A STUDY OF RETINAL INTENSITY GRADIENTS

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

Richard F. Haines

1964

THESIS

This is to certify that the

thesis entitled

A STUDY OF RETINAL INTENSITY GRADIENTS

presented by

Richard F. Haines

has been accepted towards fulfillment of the requirements for

Ph. D. degree in Psychology

S. Howard Bartley

Major professor

Date May 11, 1964

O-169

So

a gradie

intense

fact cou

ing of

been do

used

effects

was the

of glir

A

was col

sities

ferent

shaped

(0.155

the ey

small

lumino

determ

ABSTRACT

A STUDY OF RETINAL
INTENSITY GRADIENTS

by Richard F. Haines

Some previous glare-related studies have indicated that a gradient of luminance exists in the visual field around an intense glimulus (glare - stimulus). If substantiated, this fact could play an important part in furthering our understanding of glare and related energistic conditions but little has been done to quantify it. Further, most previous studies have used peripherally placed glimuli. Little is known of the effects produced by a foveally fixated glimulus. This then was the primary task of the present investigation. The effect of glimulus intensity and form were also studied.

An intense (3,968 lumen per steradian) photic source was collimated, filtered (for intermediate glimulus intensities), and reflected into S's right eye by one of three different first surface mirrors. Circular, square, and triangular shaped mirrors were used. Each had the same frontal area (0.155 square inch) in order to equate total photic flux to the eye and all subtended wholly foveal visual angles. A small (0^{o} 7' 12" diameter), moving (0^{o} 5' 30" per second), luminous (0.8 lumen per steradian), "test spot" was used to determine intensity gradients surrounding each glimulus

(mirror).
spaced me
circular
ulus. A
spot in t
ulus and
the retin
male, vol
were form

Pin
illuminat
experimen
this grad
"ideal re
around th
motion p
sity cau
form, (
actual p
triangul
round, a
ulus in
Results
of glar

I
that ex

(mirror). A modified method of limits was used. Eight equally spaced meridians around the entire 360° were studied for the circular and square glimulus and six for the triangular glimulus. A meridian was defined as the path of the moving test spot in the frontal plane. The test spot moved behind the glimulus and became "invisible" at some point in its travel due to the retinal effect produced by the glimulus. Five experienced, male, volunteers acted as observers. Experimental hypotheses were formulated and tested.

Findings indicated that: (1) glimulus-produced retinal illumination does have a measurable gradient using the present experimental technique, and, depending upon its intensity, this gradient of luminance extends some distance beyond the "ideal retinal image", (2) glimulus conditions produce an area around the glimulus' boundary where neither brightness nor motion perception is possible, (3) decreasing glimulus intensity causes glimulus perceived shape to approach its physical form, (4) perceived shape does not always correspond to the actual physical form of the glimulus, for instance, square and triangular glimuli, under high intensities, appear almost round, and (5) response variance tends to be related to glimulus intensity and unrelated to glimulus form and meridian. Results tend to support an entoptic stray illumination theory of glare.

In light of past and present findings it was concluded that existing theories of glare are adequate, in part, but none exp

cations f

navigatic

"variatle

aspects c

mental a

group of

none explain the glare experience completely. Future applications for the present findings were found in certain space navigation and rendezvous operations. The present experimental "variables" were shown to partially simulate some of the visual aspects of these operations. Suggestions for improved experimental apparatus and design were made and a rather extensive group of appendices included to supplement the text.

Approved ______________________
Major Professor

Date ________________

3-1-65

A STUDY OF RETINAL INTENSITY GRADIENTS

By

Richard F. Haines

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Psychology

1964

I wi

Bartley,

I will co

and train

work was

future.

Fur

Departmen

of Physic

Health,

press my

interest

Huront

Anatomy

histolo

labor o

preciat

in bei

comple

provid

Acknowledgments

I wish to express my sincere thanks to Dr. S. Howard Bartley, to whom I dedicate this work. In the years to come I will continue to admire the excellence of his watchful eye and trained mind. Encouragement, guidance, and support for my work was never lacking. He provided a fine example for my future.

Further to Drs. Carl Frost and Alfred Dietze in the Department of Psychology, Dr. W. D. Collings in the Department of Physiology, and Dr. W. D. Van Huss in the Department of Health, Physical Education and Recreation I would like to express my gratitude for their constructive comments and continued interest during the execution of this investigation. Mr. Huront Marcarian and Dr. T. Jenkins in the Department of Anatomy provided valuable assistance in the preparation of histological slides of the retina; their labor along with the labor of Dr. R. W. Van Pelt of Veterinary Pathology is appreciated very much.

Finally to my wife Carol I must confess a certain pleasure in being able to say that the work is just beginning with the completion of this project. Her understanding and patience provided the much needed impetus to complete the work.

R. F. H.

Table of Contents

List of Tables

List of Tables (continued)

List of Figures

List of Figures (continued)

List of Graphs

List of Appendices

INTRODUCTION

Man probably first experienced glare when he looked at or near the sun. He most likely did not attempt to understand its causes, he probably only wondered about its consequences; pain if he looked long enough and an intense afterimage that lasted many minutes. He was unaware of the possible long-range effects of the sun's radiation upon his visual system and thus he relied upon the experience of pain as a viewing guide for intense photic sources.

In more modern times the phenomena of glare has increasingly come under the questioning eye of scientific methodology and explanations have become important. Allport (1955, p. 11) feels that, "understanding is what one gets as a result of adequate explanation...To understand some phenomenon means, first, to have available and to apprehend a generalized description of it and, second, to see that the generalization makes sense in terms of the specific arrangements that are characteristic of the phenomenon." Thus in order to adequately understand the glare experience we must first describe its anteceedent conditions and associated physical relationships and then form a generalized description of the phenomenon that is in harmony with our own experience.

The word glare as the man-on-the-street uses it actually differs very little from many scientist's use of the word. Any actual difference might lie in the extent to which one group or the other specifies anteceedent conditions, personalistic reactions, methods of producing it, and so on. The author feels that those who choose to work on problems in perception should continually reevaluate terminology so as to sift technical from everyday usage. Their vocabulary should include a consistent and unambiguous set of words with which to describe phenomena, to theorize, and to exchange their ideas. It becomes apparent rather quickly that such a set of words is non-existent in glare-related research. Thus part of the present dissertation attempts to provide the reader with a logically consistent and precise set of words with which he can understand the present research and, hopefully, future research.

Two separate sets of distinctions will be made. Each set underlies a basic assumption about the nature of scientific endeavor held by the writer. Both distinctions are important. When ignored they appear to underlie a great many difficulties in scientific endeavor. One word is often used for both cause and effect, physical and physiological, stimulus and response. In such a situation it is not difficult to understand how theories can become "clogged" with their own refuse, how data interpretation can become "unmanagable", and how subsequent experimentation by others can take directions totally different from that originally intended.

The first distinction to be made is that there exists two kinds of worlds, the experiential and the energistic. This interpretation has been made before (Bartley, 1958, p. 20). Within the experiential world lie such diverse phenomena as emotions, sensations, perceptions, and the like. The psychologist, among others, deals with this kind of world. The personalistic (experiential) world is largely private, unattainable by others, except by appropriate transformations which can often mask its real nature. This world is made public only at the discretion of the person himself.

Man is a part of the physical world too, not separated from it, "so the psychologist, in relating to his environment, is obliged to start with the consideration of man as an energy system." (Ibid., p. 21) In doing so the psychologist utilizes the tools, terminology, and concepts of the so-called "physical" scientist. While doing this the psychologist's interpretations of certain personalistic responses are based, ultimately, upon his own prior experiences. The existence of an experiential domain suggests that man must investigate himself and that he look upon his own experiences as phenomena directly associated with the energistic world.

The energistic domain constitutes the second kind of world. This world of energy forms and transformations is also non-experienceable to the scientist. He merely describes its phenomena in terms of his own prior experiences. This world differs from the experiential in many ways, one of which is that it is relatively stable, maintaining its most essential characteristics over time. To be sure, mutations occur biologically and valence bonds alter molecularly, etc., but under stable conditions, and within present-day measurement techniques, basic characteristics of matter appear to remain relatively unchanged over time, whereas, the experiential world is thought to be in an endlessly changing flux, an ever moving panorama. However, it is the distinction between these two worlds that is of interest. Many words have been coined for use in one of these conceptualized worlds but have sooner or later drifted into the other world, creating some ambiguity and confusion. Such is the case with the word glare.

In dealing with the topic of glare in general, almost everyone feels qualified to describe it, discuss it, and to offer helpful information about its causes and consequences. Glare is a common experience....one that can be described similarly by the majority of people on earth. Because of its varied use by both layman and researcher alike it will be used here to indicate only the personalistic experience produced by certain energistic conditions. It will not be used to label anteceedent characteristics of the experimental situation nor will it be allowed to creep into ensuing discussions of past and present research as a catchall. If in the past the word glare has been a household word it probably must remain such but it is recognized that rather strict limitations must be applied to its use in the laboratory.

The second distinction to be made is that, just as with many other words, glare has been used in several ways. The first use has been introduced already, namely as the experience. It has also been used to describe and/or name those anteceedent conditions causing both the experience of glare and a change in perceived brightness of objects. Changes in perceived brightness are taken as indications of threshold changes. In these cases glare is taken to mean some form of reduction in one's ability to see clearly or at least as well as one normally might under optimal conditions. Here the impingement conditions are of major interest but are labelled as "glare" conditions. Thus the word glare has been used as a modifying word, e.g., glare environment, glare conditions, etc. It is usually apparent that the writer means "those characteristics of the photic environment that produce an experience of annoyance or difficulty in seeing". A review of this word's etymology illustrates this second use quite consistently.

We need to find a word for the second use of the term glare and from then on to use it consistently. When viewing conditions yield a reduced ability to see clearly, a painful sensation in the region of the eyes, a dazzling appearance in the visual field, a raised visual threshold, or an overlayed veil of light, among other things, it is not glare that is producing these things, they are the result of certain energistic characteristics of the photic environment. Glare is the resultant experience and not the cause. It is proposed that the term glimulus stand for "those stimulating characteristics of the photic environment that produce a particular experiential response which is commonly called glare and the energistic conditions in and on the retina described below as impoverishment." The word glimulus is made up of two words "glare" and "stimulus". The word impingement was not adequate here because it has gained considerable precedent (Bartley, 1958) in labelling the energy that strikes the sense organ but does not necessarily yield a detectable organismic response. The word stimulus is typically used to stand for an effective impingement in terms of eliciting some detectable organismic response. Thus it seemed most logical to use a compounding of the two words glare and stimulus (glimulus) for this use. It is acknowledged that new compounded words in science often do not add as much as they detract but no simple and concise term could be found to illustrate this particular use of the word glare. Now each can be separated from the other; each will designate a separate idea.

A third use of the word glare involves a slightly different kind of application to speech than did the first two. When a person must view something spatially near a very intense photic source the photic flux entering the eyes causes an impoverishment in the ability to see the object(s). This impoverishment is sometimes erroneously called glare. An example of this was put in the following way by Stiles and Crawford (1937, p. 255), "When an exposed light source is present in the field of view, the visibility of neighboring objects is impaired owing to what may be called the glare effect of the light source." Such reduced efficiency in seeing is thought to be due to a combination of stray illumination falling on the retina and processes of neural interaction yielding poor contrast borders between target and surround. Thus the word glare is sometimes used where the above idea of impoverishment is meant and a clear distinction between the two is lost. The word impoverishment will be used to describe the state of the visual image upon the retina in energistic and not perceptual terms. When the energistic impingements upon the retina yield some form of stray illumination or other condition(s) associated with a reduced efficiency in seeing, one form of which is commonly known as glare, the word impoverishment will be used. It must be emphasized that a glimulus always leads to some level of impoverishment.

Thus another set of distinctions has had to be made; that of different definitions for the various uses of the word glare. The words glimulus, and impoverishment do not conflict with terminology given in section three of the IES Lighting Handbook (1947, pp. 3-1 to 3-14) dealing with "Standards, Nomenclature, Abbreviations, and Symbols".

To workers in physiological optics and visual perception the area of glare-related research commonly brings to mind several things of both historical and practical interest: (1) attempts to differentiate different types of glare, and (2) attempts to provide theoretical explanations of the causes of glare. Each of these topics is briefly discussed below while a fuller treatment is included in Appendix I and II respectively.

Bell, Troland, and Verhoeff (1922) devised three different terms to separate various glare experiences; veiling glare, dazzling glare, and blinding glare. It becomes apparent that these three "types of glare" actually represent individual glimulus conditions which eventually result in the experience of glare; or in the case of veiling glare, only impoverishment occurs without the experience of glare. Some glimulus conditions produce more discomfort, annoyance, bother, or other disruption of vision than do others. The actual impoverishment of the retinal image produced by these glimulus conditions leads to various field appearances called blinding glare. Veiling and dazzling glare are likewise forms of unwanted photic flux which are not part of the object viewed, but are produced by stray illumination within the eye.

Several researchers have theorized about the causes of glare. Two main veins have been dug into the growing mound of empirical research data. The first vein has stressed the anteceedent aspects of the physical situation, i.e., the glimulus conditions. This theory has been called by various names: the physical theory of glare, scatter theory, or the entoptic stray light theory. Those using this theory can predict, before hand, many parameters of potential glare-producing situations. The second vein has remained buried in neuro-anatomical facts of the retina that explain glare by means of impulse conduction in subretinal areas of the retina. This theory has been called the physiological theory of glare or the neural interaction theory. Appendix III presents a rather detailed picture of the anatomy and physiology of the central human retina. Material in this appendix is primarily related to the neural interaction theory (see Appendix II) and is also referred to in later discussions.

As can be seen in both Appendix I and II, the great majority of studies eventually become concerned with matters of a theoretical nature. Most typically the question is asked, which is the better causative explanation of glare? In light of existing data it seems most realistic to accept both theories in part rather than support one theory alone or generate a third new theory. The writer feels that most, if not all, existing information on hand pertaining to glare, supports this point of view. It is becoming apparent that both theories are at least partially adequate although neither explain glare completely. (Crouch, 1955, p. 142) (Stiles, 1929).

Following is a summary of what is known about the major effects of certain glimulus conditions. These studies bear upon the present experiment in that they provide basic data for research.

The most traditional approach in investigating glare has been to measure the effect of a given glimulus condition in the periphery of the field of view upon the visibility or apparent brightness of an object at the center of the field or foveally fixated. This effect was then compared with the effect produced by a veiling patch of light superimposed upon the object. (Bartley and Fry, 1934) (Fry and Alpern, 1953b) (Fry and Alpern, 1955) (Holladay, 1927) (Le Grand, 1937) (Schouten and Ornstein, 1939) (Stiles, 1928b) (Stiles and Crawford, 1934) (Stiles and Crawford, 1937).

In the writer's estimation the study by Fry and Alpern (1953b) is probably the best controlled and most recent example of this type of experiment. In their study Fry and Alpern set out to determine: (1) if feeble veiling luminance superimposed on the image of a test object could produce a reduction in apparent brightness commensurate with that produced by a glimulus (peripheral), and (2) whether the effects obtained with peripheral glimuli could be accounted for in terms of stray illumination produced by the glimulus and falling in the region of the image of the test object.

By appropriate manipulations of their apparatus a veiling glimulus, having a diameter equal to 9.5°, was superimposed over the test spot, its center falling at the fixation point. All three were seen by S's right eye. S's left eye saw only the fixation point and the comparison stimulus. The luminance of the comparison stimulus was kept fixed while the luminance of the test spot was varied in order to make it match the comparison stimulus in brightness. Both the comparison stimulus and the test spot were rectangular in shape with the former lying just above the fixation point and the latter below. One S made five brightness matches per veiling intensity.

