	76	84.5

1. Meridians of the visual field.

Figure 7.

Color Zones of Left Eye of Observer Number III.

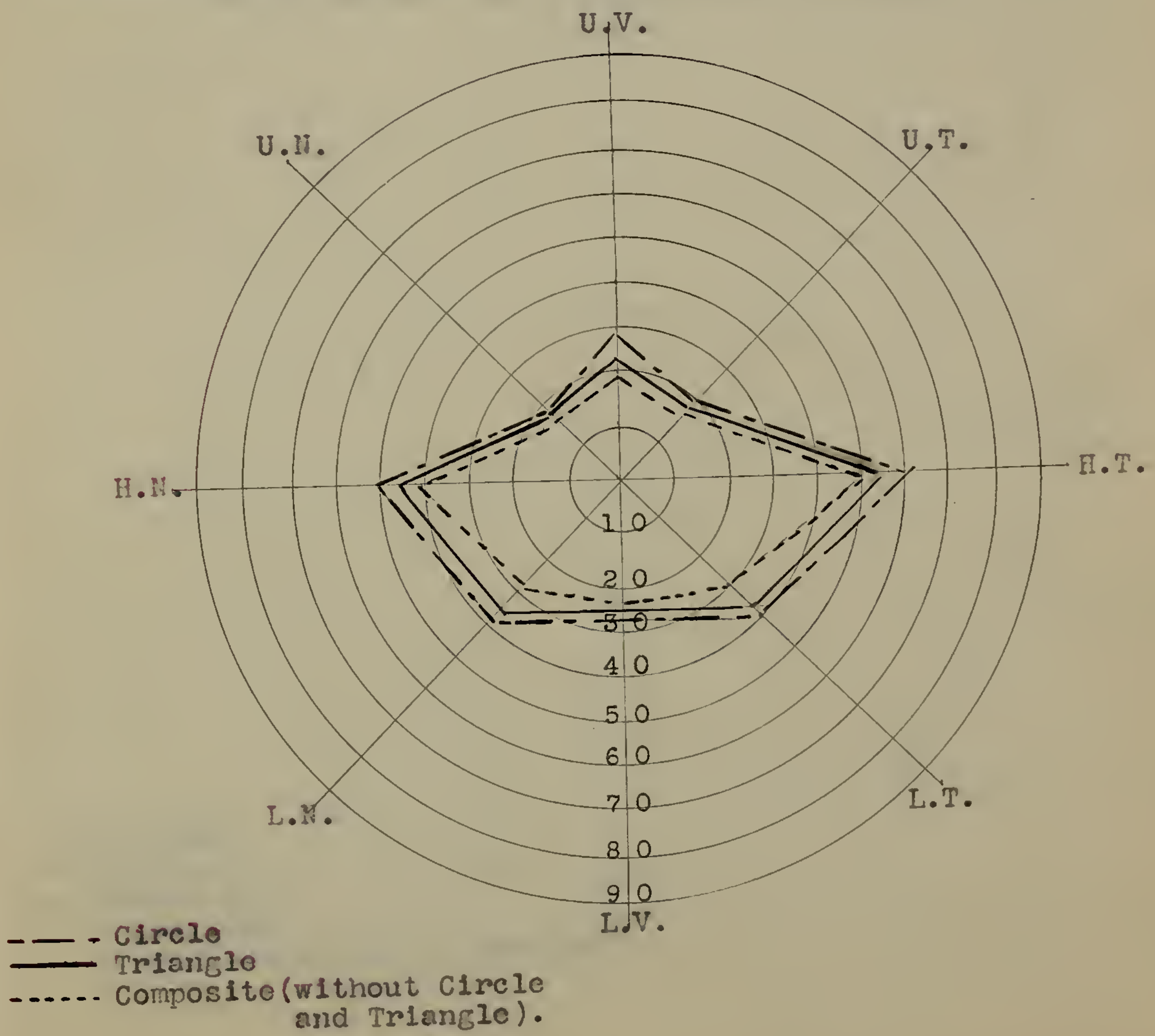


Meridian[1]	Circle	Star	Triangle	"T"	"7"	Rabbit	Circle (segmented)
Hor. Temporal	60	50	55	52	48	50	50
Hor. Nasal	50	47	48	38	44	37	40
Lower Nasal	38	28	35	28	30	28	28
Upper Nasal	19	16	18	17	15	15.5	14
Lower Vertical	28	28	25	23	20	20	28
Upper Vertical	28	20	22	18	18	20	20
Lower Temporal	40	30	38	32	30	30	28
Upper Temporal	20	18	18	17	15	16	16

1. Meridians of the visual field.

Figure 8.

Identification Zones of Left Eye of Observer Number III.