Results indicated that increasing the intensity of the veiling patch of luminance required that the test spot intensity be increased to match it in brightness. If the test spot and comparison stimulus were already matched at the beginning and the veiling luminance increased, this cut down the perceived brightness of the test spot in spite of the fact that it (the veiling luminance) added to the luminance of the test spot, and its luminance had to be further supplemented to reestablish the match with the fixed comparison stimulus.

Fry and Alpern used a value called the "glare index" (V), originated earlier by Schouten and Ornstein (1939), as their dependent variable in plotting results. Intensity of veiling luminance, varying from minus one to plus four log units (foot lamberts), was their independent variable. The glare index (V) is defined as follows:

$$V = (B_b / B_a - 1) \qquad (1)$$

where: B_a = luminance of comparison stimulus

B_b = luminance of test object

These results generally agree with previous findings (Holladay, 1927) (Luckiesh and Holladay, 1925) (Orbeli, 1934) (Schouten and Ornstein, 1939) (Stiles, 1928b) that showed that a peripherally placed glimulus causes a reduction in apparent brightness of a foveal test object.

In a study entitled, "An indirect method for measuring stray light within the human eye", Bartley and Fry (1934) used a disk and annulus as comparison stimulus and test spot. The peripheral glimulus was a 250 watt electric bulb. The differential threshold between disk and annulus, under various peripheral intensities, was determined. They found that as the peripheral glimulus increased in intensity the differential threshold at the fovea increased. The amount of stray illumination rapidly diminished for peripheral glimulus angles (θ) out to 10° and from there on diminished only slightly. (Ibid., p. 347) Hereafter the symbol θ will be used to indicate the angular distance a given photic source is from the line of fixation in degrees.

Bartley and Fry's Ss reported seeing a bright halo surrounding the glimulus with dim illumination filling the rest of the visual field.

Referring to formula (1), which is Schouten and Ornstein's glare index, it has been found that different values of this index are obtained for points equidistant from the fovea but along different retinal meridians...and that the fovea was affected more by the surrounding retina than it affected the surrounds. (Schouten and Ornstein, 1939) These researchers obtained a family of curves, each for a separate illumination level of comparison stimulus and test object, in which retinal sensitivity drop is plotted against θ. A definite drop in sensitivity was found with an increase in θ or an increase in elevation of the glimulus above the line of sight.

Luckiesh and Holladay (1925, p. 223) found that definite impoverishment due to a glimulus was also producible by a certain "equivalent veiling brightness". The resultant effect is the same as a superimposed brightness approximately proportional to the intensity of illumination E of the glimulus (originally called dazzle light) at the eye of the observer and approximately inversely as the square of angle θ. This glare practically ceases when the glimulus is more than 30° above the line of sight. A graph of equal dazzle curves is portrayed in Figure I, (after Luckiesh and Holladay, 1925).

In an early study, Holladay (1926) studied both glare and visibility. He used a ring which subtended 15° visual angle and upon which he could systematically illuminate various figures. Within the ring was a glimulus (31.5 meter candles). As the glimulus intensity was increased the figure - ring least perceptible brightness difference (j.n.d.) also increased. The least perceptible brightness difference was also found to vary inversely with the square of the angle which the glimulus makes with the line of sight and was almost independent of brightness, size, type, or distance of the glimulus.

Holladay helped establish a formula by which one can calculate the effect produced by a small glimulus placed within the field of view. It was named the "equivalent background brightness" formula. If a glimulus is placed in the peripheral field of view at θ degrees the effect at the fovea will be equivalent to a veiling patch of light having a luminance B_v, in candles per square foot, given by the following formula:

$$B_v = K \times E \times \theta^{-n} \qquad (2)$$

where: B_v = equivalent background brightness

K = constant

E = illumination in a plane through the center of the entrance pupil (foot candles)

n = constant

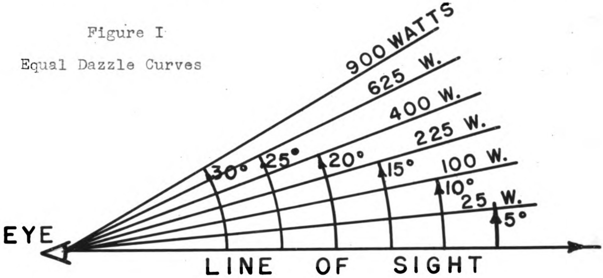
θ = angle of the glimulus from fixation line (degrees)

The following constants were obtained for ranges of θ as noted.

Investigator	θ Range	K	n
Crawford and Stiles (1935)	$2^\circ - 10^\circ$	11.5	2.1
Holladay (1926)	$2\frac{1}{2}^\circ - 25^\circ$	9.2	2
Stiles (1928b)	$1^\circ - 10^\circ$	4.16	1.5

Figure I

Equal Dazzle Curves



Le Grand (1957, p. 313) describes this formula in a slightly different way. He points out that, "...it is as if the source spreads over the field a luminous veil with a luminance β, this quantity being termed the equivalent luminance of the glare. The analysis of the average results leads to the following simple expression:

$$\beta = 10 \times E \times \theta^{-2} \qquad (3)$$

where: β = equivalent luminance (candles per square meter)

E = illuminance at S's eye (lux)

θ = angle of the glimulus from fixation line (degrees)

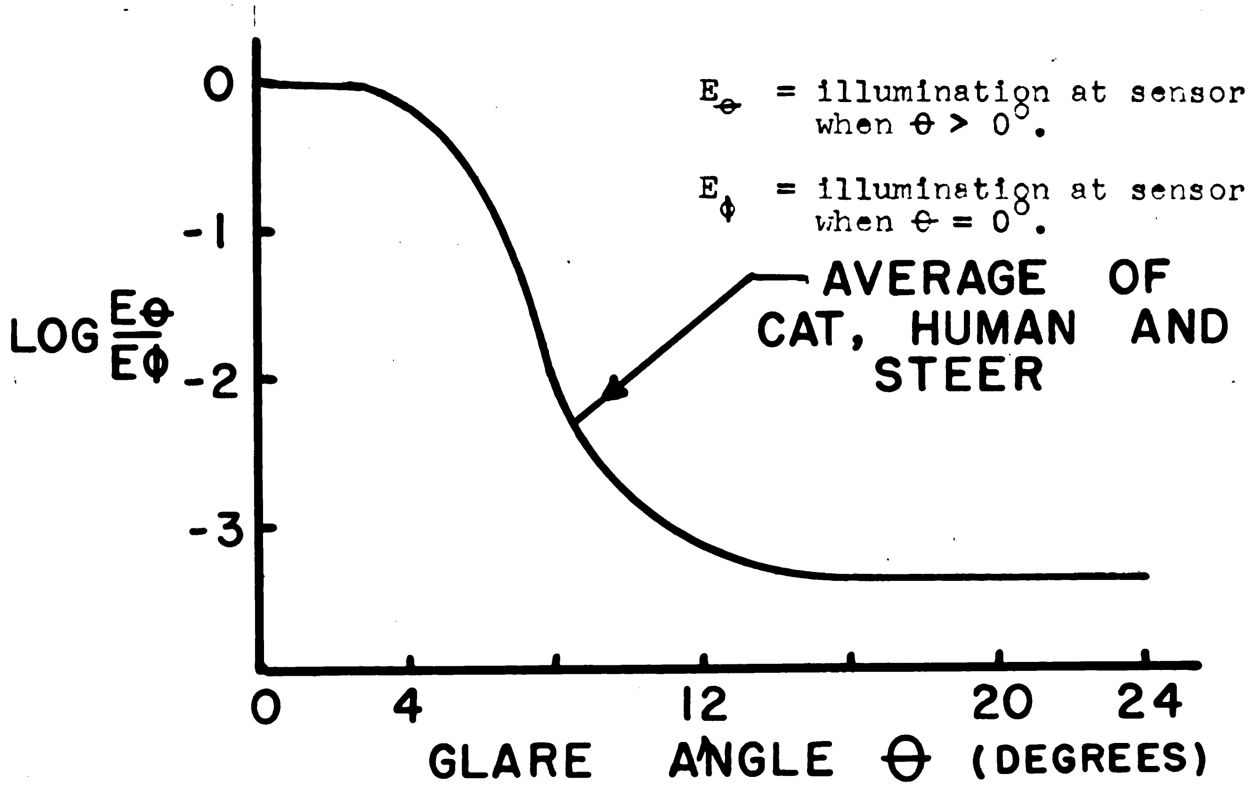
Stiles and Crawford (1937) determined that formula (3) may be used for values of θ between 5° and 50° if the factor 10 is replaced by 16.

One of the bases of impoverishment is thought to be stray illumination within the eye. All glimuli produce some impoverishment of the retinal image, thus it is important to determine those energistic relationships existing between glimulus and impoverishment in order to determine if impoverishment could be the cause of glare. Both living and excised eyeballs have been investigated. (Bartley, 1941) (Bartley and Fry, 1934) Bartley and Seibel, 1954) (Boynton, Enoch, and Bush, 1954). Such findings are typically portrayed as graphs of "stray light in the eye as a function of θ". Figure II presents the findings of Boynton, Enoch, and Bush (1954) who measured the amount of stray light in excised eyes of the cat, human, and steer. It must be remembered that since excised eyeballs are incapable of contributing to glare as an experience Figure II represents only stray illumination within the eye. It is apparent that as θ increases the magnitude of stray illumination decreases, quite rapidly at first but later tapering off.

An investigation by De Mott and Boynton (1958) attempted, among other things, to compare physical measures of entoptic stray light as a function of θ with psychophysically obtained curves of brightness as a function of θ. If the visual effects of a glimulus are solely dependent upon the stray light cast on

Figure II

Entoptic Stray Illumination as a Function of θ



a particular area of the retina (fovea) one would expect the curves of visual effect to be identical to the curves of measured intensity. These researchers then combined data from Boynton (1953), Le Grand (1937), and Holladay (1927), with their own physically measured, entoptic stray light findings. When equated at $\theta = 10^{\circ}$, all four curves were very similar to one another. (see De Mott and Boynton, 1958, Fig. 9, p. 20). These authors remark, "Perhaps the safest conclusion is that the retinal illumination, as indicated by psychophysical experiments, is similar to that obtained using excised eyes, and that stray light could probably account for <u>most</u> of the psychophysically measured effects." (Ibid., p. 22)

The usual way of studying glare has been the measurement of equivalent background brightness. When one visualizes the experimental technique used one finds that S must fixate a test spot with one eye and a comparison stimulus with the other. The test spot is usually a glimulus shown directly into S's eye but can be a reflected glimulus. In some experiments the glimulus is independent of the test spot. The experimenter systematically varies intensities and positions of the glimulus, test spot, and comparison stimulus; S matches brightnesses seen in each eye. A brightness match is assumed to provide an indication of the amount of stray illumination falling in the region of the image of the test spot. After a comprehensive review of the literature it is apparent that relatively little has been done to determine spatial and intensity characteristics produced by glimuli that are foveally fixated. Formulas such as (2) and (3) provide means of estimating the effects of peripherally placed glimuli. Another study appears warranted which would establish intensity gradients for a <u>foveally fixated</u> glimulus having different shapes.

In the following discussions the term <u>border</u> refers to the physical bounds of the object viewed; the term <u>edge</u> refers to the perceived bounds. This distinction becomes necessary when dealing with visual objects exhibiting different appearances depending upon illumination conditions.

Some evidence for the existence of an intensity gradient (surrounding intense glimuli) has been obtained but the majority of it is introspective rather than quantitative. One source (Bartley and Fry, 1934, p. 347) indicated a, "dimly illuminated field with a bright halo immediately surrounding the bright object." Findings of a pilot study,(Haines, 1963) associated with the present study, obtained similar subjective phenomena. In fact, several different field appearances were observed depending upon glimulus intensity and field position.

A round glimulus, subtending just over 1° 30' visual angle and having a luminance of 338 candles per square foot produced a ring of luminance concentric with the edge. This field appearance was definitely brighter near the edge of the glimulus than it was farther away. However, a thin dark area directly next to the boundary was observed.

It is known that the radiation forming the image of a glimulus is not the only retinal illumination. Even when the visual field surrounding a glimulus is unilluminated the retina surrounding the image is illuminated by stray illumination from many sources. Such scattered radiation is unfocused. Appendix V includes a detailed account of the sources of entoptic scattering.

A study entitled "the comparative distribution of light in the stimulus on the retina", using excised rabbit eyes, was performed by Bartley (1935). He used sources producing from

342 to 2,750 candles per square foot with a five mm. diameter artificial pupil. The brightness of the image cast upon the retina, as photometered through the eye-wall, varied from 9.5 to 78 candles per square foot while the intensity of the surrounding retina varied from 0.266 to 2.12 candles per square foot. He found that stray illumination outside of the image is a fraction of that within the image. Looking for relationships between retinal image intensity and retinal surround intensity Bartley apparently did not investigate the quantitative aspects of an intensity gradient extending out from the edge of the retinal image in different meridians.

Bartley and Seibel (1954) based their study upon the results of a previous study by Bartley (1935) that showed that stray illumination from the image of a target was proportional to the intensity and area of the target's image producing it. They sought, by a flicker method, to determine the intensity of stray illumination cast at various distances from the image of a target for targets having various intensities and areas. It was reasoned that since the target is producing the stray illumination there should be an orderly relationship between target critical flicker frequency (c.f.f.) and field c.f.f., that is, c.f.f. at various points outside the image of the target. Targets ranged in size from 51' to 31° 51' visual angle and in intensity from 0.0001 to 100 candles per square foot. Each curve that was obtained illustrated an increased c.f.f. with increased target intensity. Each curve also illustrated an orderly relation between the target c.f.f. and field c.f.f. lending support to the assumption that the target image produces the entoptic stray illumination.

The preceeding studies appear to provide sound basis for the appearances of the field surrounding the glimulus and yield certain quantitative measures of the brightness gradient involved. It was felt that more information should be obtained about this gradient. An experimental design was developed which combined proven psychophysical technique with known neuro-anatomical relationships in such a way that more information could be obtained regarding the quantitative aspects of the retinal gradient and upon the theoretical bases of glare.

Since its first formulation, the present study was founded upon the possible existence of a measurable intensity gradient surrounding a given glimulus. Since previous studies (Bartley and Fry, 1934) (Di Francia and Ronchi, 1952) (Haines, 1963) (Roaf, 1932) had found evidence for a gradient of luminance surrounding a glimulus it was reasoned that, "if an intense photic source could be imaged wholly upon the fovea centralis, where there few, if any, horizontal neural connections (see Appendix III) and a diffuse veil of luminance still exists around the glimulus' boundary then the glare experience must have a component due to entoptic stray illumination...for how else could the impression of a (perceived) luminous veil originate without some means of stimulating the retinal receptors around the glimulus' retinal image?" This then was the theoretical basis upon which the present study was founded. The present approach is somewhat similar to that used by Bartley (1941) and Schouten and Ornstein (1939); namely, that if the photic source's image occupies an area of the retina incapable of yielding certain neural impulses and glare is experienced then at least some component must be due to scattering of the photic flux over surrounding receptors.

The next question to be answered was, "how is this gradient to be measured?" A perimetry method, somewhat similar to that used by Luckiesh and Guth (1949) was devised. The exact method is presented in the following section.

Regarding the measurement of retinal glare intensity gradients, several specific experimental hypotheses were formulated. Inclusion of testable hypotheses formed an orderly framework upon which experimentation could be performed. These hypotheses are presented below:

1. A glimulus will produce retinal illumination that extends some distance from the region of the "ideal image" and under given conditions will have a physically measurable boundary.

2. The perceived shape of the glimulus should be generally isomorphic with the physical form of the glimulus.

3. Generally speaking, a glimulus should cause a larger area around the edge of the glimulus to exist where brightness and motion perception will be impossible than will a non-glimulus.

4. Decreasing glimulus intensity will cause the perceived shape to approach the physical form of the particular glimulus used.

5. The statistical variance will be larger for emerging trials, i.e., when the test spot reappears, than for entering trials, i.e., when the test spot disappears.

The fifth hypothesis refers to findings related to the methodology of the present study. Each of these hypotheses can be tested by the same basic experimental apparatus and design. Two separate experiments will be described, each using the same general psycho-physical technique but slightly different apparatus.

Information to be gained from the present study appears to be of importance on other than theoretical grounds. Some practical applications for these findings will be pointed out later in the paper.

METHOD

Apparatus

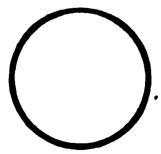
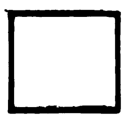
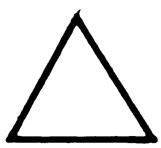
The apparatus can best be described by examining it in three sections: (1) the photic (glimulus) source (P.G.S.), (2) the secondary (glimulus) source (S.G.S.), and (3) the moving test spot (M.T.S.).

The photic source for producing glare in experiment One was an eight volt D.C., 50 watt, electric bulb (Philips, Type 13113 C/04) operated at a constant 6 volts. Its focal length was $1\frac{1}{4}$ inches. For experiment Two the photic source was a 110 volt A.C., 1,000 watt, projector lamp (Ken-Rad, Model DFT, T12C13D). Each of these sources was enclosed in the same light-tight box and positioned so that their filaments were $^{11}/_{16}$ of an inch behind a metal plate having a $\frac{1}{2}$ inch diameter hole through which they shown. The first photic source produced a luminance of 32 lumen per steradian ($\pm$ 1 lumen per steradian); the second source produced a luminance of 3,968 lumen per steradian ($\pm$ 4 lumen per steradian).

The secondary glimulus (S.G.S.) was one of three different first surface mirrors. Exact dimensions are given in Figure III.

Figure III

Secondary Glimulus Dimensions

Form	Dimension
	Diameter = 0.444" Thickness = 0.083"
	Width = 0.394" (+ 0.000" − 0.001") Thickness = 0.040" (+ 0.003" − 0.003")
	Base Length = 0.598" (+ 0.000" − 0.001") Apex Height = 0.519" (+ 0.000" − 0.001") Thickness = 0.040"

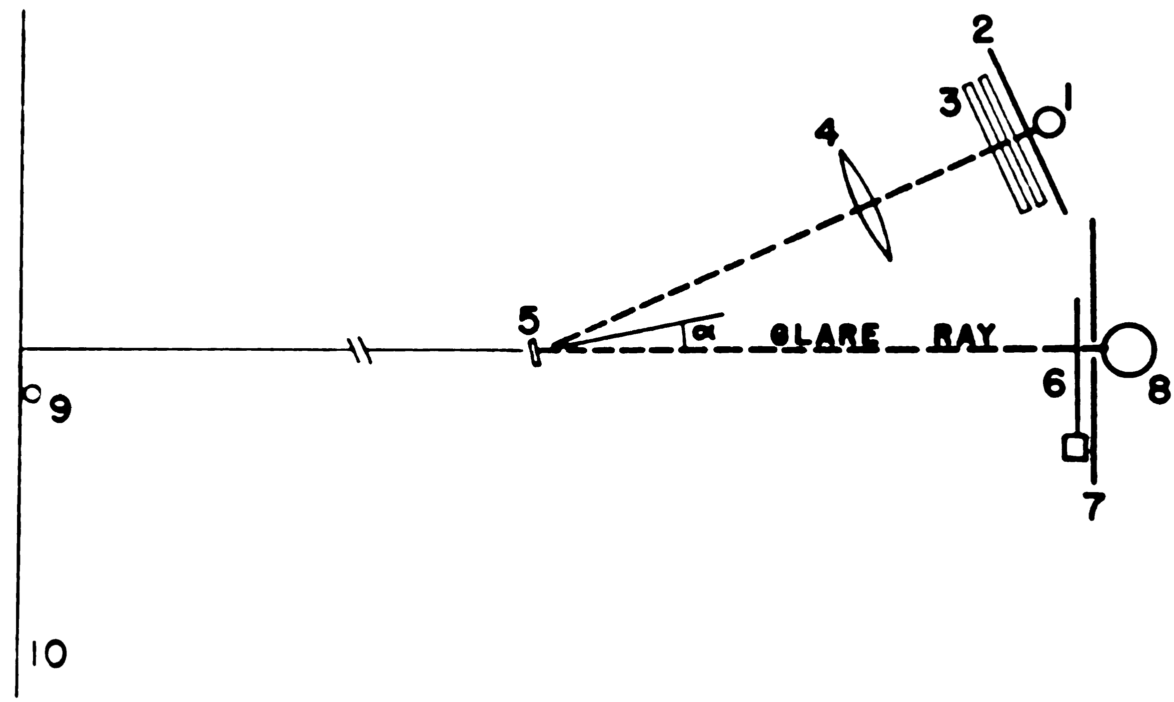
Note: All forms had a frontal area = 0.155 square inches (± 0.002")

Each mirror's front surface was fine ground, aluminized, and S_iO overcoated. All borders were backbevelled 10° from the first surface.

These mirrors were used individually and were situated so that the glimulus' ray from P.G.S. was reflected into S's right eye. The angle of incidence and reflectance was 13° and is indicated by the symbol α in Figure IV which is a schematic diagram of the apparatus. Each mirror was held in place by means of a metal rod attached to a ring stand. The triangular and square mirror's flat border was positioned horizontally as illustrated in Figure III above.

Figure IV

Schematic Diagram of Apparatus



The following numbered descriptions apply to the numbered parts in Figure IV. (1) the photic source described on the previous page. (2) the metal plate through which (1) shown. The dashed line in Figure IV indicates the path of the glimulus' ray. (3) neutral density filters used to control P.G.S. intensity. All filters were placed normal to the ray. Experiment One used only a 0.4 log filter. Experiment Two used the following Kodak Wratten neutral density filters: 0.10 log, 0.40 log, 0.50 log, 0.80 log, 1.00 log, 1.40 log, 1.80 log, and 2.00 log. (4) a two and three-quarter inch diameter collimating lens used both to reduce stray illumination in the room and to utilize as much of the photic energy as possible. (5) the secondary source described in Figure III. The front surface of all S.G.S. were placed 19½ inches from S's anterior corneal surface. Thus a visual angle of no more than 1° 50' was ever subtended by the largest dimension of any S.G.S. (6) an electric shutter operated by electronic timer to control inter-viewing interval. (7) the artificial pupil plate. Different artificial pupil diameters were investigated in a pilot study associated with the present study as well as by other investigators (Adler, 1950, p. 644) (O'Brien and Miller, 1953, p. 10). On the basis of these findings a 3½ mm. diameter pupil was used. This provided a 10½° diameter visual field. Other sources cite additional reasons for using an artificial pupil. rather than the natural pupil (Bartley and Fry, 1934) (Fry and Alpern, 1953a, p. 66). This stainless steel plate (7) was positioned normal to the line of sight and was situated directly in the center of the natural pupil. (8) S's right eye, situated approximately 1.02 inches behind the front surface of the pupil plate. By using a horizontally and vertically adjustable biting board each S was assured an unchanging viewing position. S was prevented from seeing any light except that entering the artificial pupil.

The third and final section of the apparatus to be described is the moving test spot (M.T.S.). It is represented as (9) in Figure IV. The M.T.S. was a 15 watt, 120 volt A.C., electric bulb, frosted white, within a light-tight enclosure. The enclosure was mounted on an eight-foot long track represented as (10). The M.T.S. was controllable for velocity and direction of travel along the track; this travel always being in the frontal plane. The enclosure had a $\frac{1}{4}$ inch diameter hole facing S's line of sight. At the standard viewing distance it was seen as a very small circle of dim light (0° 7' 12"). The M.T.S. luminance equalled 0.8 lumen per steradian.

The track upon which the M.T.S. travelled was supported at its middle by a stand which allowed it to rotate a full 360°. Referring to Figure IV, the S.G.S.'s center was on a line between S's eye (8) and the center of rotation of track (10). In this way any particular meridian could be investigated according to standard perimetric procedure. Thus when the track was fixed in a given meridian, the M.T.S. was first set into motion down the track and then back again, constituting two "directions" per meridian. These directions were designated by the number of degrees from vertical (0°), clockwise, the M.T.S. was travelling. Thus when the track was set vertically and the M.T.S. travelled upward the direction was designated as 0° and down as 180°. When set horizontally and the M.T.S. was travelling to the right it was designated as 90° and to the left as 270°, etc.

A M.T.S. velocity of 0° 5' 30" per second was chosen on the basis of previous studies (Aubert, 1886) (Bourdon, 1902) (Brown, 1931) (Grim, 1910) which indicated this to be suprathreshold for these viewing conditions.

A fixed millimeter scale on the track plus a pointer attached to the light enclosure made it possible to note where the M.T.S. was stopped in its travel along the track. This position was read to ½ mm. accuracy. This corresponds to a visual angle of 35.1" at S's eye. Parallax errors in reading this setting were minimized.

Because retinal adaptation is such a crucial factor under intense glimulus conditions it was necessary to control viewing time and between-viewing time precisely. This was accomplished by using an interval timer actuating an electric shutter at the front of the artificial pupil (6). It was not assumed that a completely steady state of retinal adaptation would occur during any series of observations because of the relatively short lengths of light and dark (viewing -not viewing) periods. The retina was assumed to be in a continually alternating state of light or dark adaptation; light adapting when S viewed the glimulus and dark adapting when the shutter was closed. The viewing interval for experiment One was 33 per cent of the total trial time (30 seconds) or 9.9 seconds and 42 per cent of the total trial time or 12.6 seconds for experiment Two. Several sources (Bartley, 1962, p. 941) (Hecht, 1922) (Woodworth and Schlosberg, 1958, p. 369) (Wright, 1934) indicate that light adaptation is almost completed, for the present initial intensity levels, within 60 seconds and levels off relatively fast thereafter; dark adaptation is characterized by a slower decelerating curve. Under the light - dark - light (etc.) conditions used here the resultant adaptations would most likely describe a jagged, negatively accelerating curve similar to that portrayed in (Bartley, 1962, Fig. 13, p. 941). It is conceivable that the state of retinal adaptation to the dark period of 20.1 seconds, (experiment One) as compared to the light period of 9.9 seconds, will reach an asymptotic level after at least 5 or 6 light - dark trials.

When one visualizes the movement of the M.T.S. for any given direction of travel it is clear that when the S.G.S. (mirror) is positioned directly in the line of sight and the M.T.S. is within a certain range of positions on the track behind the S.G.S. the M.T.S. will be in view until it passes behind the S.G.S. completely. Such a position is called "disappearance". Again, after some distance of travel behind the S.G.S. the M.T.S. would again "reappear" for the remainder of its journey along the track. The terms "covered" and "uncovered" will be used to denote the exact point on the track when the M.T.S. passes completely behind or emerged completely from behind the particular S.G.S.

Experimental Design and Procedures

In both experiments the variable of major interest was the effect of a foveally fixated intense photic source upon the determination of the S.G.S.'s edge, or put another way, the ability of different shaped glimuli to yield apparent brightness gradients. The logical way of determining this was to compare the effects of high glimulus intensity, zero glimulus intensity, and intermediate glimulus intensities upon the dependent variable (M.T.S. setting).

In the first experiment to be reported two other variables of interest were meridian and direction of travel of the M.T.S. Six meridians were studied for the triangular S.G.S. and eight for both the square and circular S.G.S. Each meridian was separated by 60° around the 360° possible for the triangular S.G.S. and by 45° around the 360° possible for the other two S.G.S. forms. Two directions of M.T.S. movement per meridian were also studied. Thus each S underwent the following testing conditions for the first experiment: (1) eight meridians (six meridians for the triangular form), (2) two directions of M.T.S. movement per meridian, (3) twelve "disappearing" trials per direction, (4) twelve "appearing" trials per direction, (5) three glimulus intensity conditions, (a) full intensity = 32 lumen per steradian, (b) 0.4 log intensity = 12 lumen per steradian, and (c) zero intensity = unilluminated S.G.S., and (6) three S.G.S. forms. In addition to these conditions the author, as S, repeated experiment One in its entirety. Results are labelled Series One and Series Two respectively.

The rationale upon which experiment Two was based was that if relatively consistent findings were obtained for all meridians and S.G.S. forms in experiment One, a single meridian and form could be investigated under a wider range of intensities in experiment Two. Thus in experiment Two, only one meridian (0°), two directions (IN and OUT), one S.G.S. form (square), and nine intensities were studied. The specific intensities were as follows: full intensity (zero log) = 4248.72, 0.10

log = 3398.97; 0.40 log = 1699.48; 0.50 log = 1359.59; 0.80 log = 679.79; 1.00 log = 424.87; 1.40 log = 169.94; 1.80 log = 67.97; 2.00 log = 42.48 foot lamberts.

The above conditions amounted to a total of 576 observations per S for experiment One and 240 per S for experiment Two. In experiment One limitations of the apparatus required that six one direction presentations be given under a given intensity, six more under the second intensity, and six more under the third intensity, then the direction of travel was reversed 180° and the entire procedure repeated. Illuminance level (S.G.S.) order of presentation was randomized, thus S might observe full intensity first, zero intensity second, and 0.4 log intensity last. When another meridian was studied a new order was used. Order of meridian presentation was likewise randomized. Six minutes was allowed for dark adaptation after <u>every</u> full and 0.4 log illuminance condition. S typically observed no more than two meridians per setting or a total of 144 observations.

The procedure used was similar for both experiments and was as follows. S was fitted to the wax biting board and made comfortable in the seat. The M.T.S. was begun at a point at least 3° beyond the calculated border of the particular S.G.S. being studied. It travelled toward the S.G.S.'s border at a constant velocity. A button, upon which S rested his right forefinger, could immediately stop the M.T.S. if pressed. When S observed the M.T.S. pass completely out of sight (disappear) behind the S.G.S. he immediately pressed the button. The scale reading was recorded and E caused the M.T.S. to continue its travel behind the S.G.S. and then into view (reappear), at which time S again pressed the button. This scale reading was recorded and the M.T.S. reset for five more presentations in the same direction and meridian.

The directions given to each S are presented in Appendix IV. To S the S.G.S. appeared as a small highly specular surface. When S first fixated on its center slight pain sensations were sometimes felt; they quickly disappeared. S was told again, if necessary, to fixate on the center of the S.G.S.'s surface. If S's fixation wavered more than 50' visual angle he was told to tell E who did not record that presentation but repeated it later. (Note: 50' visual angle corresponds to approximately one-half the widest dimension of any S.G.S. used). It was found from a pilot study, as well as by O'Brien and Miller (1953, pp. 32, 40) that, "A skilled observer can fixate the center of a 45' circle quite accurately, although not with the precision with which he might fixate a small cross or other fine detail." For experiment Two, a fine cross-hair reticle was positioned between S's eye and the center of the S.G.S. This device helped provide stable fixation.

Subjects

Five subjects were used in the present research. Table I presents relevant information concerning each. Subjects in experiment Two were volunteers from an advanced experimental psychology class with 20:20 vision as noted below.