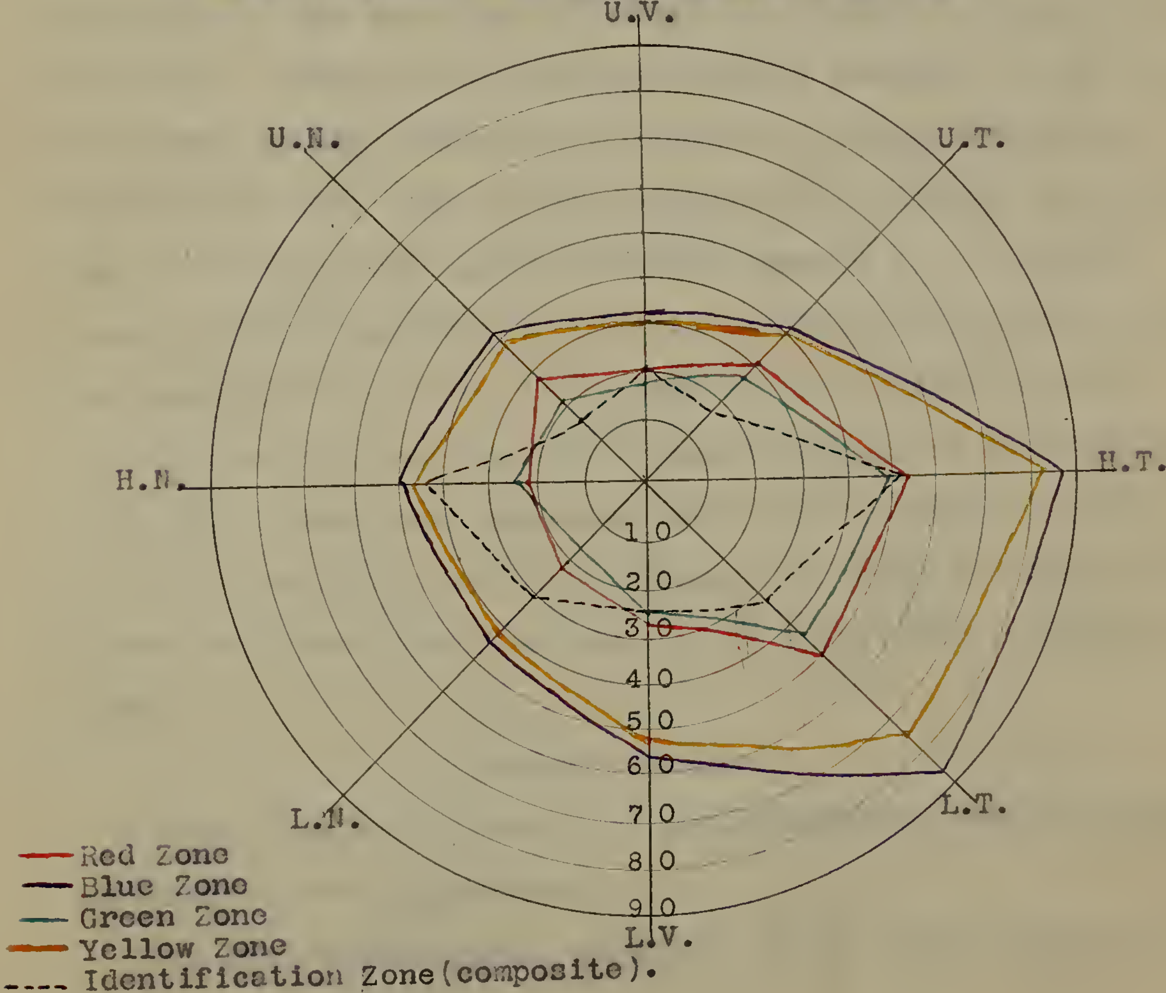


Meridian[1]	Average of all forms.
Hor. Nasal	43.4
Hor. Temporal	52
Lower Temporal	32.5
Upper Temporal	17
Upper Vertical	21
Lower Vertical	24.6
Lower Nasal	31
Upper Nasal	16.3

1. Meridians of the visual field.

Figure 9.

Color Zones of Left Eye of Observer Number III with Average Identification Zone Superimposed Upon Them.



Comparison of the Color Zones of Three Forms of Same Area. In attempting to ascertain the effect of form on the color zones it was necessary to have forms that were of equal area. The triangle, the star and the letter "T" used in the previous experiments were all of equal area (128 sq. mm.). The data obtained on "The Relative Extension of the Color Zones" was used here in this particular study. Along the upper temporal meridian of the visual field it was found that the limit of the blue zone of the "T" was 40.7^{o}; that of the triangle was 40^{o}; and that of the star was 41^{o} (taken from data of observer number III). Along the horizontal temporal meridian of the visual field it was found that the limit of the yellow zone of the "T" was 72^{o}; that of the triangle 72^{o}; and that of the star was 72^{o} (taken from data of observer number I). Along the lower vertical meridian of the visual field, the limit of the red zone for the "T" was 30^{o}; that of the triangle was 30^{o}; and that of the star was 31^{o} (taken from data of observer number III). From these representative cases, taken at random, one would conclude that (with stimuli of equal area and main dimensions) form has no effect on the extension of the color zones.

B. General Summary.

Under the conditions of these experiments, the following statements seem justifiable:

1. All colors appear colorless at the outer extremity of

the periphery and as they approach the fovea they appear bluish and yellowish; then reddish and greenish.

2. In moving forms across the retina, from the periphery inward, their perception is as follows: (1) perception of background only, (2) perception of vague form, (3) perception of potential form, (4) identification, (5) clear identification.