Table I

Experimental Subjects

Name	Age	Vision	Prior Experience
		- Experiment One -	
Thomas Snyder	25	20:20 corrected	Moderate amount for general visual phenomenon, non in glare experimentation.
Richard Haines	27	20:20 corrected	Highly trained in glare-related observation.
		- Experiment Two -	
Robert Nettleman	25	20:20 uncorrected	Undergraduate student in psychology. Little prior experience.
Bruce Marcucci	21	20:20 corrected	Undergraduate student in psychology. Little prior experience.
John Mullen	23	20:20 uncorrected	Undergraduate student in premedicine. No prior experience.
Richard Haines	27	20:20 corrected	Highly trained in observing glimulus conditions.

<u>Miscellaneous Experimental Conditions</u>

The experimental room was dark except for one 60 watt, red, overhead, lamp providing approximately 0.8 foot candles illumination at desk-top distance. This was enough illumination to record data and safely move about the room. Room temperature during testing was held constant at about 80° F. The room's noise level was low at all times. An electric cooling fan for the P.G.S., within the light-tight box, helped mask most soft noises.

RESULTS

The results obtained from this study are most easily understood when associated with each of the experimental hypotheses.

Hypothesis One

The first hypothesis was that, "A glimulus will produce illumination that extends some distance from the region of the "ideal image" and under given conditions will have a physically measurable boundary." The glimulus' retinal illumination will be larger than the glimulus' retinal image. The difference between these two is what was measured. The procedure used to test this hypothesis was to plot the glimulus intensity gradient surrounding a given S.G.S. form by the perimetric method described previously. Referring to Figures V through XI it is apparent that the perceived edge of the glimulus was larger than its physical boundary. Tables II through VIII present the size of this difference for each meridian studied and for the three forms respectively. Statistical significance between the two glimulus intensities and zero intensity are indicated as asterisk(s). It will be noted that the S.G.S.'s boundary is

Figure V

Intensity Gradients for a Circular Glimulus under Two Glimulus Intensities

Series One

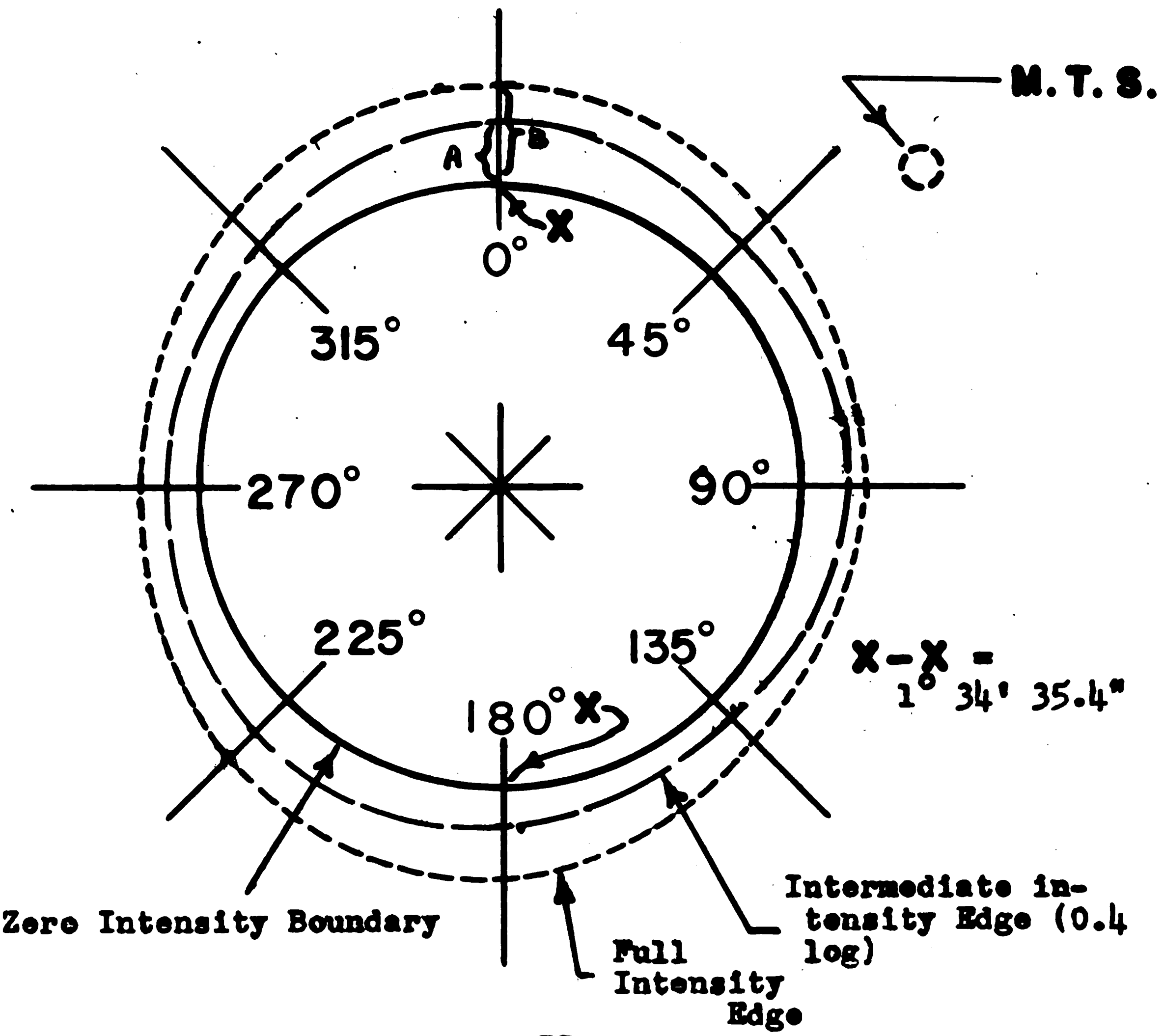


Table II

Differences between Boundary and Edge for a Circular Glimulus under Two Glimulus Intensities
Series One

Meridian	(A) Visual Angle		(B)	
	0.4 log Intensity		Full Intensity	
0°	10'	3.3" *	15'	25.4" *
45°	5'	39.4" **	11'	27.7" *
90°	7'	0.6" *	10'	16.7" *
135°	4'	6.1	8'	44.1" *

Table II continued

180°	5'	33.9" *	13'	48.3" *
225°	7'	4.4" *	12'	12.4" *
270°	5'	13.2" *	9'	33.4" *
315°	4'	41.2" **	11'	2.1" *
Mean	5'	30.8"	11'	35.6"

* Significant above P = .005

** Significant above P = .05

Figure VI

Intensity Gradients for a Circular Glimulus under Two Glimulus Intensities Series Two

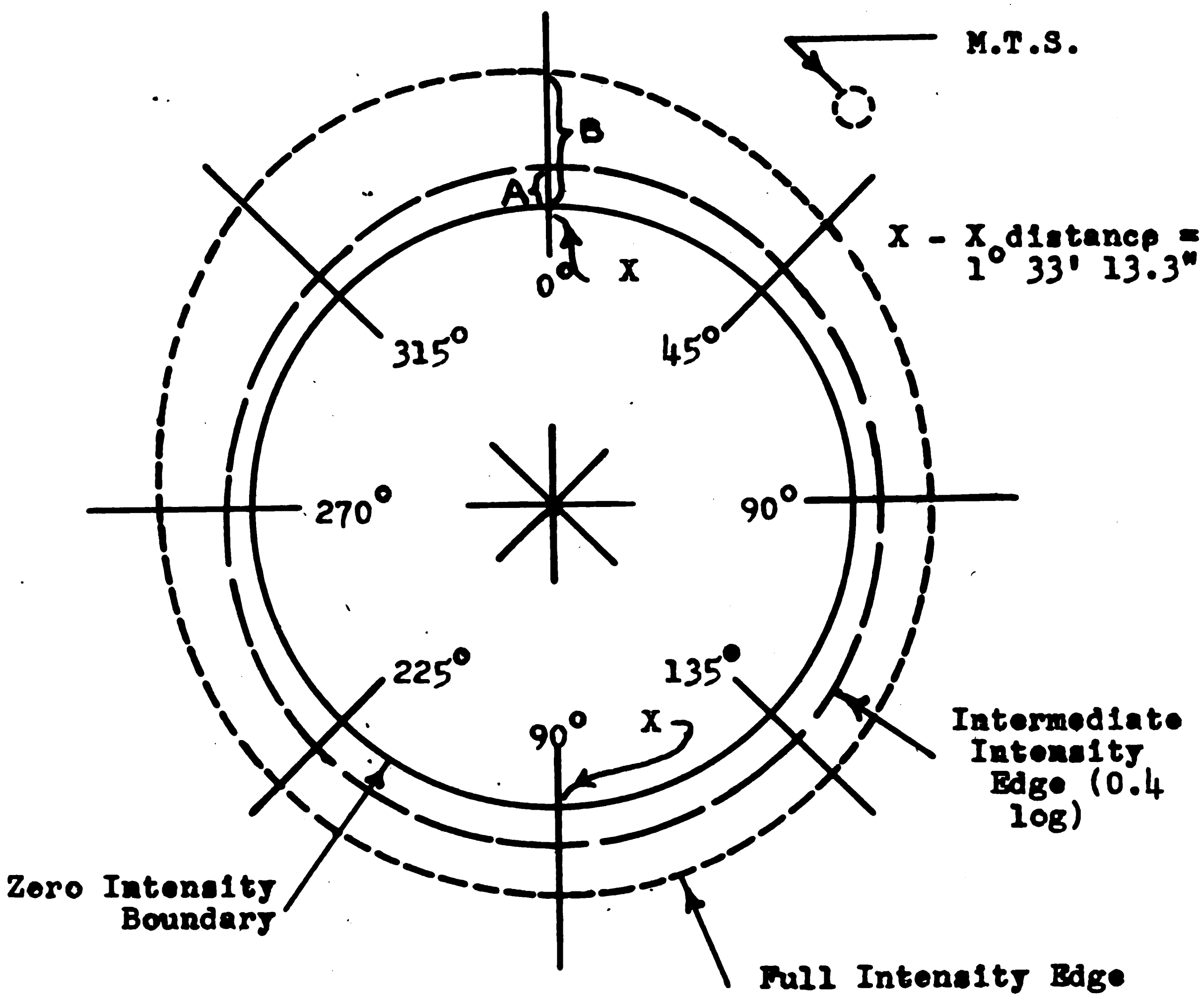


Table III

Differences between Boundary and Edge
for a Circular Glimulus under Two
Glimulus Intensities
Series Two

Meridian	(A) Visual Angle		(B)	
	0.4 log Intensity		Full Intensity	
0°	6'	32.3"	20'	35.9"
45°	7'	46.1"	13'	16.5"
90°	9'	38.3"	12'	39.2"
135°	6'	9.1"	12'	47.0"
180°	14'	55.0"	13'	8.0"
225°	5'	4.4"	12'	26.6"
270°	3'	8.0"	13'	8.0"
315°	2'	26.2"	20'	33.0"
Mean	6'	31.1"	14'	29.5"

Figure VII

Intensity Gradient for a Circular
Glimmlus under One Glimulus Intensity
(Subject T.S.)

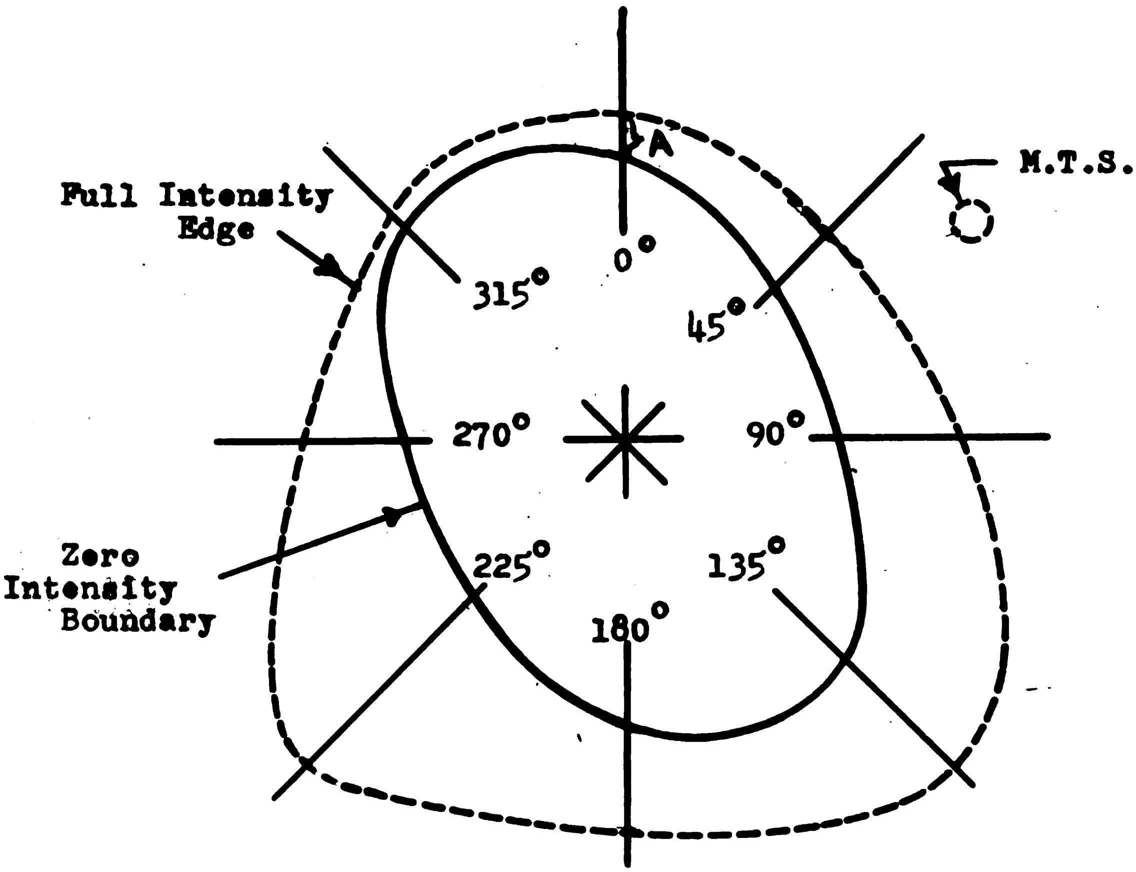


Table IV

Difference between Boundary and Edge for a Circular Glimulus under One Glimulus Intensity

(Subject T.S.)

Meridian	(A) Visual Angle
0°	6' 4.9"
45°	12" 52.6"
90°	20' 28.1"
135°	23' 20.9"
180°	15' 0.5"
225°	38' 16.4"
270°	14' 22.5"
315°	1' 39.3"
Mean	16' 25.4"

Figure VIII

Intensity Gradients for a Square Glimulus
under Two Glimulus Intensities
Series One

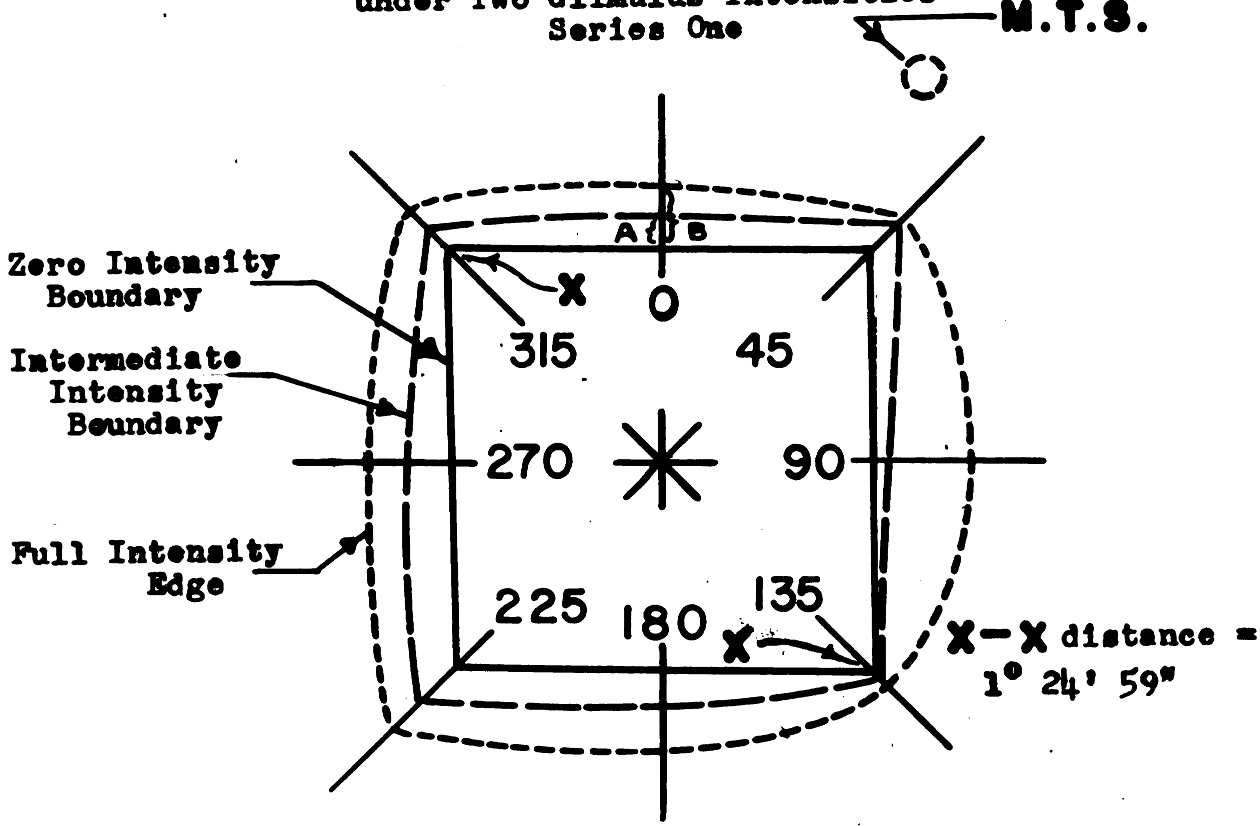


Table V

Differences between Boundary and Edge
for a Square Glimulus under Two
Glimulus Intensities
Series One

Meridian	(A) Visual Angle		(B)	
	0.4 log Intensity		Full Intensity	
0°	5'	16.3"	8'	59.2"
45°	7'	1.8"	7'	57.4"
90°	0'	37.9"	12'	3.3"
135°	5'	51.5"	8'	50.0"
180°	4'	37.6"	11'	7.8"
225°	8'	31.4"	14'	9.2"
270°	3'	59.7"	9'	22.4"
315°	9'	49.1"	14'	18.3"
Mean	5'	36.6"	10'	31.2"

Figure IX

Intensity Gradients for a Square Glimulus under Two Glimulus Intensities Series Two

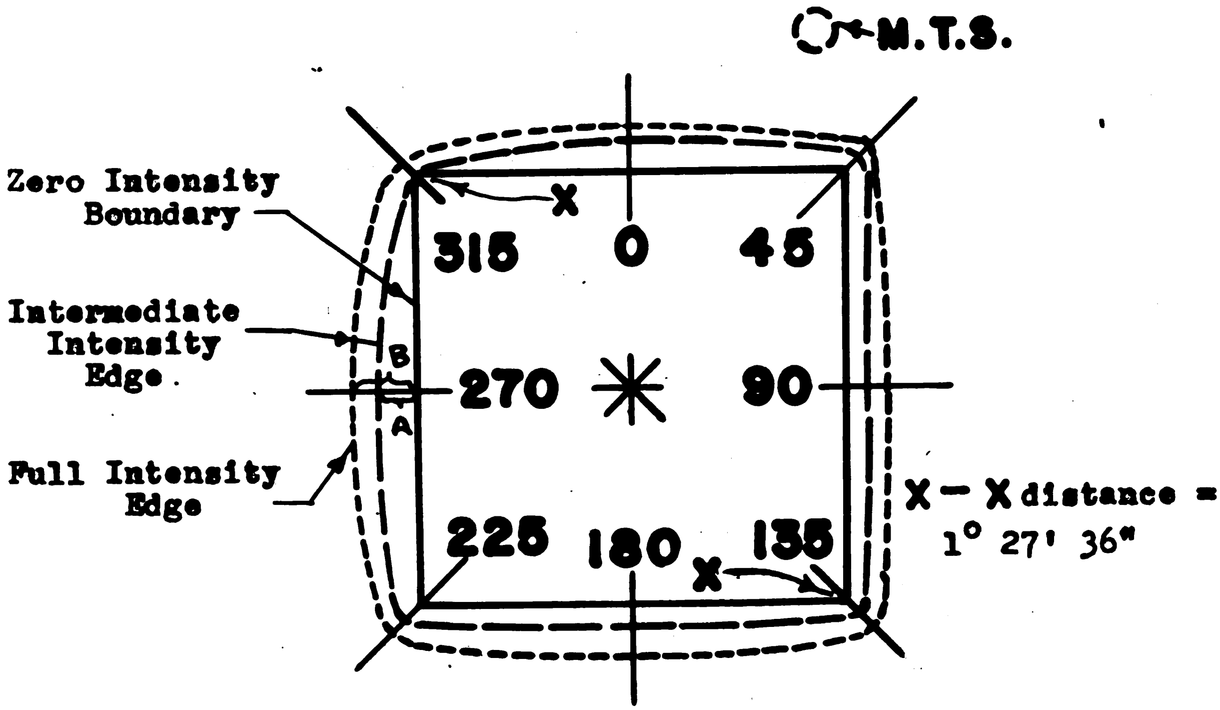


Table VI

Differences between Boundary and Edge for a Square Glimulus under Two Glimulus Intensities Series Two

Meridian	(A) Visual Angle 0.4 log Intensity		(B) Full Intensity	
0°	3'	2.1"	5'	55.0" **
45°	6'	26.0"**	8'	0.1" *
90°	2'	0.1"	4'	38.4" **
135°	4'	38.4"**	7'	54.4" *
180°	2'	17.7"	6'	29.4" **
225°	6'	17.5"*	9'	28.0" *
270°	4'	24.2"**	8'	14.9" *
315°	2'	20.6"	4'	44.0" **
Mean	3'	29.5"	6'	35.8"

* Significant above P = .005

** Significant above P = .05

Figure X

Intensity Gradients for a Triangular Glimulus
under Two Glimulus Intensities
Series One

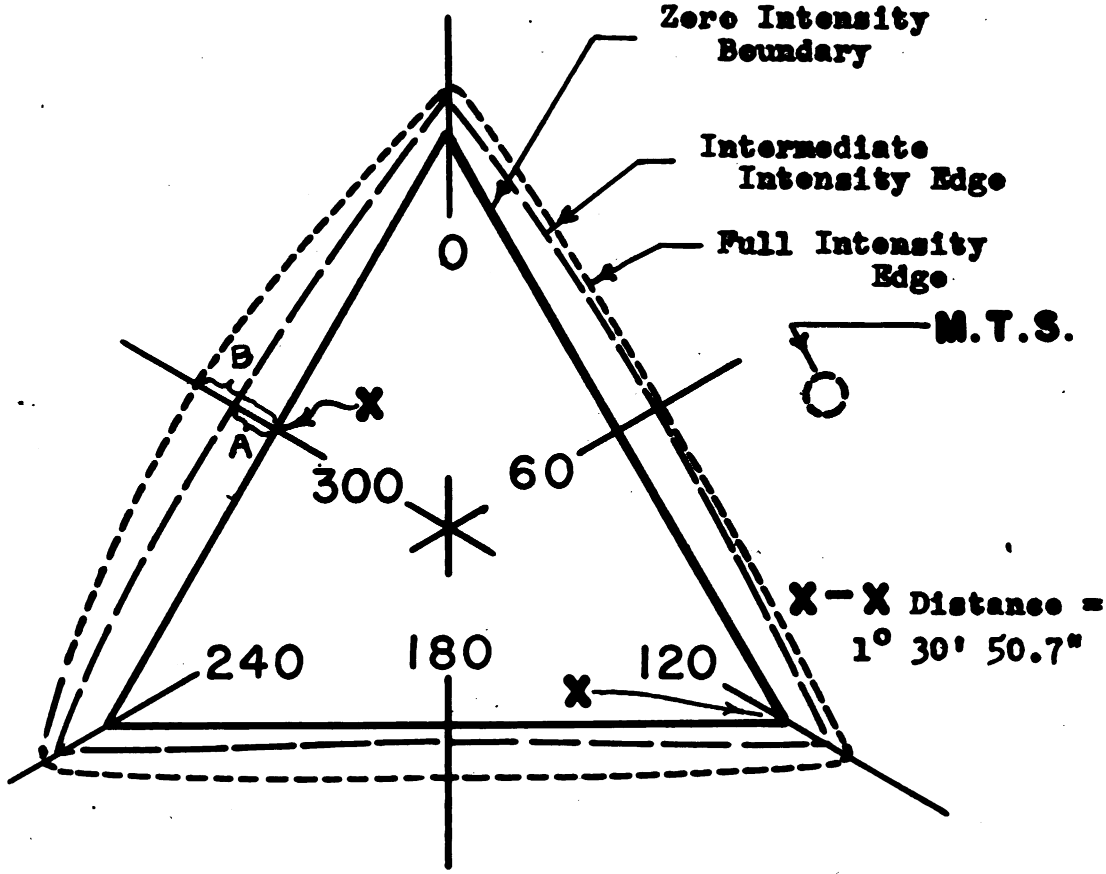


Table VII

Differences between Boundary and Edge
for a Triangular Glimulus under Two
Glimulus Intensities
Series One

Meridian	(A) Visual		Angle (B)	
	0.4 log Intensity		Full Intensity	
0°	6'	41.4"	6'	58.3"
60°	0'	2.6"	8'	0.8"
120°	6'	55.4"	10'	8.7"
180°	3'	7.7"	7'	15.7"
240°	9'	37.2"	11'	5.1"
300°	6'	44.2"	13'	34.8"
Mean	5'	31.0"	9'	22.2"

Figure XI

Intensity Gradients for a Triangular Glimulus under Two Glimulus Intensities Series Two

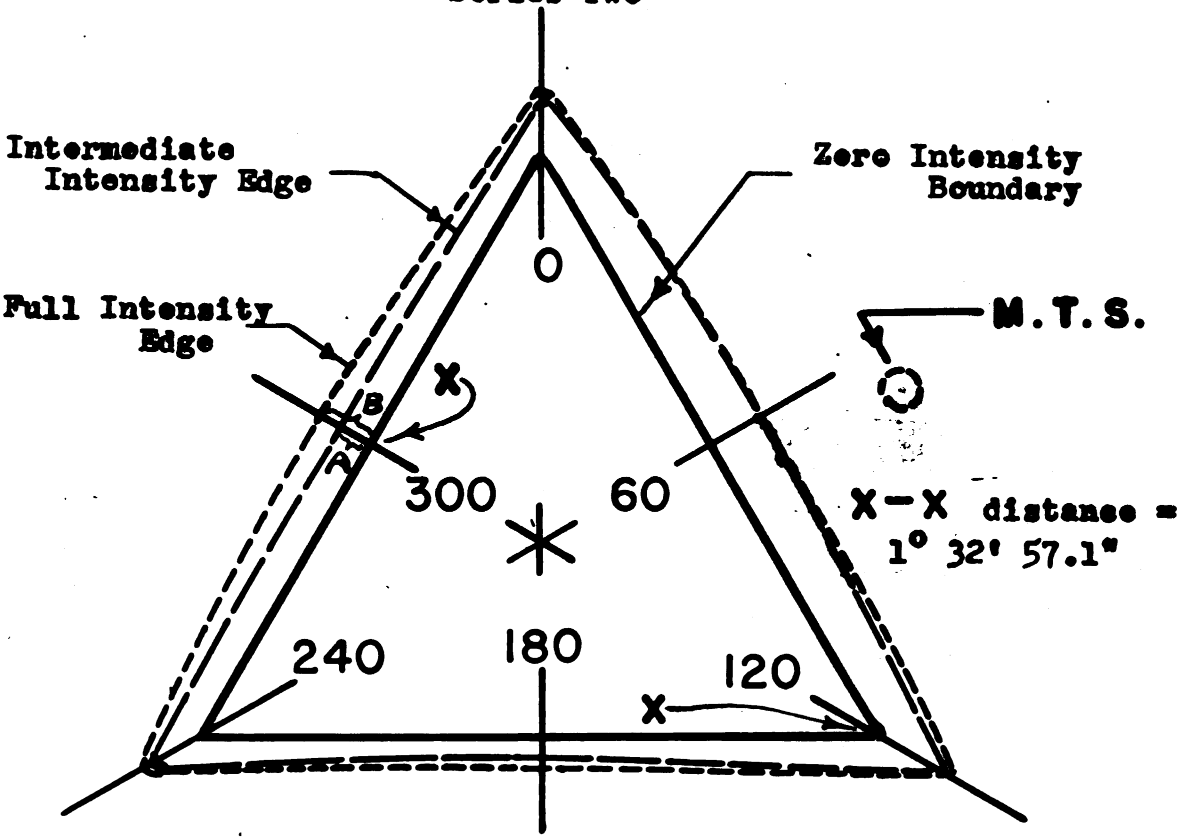


Table VIII

Differences between Boundary and Edge for a Triangular Glimulus under Two Glimulus Intensities Series Two

Meridian	(A) Visual Angle			(B)		
	0.4 log Intensity			Full Intensity		
0°	5'	31.1"	**	7'	48.2"	**
60°	7'	39.7"	**	7'	37.4"	**
120°	9'	7.7"	*	10'	17.8"	*
180°	3'	37.2"		4'	53.1"	**
240°	6'	24.0"	**	6'	56.2"	**
300°	4'	47.6"	**	8'	50.0"	*
Mean	4'	33.7"		7'	43.7"	

* Significant above P = .01

** Significant above P = .05

represented as a solid line and its perceived edge as dashed lines in Figures V through XI.

These findings illustrate that, for all meridians studied, a roughly concentric gradient plot was measurable using this technique. The small circle near each figure illustrates the relative size of the M.T.S. Full intensity conditions produced roughly twice the visual angle between boundary and edge as did the 0.4 log intensity. This was the case for almost every form studied. In visual terms this means that a larger area surrounding the glimulus is produced under full intensity than under a lesser intensity (where the present test spot was invisible). Table IX presents a summary of differences obtained for all glimulus forms for subject R.F.H. only.

Table IX

Summary of Vectoral Differences
between Boundary and Edge for
all Glimulus Forms
(Subject R.F.H.)

Glimulus Form	N	Visual Angle	
		0.4 log Intensity	Full Intensity
Circle (Series One)	96	5' 30.8"	11' 35.6"
(Series Two)	96	6' 31.1"	14' 29.5"
Square (Series One)	96	5' 36.6"	10' 31.2"
(Series Two)	96	3' 29.5"	6' 35.8"
Triangle (Series One)	72	5' 31.0"	9' 22.2"
(Series Two)	72	4' 33.7"	7' 43.7"
Grand Mean	88	5' 29.5"	9' 30.8"

The above values (Table IX) represent visual angles averaged across meridians, and for the grand mean, across glimulus forms. Interpretations using these values should take this into account.