3. A circle with a segment cut out of it always first appeared as a complete circle.

4. The color zones of blue and yellow are coextensive and larger than the color zones of green and red which are also coextensive. The color zones extend farthest along the horizontal nasal meridian of the retina and least along the lower vertical meridian of the retina. The extension of the color zones vary with individuals.

5. The form zone in which the background only is perceived is coextensive for all forms. The same is true for the zone in which a vague figure is perceived; for the zone in which a potential form is perceived; and for the clear identification zone. The zone for identification is coextensive for all forms except the circle and triangle, in which case the circle is the largest. The extension of the form zones vary with individuals.

6. The identification zone for form extends farther on the nasal half of the retina than does the color zones for red and green.

7. The form of the stimulus is not a variable factor that influences the relative extent of the color zones. (Limited to forms of equal areas and main dimensions.)

BIBLIOGRAPHY

Baird, J. W., "Color Sensitivity of the Peripheral Retina", Carnegie Inst. of Washington, 1905.

Boring, E. G., "A History of Experimental Psychology", The Century Co., 1929.

Collier, R. M., "Form Perception in Indirect Vision", J. of Comp. Psych., Feb. 1931, V. 11, p. 281.

Ferree, Rand and Monroe, "Area of Form Fields",AAmer. J. Ophth., 1926, V. 9, p. 101.

Geissler, L. R., "Form Perception in Indirect Vision", Psych. Bul., 1926, V. 23, p. 135-136.

Helson, H., "The Psychology of Gestalt", Amer. J. Psych., 1925, V. 36, p. 342-370, p. 494-526; 1926, V. 37, p. 25-62, p. 189-223.

Hsiao, H. H., "A Suggestive Review of Gestalt Psychology", Psych. Rev., 1928, V. 35, p. 280.

Kleitman and Blier, "Color and Form Discrimination in Periphery of Retina", Amer. J. Phys., 1928, V. 85-86, p. 178-190.

Kohler, W., "Gestalt Psychology", Horace Liveright Co., 1929.

Ladd-Franklin, C., "Colour and Colour Theories", Harcourt, Brace and Co., 1929.

Lindworsky, S. J., "Experimental Psychology", Macmillan Co., 1931.

"Report of Committee on Colorimetry for 1920-21", L. T. Troland, Chairman, J.O.S.A. and R.S.I., Aug. 1922, V. 6, p. 527-596.

Warren and Carmichael, "Elements of Human Psychology", Revised Edition, Houghton Mifflin Co., 1930.

Wheeler, R. H., "The Science of Psychology", Thomas Y. Crowell Co., 1929.

Woodworth, R. S., "Psychology", Revised Edition, Henry Holt and Company, 1929.

Zigler, Cook, Miller, and Wemple, "The Perception of Form in Peripheral Vision", Amer. J. Psych., 1930, V. 42, p. 246-259.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation for the experimental technique suggested by Dr. M. J. Zigler; for the advice and criticisms given by Dr. H. N. Glick in directing this thesis; and for the suggestions, criticisms and comments made by Mr. A. H. Holway who must be complimented for his sincere and keen interest in the problem. The writer also wishes to thank Dr. H. N. Glick and Mr. A. H. Holway for acting as observers.

The writer also is indebted to Dr. Holland, Dr. Bradley, and Dr. Fuller for their suggestions and criticisms.

Date Field Observer

Stimuli	90°		80°		70°		60°		50°		40°		30°		20°		10°		Blind Spot
	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	
Red Rabbit																			
Blue Rabbit																			
Yellow Rabbit																			
Red Star																			
Blue Star																			
Yellow Star																			
Red Triangle																			
Blue Triangle																			
Yellow Triangle																			
Red "T"																			
Blue "T"																			
Yellow "T"																			
Red "7"																			
Blue "7"																			
Yellow "7"																			
Red Circle																			
Blue Circle																			
Yellow Circle																			
Red "nonsense"																			
Blue "nonsense"																			
Yellow "nonsense"																			
Red "mutilated"																			
Blue "mutilated"																			
Yellow "mutilated"																			

Physical Condition of Observer

Condition of eye of Observer

Date | Field | Observer

Stimuli	90°		80°		70°		60°		50°		40°		30°		20°		10°		Blind Spot
	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	
Red Rabbit																			
Blue Rabbit																			
Yellow Rabbit																			
Red Star																			
Blue Star																			
Yellow Star																			
Red Triangle																			
Blue Triangle																			
Yellow Triangle																			
Red "T"																			
Blue "T"																			
Yellow "T"																			
Red "7"																			
Blue "7"																			
Yellow "7"																			
Red Circle																			
Blue Circle																			
Yellow Circle																			
Red "nonsense"																			
Blue "nonsense"																			
Yellow "nonsense"																			
Red "mutilated"																			
Blue "mutilated"																			
Yellow "mutilated"																			

Physical Condition of Observer

Condition of eye of Observer

Approved by:

H. N. Glick

Leon A. Bradley

Edw. B. Stabbard

Graduate Committee

Date June, 13, 1932