Tables II through VIII provide a mean value beneath each intensity studied. These means are calculated across all meridians and are based upon 288 observations each, 144 IN and 144 OUT.

It is apparent that in experiment One, at the point of disappearance (covered) or reappearance (uncovered), the S.G.S. appeared to have some shape, i.e., straight surface, curved surface, 90° corner, or 60° corner. An analysis was performed upon the data to determine the effect each of these shapes had upon M.T.S. setting under various intensity conditions. Raw data from each of the appropriate points of "covered" or "uncovered" were calculated across <u>all</u> glimulus forms and all meridians (when more than one meridian contributed to the calculation). The magnitude of these boundary - edge visual angles is portrayed in Table X. Column A presents visual angles for full intensity - zero intensity conditions while column B presents visual angles for 0.4 log intensity - zero intensity conditions. Numbers in parentheses after boundary form name indicate the number of sets of six IN <u>and</u> six OUT trials each is based upon. In order to make the findings in Table X more meaningful they are presented in graphic form in Figure XII. Shaded figures represent the S.G.S.'s surface. It will be noted that the two broken (corner) boundary forms (90°

Table X

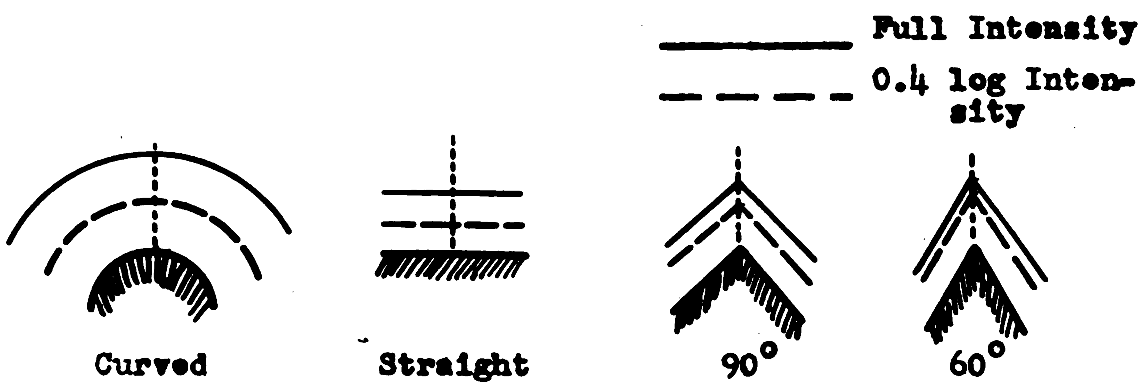
Effects Produced by Different Boundary Forms upon Boundary - Edge Determination.

Boundary Form	Visual Angle (minutes & seconds)			
	A		B	
Curved (16)	12'	29.3"	6'	26.8"
90° (8)	8'	26.7"	5'	36.1"
60° (6)	8'	35.7"	6'	41.1"
Straight (14)	7'	33.8"	3'	31.8"

and 60°) tend to yield full intensity and 0.4 log intensity gradients close to one another. On the other hand, the straight and curved, non-broken, boundary forms yield 0.4 log intensity gradients roughly <u>half</u> the distance to the full intensity gradients.

Figure XII

Graphic Illustration of data from Table X



From S's standpoint the data portrayed in Figure XII illustrates that under these intensity conditions the M.T.S. disappears and reappears at different distances from the S.G.S.'s boundary for curved and straight boundary forms but close to the same distances for 90° and 60° corner boundary forms. It does not seem unwarranted to predict that as corner angles get smaller (approaching about 5°) the full intensity gradient and 0.4 log intensity gradient will coincide.

Hypothesis Two

The second hypothesis states that, "glimulus perceived shape will generally be isomorphic with its physical form." It must be pointed out that although this hypothesis sounds rather obvious, to the writer's knowledge, no precise data has been collected concerning it.

Referring again to Figures V through XI it is apparent that all of the intensity gradients obtained appeared to be roughly concentric with the S.G.S.'s boundary. Ss typically reported seeing an intense central area, which was the S.G.S., surrounded by a gradually decreasing field intensity with increased distance normal to the S.G.S.'s boundary. The shape of the central area seen was usually the same as the actual form, i.e., square, circular, or triangular, but a few times S reported either an undulating central area or an amorphous, ill-defined area. The shape of the luminous field produced by a particular glimulus form was different from what one might expect in several cases.

The luminous field surrounding the circular glimulus form was concentric with the form out to the limits of the field of vision. This fact is portrayed in Figures V and VI. Data from

Subject T.S. (Figure VII) exhibited a great deal of variability. He repeatedly remarked of eye strain, tears, and involuntary blinking. Non-concentric results such as this were included as an example of the kinds of deviations one might obtain in this type of research.

For the square and triangular glimulus forms the intensity gradients did not follow the S.G.S.'s boundary as closely. For the square form the full intensity edge (Figures VIII and IX) often "filled out" at the straight sides to form a rounded square. Similar findings were obtained for the triangular form (Figures X and XI). It is noted that the 0.4 log intensity produced an intermediate amount of "filling out" for all glimulus forms studied. In general then, the perceived shape of a glimulus will largely depend upon its physical form rather than its intensity, however, a strict 1:1 correspondence is not necessarily found.

Hypothesis Three

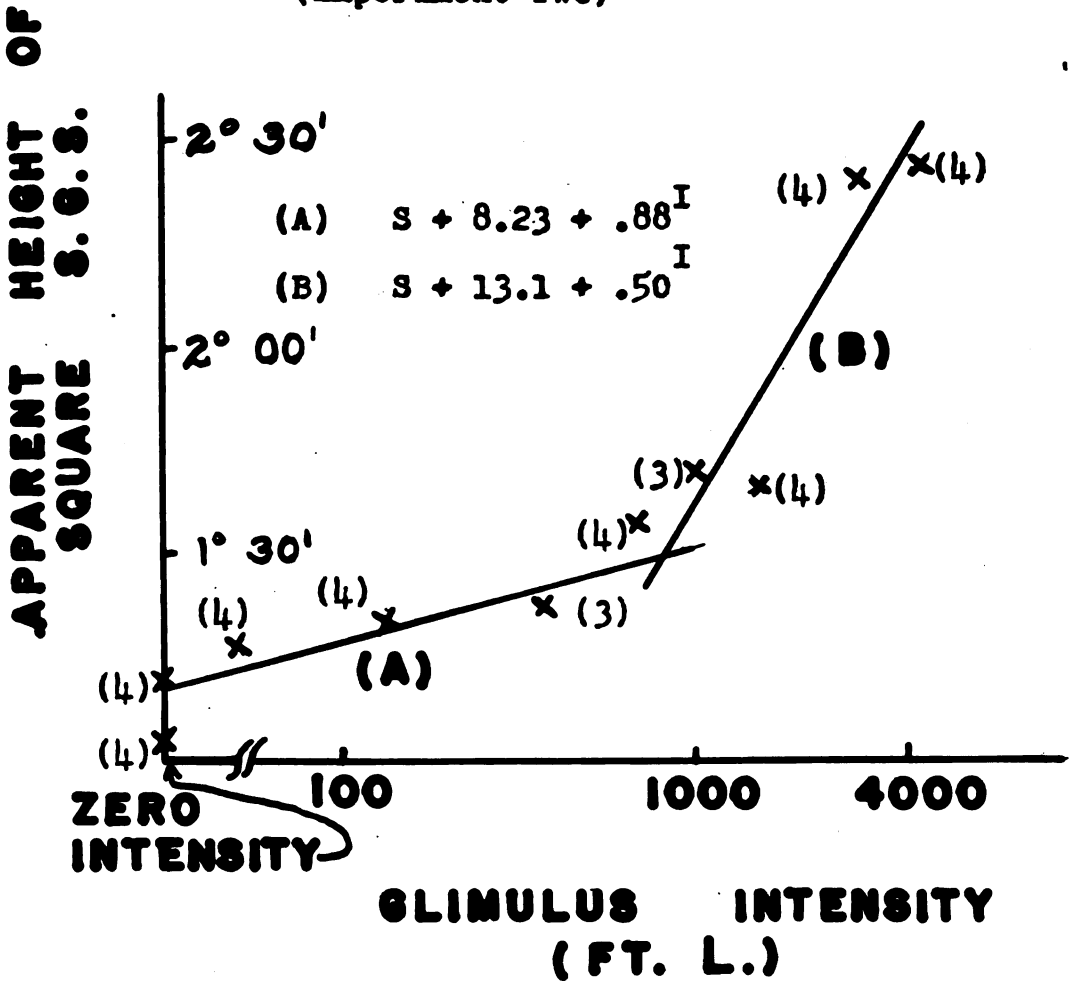
Hypothesis three states that, "generally speaking, glimulus conditions should cause a larger area of space around the boundary of the glimulus to become unusable for brightness and motion perception than a non-glimulus condition (zero intensity)." This hypothesis was tested in experiment One by using the moving photic test spot (M.T.S.) to chart the gradients for two intensities. After entering the field of view the M.T.S. seemed to disappear behind the S.G.S. relatively fast if the glimulus intensity were zero. When the intensity was full the M.T.S. appeared to disappear relatively slowly and farther from the S.G.S.'s boundary. The areas in Figures V through XI, bounded on the outside by the glimulus gradient and on the inside by the zero intensity (S.G.S. boundary), represent the unusable area. These figures present findings for individual glimulus form, meridian, and subject; Table IX presents a summary of these findings across vector and subject. Results appear to support the present hypothesis. Statistical tests (Student t) performed upon data in Figures V through XI indicate rather high significance levels for full intensity - zero intensity gradients over all glimulus forms.

Hypothesis Four

The fourth hypothesis offered was that, "decreasing the glimulus intensity will cause the perceived shape to approach the physical form of the particular glimulus used." The results from experiment Two apply to this hypothesis. Graph I presents these results for all four Ss tested. This curve represents the change in apparent height of a glimulus under a wide range of intensities. It is based upon data from one meridian (0^o), and two directions (IN and OUT). This curve could very well have come from any vector or glimulus form according to the findings cited in support of the previous hypotheses tested in experiment One. The data presented in Table X indicates that there would be minor variations in the curve's shape depending upon what point on the S.G.S.'s boundary the M.T.S. happened to disappear or reappear. One would expect to obtain similarly shaped glimulus gradients, in the frontal plane, under very intense glimulus intensities as those obtained under lesser intensities, such as those studied in experiment One.

Graph I

Effect of Glimulus Intensity upon
Apparent Height of the S.G.S.
(Experiment Two)



This curve is not meant to automatically extend the findings of experiment One to the glimulus intensities used in experiment Two for it is based upon only one glimulus form, one meridian, and two directions. It does provide preliminary data on certain aspects of viewing objects that have very intense intensities.

Each point plotted as a cross in Figure XIII is based upon data from the number of Ss noted in parentheses. Each S observed 24 trials per point. Zero intensity, on the abcissa, represents the apparent height (apparent diameter) of the square form under zero intensity.

Hypothesis Five

The traditional psychophysical method of limits was used in experiment One. This methodology uses an ascending and descending series of trials which allows one to locate the transition point between one type of respose and another. In the present case the response of pushing a button was supposed to indicate time of occurrance of a critical visual task. On the basis of many previous psychophysical experiments, showing the existence of anticipation errors, response latency, and perseveration errors, it was hypothesized that, "statistical variance will be larger for appearing trials than for disappearing trials." It was reasoned that since S did not know exactly when the M.T.S. would reappear, among other reasons, his responses would be more variable during these trials. Appearing trials are labelled as OUT trials in the following tables, disappearing are labelled as IN. The M.T.S., during IN trials, was always visible until it disappeared. For these trials S usually had less trouble seeing it and possibly of even forming some idea of its apparent velocity. In order to test hypothesis five the statistical variance was calculated for one data series for each glimulus form. Table XI, XII, and XIII present the results of this analysis.

Table XI

Results of Homogeneity of Variance Test for a Circular Glimulus Form

Series One

Condition	Variance			
	Meridian			
	0° - 180°	45° - 225°	90° - 270°	135° - 315°
Full Intensity IN	0.127	0.519	0.047	0.029
	↓	↗	→	↖
Full Intensity OUT	0.689	0.097	0.052	0.141
Full Intensity IN	0.111	0.166	0.071	0.084
	↑	↙	←	↘
Full Intensity OUT	0.168	0.079	0.140	0.048
0.4 log Intensity IN	0.299	0.248	0.443	0.081
	↓ *	↗ *	→	↖
0.4 log Intensity OUT	0.017	0.007	0.006	0.030
0.4 log Intensity IN	0.049	0.114	0.016	0.073
	↑	↙	←	↘
0.4 log Intensity OUT	0.067	0.074	0.102	0.048
Zero Intensity IN	0.023	0.006	0.011	0.026
	↓	↗	→	↖
Zero Intensity OUT	0.009	0.006	0.005	0.023
Zero Intensity IN	0.006	0.011	0.009	0.014
	↑	↙	←	↘
Zero Intensity OUT	0.009	0.011	0.010	0.005

* Indicates variances differ significantly at the P = .01 level.

Note: Arrows, within each cell, indicate M.T.S. direction of travel.

Table XII

Results of Homogeneity of Variance Test for a Square Glimulus Form

Series One

Condition	Variance — Meridian 0° - 180°	45° - 225°	90° - 270°	135° - 315°
Full Intensity IN	0.119	0.069	0.013	0.057
(direction)	↑	↗	→	↖
Full Intensity OUT	0.208	0.015	0.054	0.018
Full Intensity IN	0.024	0.016	0.061	0.018
(direction)	↓	↙	←	↘
Full Intensity OUT	0.057	0.062	0.014	0.018
0.4 log Intensity IN	0.040	0.022	0.013	0.036
(direction)	↑	↗	→	↖
0.4 log Intensity OUT	0.036	0.040	0.046	0.017
0.4 log Intensity IN	0.008	0.013	0.025	0.042
(direction)	↓ *	↙	←	↘
0.4 log Intensity OUT	0.055	0.018	0.027	0.008
Zero Intensity IN	0.006	0.008	0.010	0.048
(direction)	↑ *	↗	→	↖
Zero Intensity OUT	0.042	0.040	0.017	0.051
Zero Intensity IN	0.008	0.045	0.023	0.023
(direction)	↓	↙	←	↘
Zero Intensity OUT	0.038	0.012	0.027	0.045

* Indicates variances differ significantly at P = .01 level.

Note: Arrows, within each cell, indicate M.T.S. direction of travel.

Table XIII

Results of Homogeneity of Variance Test for a Triangular Glimulus

Series One

Condition	Variance		
	Meridian		
	0° - 180°	60° - 240°	120° - 300°
Full Intensity IN	↑ 0.994	↗ 0.116	↖ 0.087
Full Intensity OUT	0.626	0.010 *	0.045
Full Intensity IN	↓ 0.013	↙ 0.048	↘ 0.114
Full Intensity OUT	0.013	0.022	0.006 **
0.4 log Intensity IN	↑ 0.618	↗ 0.046	↖ 0.047
0.4 log Intensity OUT	0.039 **	0.049	0.033
0.4 log Intensity IN	↓ 0.065	↙ 0.020	↘ 0.008
0.4 log Intensity OUT	0.072	0.034	0.027
Zero Intensity IN	↑ 0.018	↗ 0.041	↖ 0.040
Zero Intensity OUT	0.027	0.009	0.073
Zero Intensity IN	↓ 0.020	↙ 0.023	↘ 0.049
Zero Intensity OUT	0.140 *	0.048	0.044

* Indicates variances differ significantly at P = .05 level.
** Indicates variances differ significantly at P = .01 level.

Note: Arrows within each cell indicate M.T.S. direction of travel.

An F_{max} test was used to test significance of difference between variances. (Walker and Lev, 1953, p. 192) In order to support hypothesis five the OUT variances would have to exceed the IN variances.

Table XI presents the results of 24 F_{max} tests upon data for the circular glimulus. Of the 24 cells only 10 exhibited larger OUT variances than IN. Only two cells were significant and <u>both</u> were in a direction opposite that expected!

Table XII presents 24 F_{max} tests upon data for the square glimulus. Sixteen of the 24 cells exhibited larger OUT variances than IN. Two cells were found to differ significantly at the $P = .01$ level and both were in the expected direction.

Results for the triangular glimulus are presented in Table XIII. Of the 18 F_{max} tests performed only 3 were in the expected direction. Four cells exhibited statistical significance but only one of these was in the direction expected.

On the basis of the above findings hypothesis five cannot be considered to be supported. The above tables contain a great deal of information concerning response variability and two additional observations must be made: (1) for the three glimulus forms studied, variance tended to be larger under full intensity conditions than under intermediate or zero intensity conditions, and (2) analysis of response variance by meridian did <u>not</u> exhibit any decided trends.

DISCUSSION

The present study investigated several aspects of the glare phenomenon: (1) intensity gradients surrounding a glimulus, (2) the effect of glimulus intensity upon perceived glimulus shape, and (3) the effect of different glimulus forms upon the shape of intensity gradients. Experimental hypotheses were proposed (see pages 21 and 22) concerning the above aspects of glare. Each was tested and appeared to provide a consistent picture of glare, certain glimuli, and certain aspects of impoverishment. Experiment One tested Hypotheses I through 3. Hypothesis 4 was tested in experiment Two. Data from portions of experiment One were used to test Hypothesis 5.

By repeating experiment One in its entirety an indication of the reliability of the data was obtained. A comparison between results from Series One and Two shows very small boundary - edge visual angle differences (see Figures V and VI, VIII and IX, and X and XI, respectively). Referring to Tables II <u>and</u> III the mean difference between boundary and edge for full intensity conditions was under 4 minutes of visual angle and under 2 minutes for the 0.4 log intensity condition. Mean boundary - edge differences for the square and triangular glimuli were even smaller. This consistency appears to illustrate a basic reliability in the data. Response consistency is also illustrated by the extremely small variability of responses shown in Tables XI, XII, and XIII. Being so small, these variances show that S set the M.T.S. in the same position, relative to the perceived edge of the S.G.S. for any given experimental condition.

The trends exhibited in Tables XI, XII, and XIII show that responses are more variable under high intensities than under zero intensity. One might expect this just by "common sense". It is important to note, however, that most Ss remarked that the zero intensity condition was the hardest in terms of judging when to stop the M.T.S. This subjective opinion was <u>not</u> borne out by their actual responses. The apparent difficulty in making critical judgments under zero intensity was probably due to the fact that the mirror's (S.G.S.) boundary produced some diffraction of the M.T.S.'s rays. This diffraction could have made it difficult to tell just when the M.T.S. had completely disappeared or appeared. A further study seems warranted which would analyze different boundary forms and M.T.S. diameters, much as was done in Table X and in Figure XII.

It is hypothesized that response variance will be smaller if the M.T.S. is "covered" or "uncovered" by a curved or straight, rather than by a corner, boundary form. (see Figure XII) Diffractions would be produced by <u>both</u> sides of a corner boundary form as the M.T.S. passed behind the "point" of the corner. M.T.S. direction of travel is portrayed by a dotted line in Figure XII (page 46). In the present study Ss said that they felt the M.T.S. disappeared or appeared faster if it was approaching or leaving a curved or straight boundary form rather than a corner boundary form. This finding provides some foundation, although shaky, for the above hypothesis. It is conceivable that response variance, under these conditions, is related to one's subjective estimate of "speed of disappearance" (or appearance).

Regarding the boundary - edge distances obtained for <u>both</u> intensities studied in experiment One, one would expect that the 0.4 log intensity, being just under one-third the full intensity, would produce a gradient about one-third the distance to the full intensity gradient. Only one case (see Figure VI) exhibited this. The remaining results from experiment One exhibited a 0.4 log intensity gradient that fluctuates widely between the S.G.S. boundary and the full intensity gradient. This suggests that there is a nonlinear relationship between glimulus intensity and boundary - edge distance. Results from experiment Two (see Graph I) further support this view.

Referring to Graph I it is apparent that the data can be characterized by two straight lines labelled "A" and "B". No single straight line could be fitted to the whole range of data. The portion of the curve labelled "A" can be characterized by the following formula:

$$G.E. = S + 8.23 + .88^{I} \qquad (4)$$

The portion labelled "B" by:

$$G.E. = S + 1.31 + .50^{I} \qquad (5)$$

where:	G.E.	=	Glimulus Edge (normal to glimulus' boundary)
	S	=	radius of glimulus (cm.)
	I	=	intensity of glimulus (ft. l.)

Formulae (4) and (5) must be regarded as tentative until more glimulus conditions have been investigated. Each formula provides a means of calculating the approximate distance the edge will extend normal to the glimulus' boundary.

When the crosses in Graph I are fitted by a single curved line the high intensity portion appears to reach an asymptote at approximately 2° 27' visual angle and tends to level off at low glimulus intensities...eventually reaching the glimulus' boundary at zero intensity. If one accepted this kind of analysis one would commit oneself to a position that, "no further increase in glimulus intensity would increase the apparent height (or diameter) of the glimulus". It would seem that, in order to hold this position, one would have to posit some form of "limiting mechanism". If such a "mechanism" exists the writer feels that is probably physiological in nature rather than physical. The question actually becomes, "does the effective size of the retinal impoverishment increase with increased glimulus intensity indefinitely or does it level off at a given intensity?" Since there have been so few glare-related studies that have used truly high photic intensities this question must remain open. On the basis of the present findings it is tentatively predicted that the formulas best describe the phenomenon in question.

In the present experiment S fixated on the center of the S.G.S. If fixation varied the particular retinal mosaic impinged upon by the S.G.S.'s image would change leading to changes in adaptation and thus perceived brightness of both S.G.S. and M.T.S. It was felt that this might account for the fluctuations of the 0.4 log intensity gradient until it was noticed that full intensity gradients should be similarly affected, if not in magnitude then in direction. Assuming a "random" fixation pattern for all viewing conditions in experiment One, i.e., fixation that is stable for each trial but in a slightly different position for different trials, in a random fashion, both intensity gradients should be concentric with the glimulus' boundary. Such was not always the case (see Figures VI and VIII). To explain these findings one would have to assume that fixation position was systematically influenced as a function of glimulus intensity. At the present state of understanding it seems more judicious to assume that some form of "error" was the cause of these non-concentric gradients Figure VI illustrates that the full intensity edge deviates from a perfect circle only at two meridians (0° and 315°). If a perfect circle was superimposed over this gradient the amount of "deviation" (from a perfect circle) would be less than the diameter of the M.T.S. Further experimentation of this type should use a smaller diameter test spot to see if this "deviation" decreases.

When the results from experiment One (see Figures V through XI) are compared with the size and position of the fovea centralis, assuming stable fixation, equal frontal area of all glimulus forms, and equal P.G.S. intensity incident upon the mirror's surface, several interesting things are noticed: (1) the full intensity edge produced by the circular glimulus fell entirely outside of the assumed foveal area while the glimulus' physical boundary was still imaged almost completely within the fovea. The boundary image extended some 6' visual angle directly above (0°) and below (180°) the assumed boundary of the fovea, (2) the full intensity edge for the square glimulus extended outside the foveal area only at the corners by some 9' of visual angle. The image of the physical boundary fell entirely within the foveal area, and (3) the full intensity edge produced by the triangular glimulus fell outside the foveal area only at the corners by some 29' of visual angle. The physical boundary's image also fell outside of the fovea at the corners by some 17' 34.5" visual angle. The glare experienced from each of these situations yields some interesting comparisons.

Those who suggest that glare is due to neural interaction in sub-recepter structures feel that parafoveal stimulation travels to surrounding recepter neurons via fiber and ganglionic layers (see Figure XVIII) and thence to higher "interpretive centers" as if the surrounding receptors had been directly stimulated. This explanation seems valid as far as it goes but it does not provide any explanation of how glare arises when only the fovea is stimulated. It was pointed out in Appendix III that much evidence exists in favor of a 1:1 connective

scheme between cone and optic tract...from the foveal area. This almost precludes any horizontal spreading out...at least at this level of the nervous pathway. The present study found that photic energy falling entirely within the foveal area does spread out beyond the assumed foveal boundary or "rod line" as it has been called. This finding thus tends to support the entoptic stray light explanation of glare.

The form of the glimulus appears to play an integral part in the resultant glare. In case (3) above, for instance, both boundary and edge extended outside of the fovea at the three corners. When Ss were asked if the glare appeared as a perfect equilateral triangle or an uneven or undulating one they remarked that it appeared quite even and "regular". No abrupt discontinuities along any edges were reported. The writer, serving as S, did not experience any perceptible difference between the corners of the triangle and its center in terms of brightness, edge continuity, or spectral characteristics. These data provide further support for the stray light explanation of glare.

Despite the growing number of experimental studies in favor of this theory of glare the author considers the controversy still open. Methodologies tend to be quite different from one another; such differences might contribute to the apparent differences of opinion of researchers.

The present study differs in two ways from the traditional glare study. These are differences in the role played by the retina. The first is a static - dynamic difference and the second is a central - peripheral difference. Regarding the first of these it is obvious that nothing is seen to move in the traditional method. No retinal image sweeps across receptors except those causes by shifts in fixation. In the present method the moving test spot moves across the field of view, first approaching the glimulus and then receeding from it. The second principal difference between these two methods lies in the fact that the comparison area, used in the traditional method as one-half of the brightness-matching area, acts as a test spot but lies on or very near the fovea. The moving test spot, used in the present study, begins in the periphery and approaches the fovea. Previous studies have indicated that the parafoveal areas (stimulated in this study) are more sensitive to movement of a photic image than are foveal areas (Brown, 1931) (Stevens, 1962, p. 895) and it is common knowledge that rods are generally more sensitive to motion than are cones. If we compare the two "test spots" on the basis simple visibility it seems justified to assume that the moving "peripheral" test spot, i.e., the M.T.S., is likely to be more visible than is the stationary comparison area, at least for the present kind of experimentation. Thus the M.T.S. should be a more precise indicator of the occurrance of the present critical visual task. In this case the critical task was that of stopping the M.T.S. when it disappeared (or appeared).

When the effects of a glimulus are seen in terms of retinal adaptation the present findings are similar to those obtained by Stiles and Crawford (1937). In their study of glimulus effects on parafoveal vision they derived the term "liminal brightness increment" or l.b.i. for short. The l.b.i. was defined as the smallest difference in brightness between a given test spot and its immediate surround such that the test spot can just be detected, the test spot brightness being greater than the surround brightness. One aspect of their study involved l.b.i. measurement for a source of constant intensity and angle θ but placed in different meridians. θ was held constant at 5°. Their test spot was a small (0° 4' 19") point of light exposed for 0.05 seconds every 3 seconds. No systematic change in l.b.i. was found for different meridians. When the glimulus' image fell on the fovea or the blind spot the l.b.i. was no different from values obtained for any other point at an equal distance from the test spot. In the present study (experiment One) θ was approximately equal to 1° for the circular glimulus. The "roughly" concentric gradients obtained showed that the M.T.S. brightness was fairly constant at this value of θ over all meridians studied.

If portions of this research were to be repeated several alterations in equipment and design would be suggested. First, in terms of ease of data collection a reversible motor on the track would make it possible to alternate direction of M.T.S. movement every trial. It is felt that results would not be greatly altered by this change in equipment. Also, a tape recorder was used during portions of the present experiment. This method of data collection required a great deal of

analysis time; it did help fill in data originally missed such as S's verbalizations, etc. A digital, direct print-out of the M.T.S. position (on the track) would probably be the best answer to data collection. The writer would recommend a longer time interval between trials. At least a one minute interval would help S's retinal adaptation become stabilized.

Regarding future experimental design, another study should investigate more meridians (every 5 or 10 degrees) on one glimulus form. In addition to this, another study should analyze the effect of boundary form upon perceived boundary - edge distance...much as was done in the present research (see Table X and Figure XII). Corners ranging from about 10° to straight (180°), in 10° increments, would need to be studied in order to better clarify the effects of diffraction produced by the glimulus' boundary. A further study should determine the effects of M.T.S. diameter on boundary - edge distance. The present M.T.S. diameter was chosen on a practical (construction) basis. It was close to a point source of photic radiation.

It was felt that repeating experiment One <u>in toto</u> was far better than doubling the number of trials per condition. Possible diurnal effects are minimized in this way. Repeating the entire experiment also provided a means of assessing any learning effects. It is also suggested that using a few highly trained Ss is better, in terms of reducing response variance, than using many untrained Ss. Of course, the sample tested should, in some cases, reflect the universe upon which the particular results are to be applied.

For viewing durations longer than about 10 seconds the glimulus' intensity can become critical as far as retinal damage is concerned. Further work in this area should be guided by basic principles of safety layed down in previous studies (Severin, et al., 1962) (Severin, 1963). Subjective discomfort and pain are not always an adequate indication of retinal damage (e.g., ultraviolet radiation) thus preliminary research on non-human eyes, in the wavelengths and intensities of interest, is essential. Guth's work (1951), on the borderline between comfort and discomfort (BCD), provides additional information for the researcher. Intense glimulus conditions can be dangerous. Caution should be exercised in all phases of experimentation; not only during data collection but also during the important preliminary "set-up" stages.

The following pages discuss some of the possible applications for the present findings. Intense glimuli exist in almost everyone's lives; the sun's radiation reaches everyone, electricity has brought illumination to most parts of the world, photographic flash-bulbs are common in the modern world, many other examples exist. Many glimuli are potentially dangerous, leading to some sort of bodily injury or impairment. In some cases intense photic flashes leave one temporarily blinded and often unable to react appropriately to environmental stimuli. The point of the matter is that if some means of filtering this intense photic energy is available the potential danger is often reduced.

Within the past several years man has progressively persuaded himself to enter space. Many problems associated with man-in-space have been uncovered and appear to be solvable but others remain hidden. The visual problems of man-in-space seem to lie somewhere between these extremes. As will become apparent, new approaches to optical filtering are needed. The present research has relevance to some of these problems and attempts to provide future developmental research with more than a subjective basis.

In space the sun will consitute an extremely intense glimulus having a luminance over 12,000 lumen per square feet (Eisner, 1962) (Jones, 1960, p. 4). If the sun reflects off a highly specular surface that surface will also become a glimulus. Space is dark, except for photic energy from the sun and stars, and reflections of the sun's radiation from the earth, moon, and planets. Man in space will thus be dark adapted to a very complete degree unless otherwise protected; under these conditions the glare experience is likely to be severe. Another visual aspect of space that is often unrecognized is that, because of no atmosphere, man will not see the sun unless he looks in a direction that allows the sun's rays to enter his eyes. A little "angular tolerance" beyond this direction of fixation might occur due to reflections of the sun's rays from his nose, cheek, etc. This means that he will have no advance warning of the sun's appearance. This unexpected nature of the sun constitutes a potentially dangerous situation. The best solution to all of these problems so far has been to provide different optical filters across the full expanse of the space vehicle's window. This has been a stop-gap solution. The specific tasks of man in space must be determined before any adequate solution can be arrived at.

It is generally agreed that two tasks, in particular, are going to be critical to the majority of future space flights. They are navigation and rendezvous in space. It is the first of these that is to be discussed. The second rests upon similar considerations and is left for a future publication.

One means of locating oneself in space (navigation) is by comparing the angular positions of three objects simultaneously. This method is called triangulation and is by no means the only or the best method. It is one method that is under present consideration for future space operations. Usually the observer's space vehicle is one object, the earth or some point on its surface is the second, and some star or star pattern (or moon landmark) is the third. Under solar illumination the observer cannot see the stars near the sun due to the intense retinal impoverishment. The sun's intensity is also related to the albedo of the earth which is the percentage of solar illumination reflected back into space. This illumination often makes it difficult to find specific land positions. To help alleviate these visual problems the National Aeronautics and Space Administration's Project Mercury used a window that transmitted from about 35 to 50 per cent in the visual range when observations were perpendicular to the window and from 15 to 25 per cent for a 60° viewing angle; this was the normal viewing

angle (Jones, 1960, p. 22) An anti-reflectant as well as phase polarization was used as filters and were manufactured across the entire Vycor glass window. Thus the window in the Mercury capsule occluded many of the less intense but potentially useful background stars. The present dissertation findings have relevance to this particular problem.

In this study different glimulus forms were used to <u>simulate</u> different space vehicle forms and the round sun. The M.T.S. can be thought of as representing a single star behind the "simulated space vehicle". Its movement (M.T.S.) can be translated into observer movement since, apparently, the two are equivalent situations. The question can then be asked, can the glimulus' boundary be determined under intense glimulus conditions? Or, put in other words, can the boundary of a space object be used as an aid to navigational "fixes" under intense glimulus conditions, using a star as a reference point?

When applied to this question the present findings indicated that, depending upon glimulus intensity and form, it will be relatively inaccurate to use a glimulus boundary as a navigational aid. Astronomical distances make very slight angular deviations from the line of sight amount to <u>very</u> gross distances. An angular variation, due to one of the present glimulus conditions, could amount to literally hundreds of miles error. What is needed then is one of two things: (1) a filtering system that eliminates most photic energy from the glimulus' form alone leaving the periphery unfiltered (or filtered to an intermediate degree), or (2) correction factors for given glimulus intensities, forms, and sizes in space. These correction factors would be used to estimate the actual glimulus boundary from the perceived edge. Since the first alternative has not yet been built, but is in design stages (Rogers, 1960) (Rogers, 1962), it remains but to compute estimated boundary - edge angles for various glimulus conditions and extend the data of the present experiment. Such work is now underway.

Regarding the first alternative above, the writer feels that it promises to be the best answer to glare-in-space as well as many glare problems on earth. No new technological break-throughs are needed to fully develop the "electro-optical light shutter" as it has been called.

Although a description of this device is left for the reader to research, several comments should be made at this time. To adapt the electro-optical light shutter to human visual needs some form of "head position sensor" would be needed. This "modulation" sensor would provide the electrical potential needed to drive the molecular activity in a shape-selective fashion. Thus unwanted portions of the visual field would be filtered according to specific shape and intensity parameters. Since the filter acts at a molecular speed no danger of solar (or nuclear) flash blindness could occur from the unexpected appearance of intense photic energy. Such a device would have a multitude of uses.

Another application for the present findings is that of identification of unknown objects in space. The present study has shown that perceived shape does not always correspond to the physical form of the glimulus. If one had to approach and visually identify some unknown object under intense glimulus conditions the task might be quite difficult as well as dangerous. It must be remembered that the sun's intensity is some four times that of the photic source used in experiment Two. If the curve presented in Figure XIII is asymptotic then there appears to be a limit to the change in perceived shape and size of the glimulus as a function of intensity. If, on the other hand, the upper portion of the curve is best defined by formula (5) one would not know exactly what shape to expect! Further work with higher intensities under extended viewing durations is needed.

It is predicted that glare-related research will again come into vogue so to speak. New experimental techniques and devices will probably be developed in order to adequately study the phenomenon called glare. It remains to be seen whether or not researchers will tie themselves to the next to useless vocabulary of past decades. Will new theoretical approaches be forthcoming? It is hoped that future glare-related research will lead, eventually, to a full understanding of glare, related glimulus conditions, and retinal impoverishment.

BIBLIOGRAPHY

Abribat, M., (1935), Sur le rendu photographique des luminosities. Reun. Inst. Opt., 6, 3rd. symposium, p. 3.

Adler, F.H., (1950), Physiology of the Eye - Clinical Applications. New York, The C.V. Mosby Co.

Allport, F.H., (1955), Theories of Perception and the Concept of Structure. New York, John Wiley & Sons, Inc.

Anderson, E.E., & Weymouth, F.W., (1923), Visual perception and the retinal mosaic. I. retinal mean local sign - an explanation of the fineness of binocular perception. Amer. J. Physiol., 64, 561.

Anon, (1958), Van Nostrands Scientific Encyclopedia. New York, D. Van Nostrand Co., Inc.

Aubert, H., (1886), Die Bewegungsempfindung. Arch. ges. Physiol., 39, 347-370.

Bartley, S.H., (1935), The comparative distribution of light in the stimulus on the retina. J. comp. Psychol., 19,149-154.

__________, (1941), Vision: A Study of its Basis. New York, D. Van Nostrand Co., Inc.

__________, (1958), Principles of Perception. New York, Harper & Brothers.

__________, (1962), The psychophysiology of vision. (Chpt. 24 in S.S. Stevens, Handbook of Experimental Psychology.) New York, John Wiley & Sons, Inc.

__________, & Fry, G.A., (1934), An indirect method for measuring stray light within the human eye. J.O.S.A., 24,342-347.

__________, & ________, (1935), Relation of entoptic stray light to flicker and the perception of movement. Proc. Soc. exp. Biol. & Med., 32, 1180-1181.

__________, & Seibel, J.L., (1954), A further study of entoptic stray light. J. Psychol., 38,313-319.

Bell, Troland, L.T., & Verhoeff, (1922), Report of the subcommittee on glare of the research committee. Illum. Engr. Soc., 17,743.

Bietèl, R.J., (1934), Spatial summation of subliminal stimuli in the retina of the human eye. J. gen. Psychol., 10,311-327.

Bourdon, B., (1902), La Perception Visuell de l' espace. Librairie C. Reinwald, Schleicher Freres, ed., Paris.

Boynton, R.M., (1953), Stray light in the human electroretinogram. J.O.S.A., 43,442-449.

__________, Bush, W.R., & Enoch, J.M., (1954), Rapid changes in foveal sensitivity resulting from direct and indirect adapting stimuli. J.O.S.A., 44,56-60.

__________, Enoch, J.M., & Bush, W.R., (1954), Physical measures of stray light in excised eyes. J.O.S.A., 44,879-886.

Brown, J.F., (1931), The threshold for visual movement. Psychol. Forsch., 14,249-268.

Cajal, Ramon y., (1894), Die Retina der Wirbelthiere: Untersuchungen mit der Golgi - Cajal Chromsilbermethode und der Ehrlich'schen Methyl-enblaufarbung. (Trans. by R. Greeff), Wiesbaden, Bergmann.

Crampton, G.H., (1956), Effect of a glaring source on the human electroretinogram. J. comp. Physiol. Psychol., 49,534-538.

Crawford, B.H., (1936), Integration of the glare effects from a number of sources. Proc. Physical Soc. (London), 121,35.

______________, (1947), Visual adaptation in relation to brief conditioning stimuli. Proc. Roy. Soc. (London), ser. B. 134, 283-302.

______________, (1935), J. Sci. Instrumentation. 12,177.

Crouch, C.L., (1955), Review of visual research as related to illuminating engineering. C.I.E. Proceedings, Zurich session Meeting 1.4.1., Vol. I, 5, (from: 13th. session of the International Commission on Illumination).

De Mott, D.W., & Boynton, R.M., (1958), Retinal distribution and entoptic stray light. J.O.S.A., 48,13-21.

Di Francia, S.M., & Ronchi, L., (1952), Directional scattering of light by the human retina. J.O.S.A., 42,782.

Duke-Elder, W.S., (1942), Textbook of Ophthalmology. St. Louis, Mo., The C.V. Mosby Co., vol. I.

Eisner, L., (1962), (personal communication), Technical Planning Staff, Barnes Engineering Co., Stamford, Conn.

Fincham, E.F., (1925), Photomicrographs of sections of the human eye. Trans. Opt. Soc. (London), 26,198.

Fritsch, G., (1908), Euber Bau und Bedeutung der Area Centralis des Menschen. Reiner, Berlin.

Fry, G.A., (1954), A re-evaluation of the scattering theory of glare. Illum. Engr., 49,98-102.

___________, & Alpern, M., (1953a), The effect of foveal vision produced by a spot of light on the sclera near the margin of the retina. J.O.S.A., 43,187-188.

___________, & ___________, (1953b), The effect of a peripheral glare source upon the apparent brightness of an object. J.O.S.A., 43,189-195.

___________, & ___________, (1955), Effect of a peripheral glare source upon the apparent brightness of an object. Illum. Engr., 50,31-38.

___________, & Bartley, S.H., (1935), The relation of stray light in the eye to the retinal action potential. Amer. J. Physiol., 3, 335-340.

Granit, R., (1930), Comparative studies on the peripheral and central retina: I. Amer. J. Physiol., 94,41-50.

Grim, K., (1910), Über die Genaugkeit der Wahrnemung und Ausfuhrung von Augenbewegungen. Z. f. Sinnesphysiol., 45,9-26.

Guth, S.K., (1951), Comfort brightness relationships for critical and causal seeing. Illum. Engr. 46,65-75.

Guyton, A.C., (1961), Textbook of Medical Physiology. Philadelphia, W.B. Saunders, Co.

Haines, R.F., (1963), A study of intense glimuli and boundary perception. (unpubl. study, Michigan State University).

Hanes, R.M., (1951), Suprathreshold area brightness relationships. J.O.S.A., 41,28.

Hartridge, H., (1950), Recent Advances in the Physiology of Vision. Philadelphia, The Blakiston Co.

Hecht, S., (1922), The nature of foveal dark adaptation. J. gen. Physiol., 4, 113-139.

Helmholtze, H., (1924), Helmholtz's Treatise on Physiological Optics. Vol. I., (ed. J.P. C. Southall), Menasha, Wisconsin, The Optical Soc. Amer.

Henle, J., (1866), Handbuch der sistematischen Anatomie des Menschen. Braunschweig, F. Vieweg U. Sohn, II, 636-670.

Holladay, L.L., (1926), The fundamentals of glare and visibility. J.O.S.A., 12,271-319.

____________, (1927), Action of a light-source in the field of view in lowering visibility. J.O.S.A., 14,1-15.

Illuminating Engineering Society, (1924), Transactions of the I.E.S., 19,788-789.

________________________, (1947), IES Lighting Handbook. Ist. ed., New York.

Jones, E.R., (1960), Prediction of man's vision in and from the Mercury Capsule. (paper presented at the 31st. annual meeting of the Aerospace Med. Assoc., May 9, 1960, Miami Beach, Florida.

Judd, D.B., (1950), Colorimetry. Nat. Bureau of Standards Circular No. 478, Wash., D.C., p. 2.

Karn, H.W., (1936), Area and the intensity - time relationships in the fovea. J. gen. Psychol., 14,360-369.

Kolliker, A. von., (1854), Mikroskopische Anatomie oder Gewebelehre des Menschen. Leipzig, Germany.

______________, (1902), Handbuch der Gewebelehre des Menschen. (Sechste umgearbeitete Auflage.), Dritter von V. v. Ebener, Leipzig, Engelmann, p. 976.

Krause, C., (1842), Handbuch der menschlichen Anatomie. Hannover, I, 2.5, 535.

Kris, E.C., (1958), A technique for electrically recording eye position. WADC Tech. Rep. No. 58-660.

Kruger, L., & Boname, J.R., (1955), A retinal excitation gradient in a uniform area of stimulation. J. gen. Psychol., 49, 220-224.

Le Grand, Y., (1937), Recherches sur la Diffusion de la Lumiere dans l'Oeil Humain. Review d' Optics, 16,201, 241.

__________, (1957), Light, Colour, and Vision. New York, John Wiley & Sons, Inc.

Luckiesh, M., & Guth, S.K., (1949), Brightness in visual field at borderline between comfort and discomfort. Illum. Engr., 44,650.

__________, & Holladay, L.L., (1925), Glare and visibility. Illum. Engr., 20,221-252.

__________, Taylor, A.H., & Holladay, L.L., (1925), Relative glare of moderately colored lights. J.O.S.A., 11,311.

Mackavey, W.R., (1959), A further investigation of the double flash phenomenon. Ph. D. dissertation, Dept. Psychol., Michigan State University.

Moon, P., & Spencer, D.E., (1943), The specification of foveal adaptation. J.O.S.A., 33,444.

Muller, H., (1852), Bemerkungen uber den Bau und die Funktion der Retina. Verhandl. der Wurzburger, Physik. Med. Gesells., S. 216; III. 336; IV, 96.

Oatman, E.L., (1913), Diagnostics of the Fundus Oculi. New York, The Southworth Co.

O'Brien, B., & Miller, N.D., (1953), A study of the mechanism of visual acuity in the central retina. WADC Tech. Rep. No. 53-198.

Orbeli, L.A., (1934), On interaction between macula and periphery of the retina. Physiol. J. of the U.S.S.R., 17,1105, (in Russian).

Osterberg, G., (1935), Topology of the Layer of Rods and Cones in the Human Retina. Nyt Nordisk Forlag, Copenhagen, Arnold Busch.

Perera, C.A., (1949), May's Manual of the Diseases of the Eye. 20th. ed., Baltimore, Maryland, Williams & Wilkins Co.

Pieron, H., (1929), De la summation spatiale des impressions lumineuses au niveau de la fovea. Ann. Psychol., 30,87-105.

Pirenne, M.H., (1948), Vision and the Eye. London, Chapman & Hall, Ltd.

Pitt, F.H.G., (1945), The nature of normal trichromatic and dichromatic vision. Proc. Roy. Soc., (London), ser. B., 132, 101.

Polyak, S., (1941), The Retina. 1st. ed., Chicago, The Univ. of Chicago Press.

Roaf, H.E., (1932), The influence of coloured surrounds and coloured backgrounds on visual thresholds. Proc. Roy. Soc., (London), ser. B., 110,448-482.

Rogers, J.G., (1960), Electro-optical light shutter. U.S.A. Patent No. 2,960,914, November 22, 1960.

____________, (1962), Proposal for the research and development of multilayer light modulation devices. (Assigned to the Hughes Aircraft Co.), mimeographed sheets from author.

Schouten, J.F., & Ornstein, L.S., (1939), Measurement on direct and indirect adaptation by means of a binocular method. J.O.S.A., 29,168-182.

Severin, S.L., Newton, N.L., & Culver, J.F., (1962), A study of photostress and flash blindness. Sch. Aviat. Med. Tech. Rep. No. 62-144. (Dec. 1962).

______________, Adler, A.V., Newton, N.L., & Culver, J.F., (1963), Photostress and flash blindness in aerospace operations. Sch. Aviat. Med. Tech. Rep. No. 63-67. (Sept., 1963).

Schultze, M., (1866), Zur anatomie und physiologie der retina. Arch. Mikr. Anatomie, 2,175-286.

Southall, P.C., (1961), Introduction to Physiological Optics. New York, Dover Publ. Co., Inc.

Stevens, S.S., (1962), Handbook of Experimental Psychology. New York, John Wiley & Sons, Inc.

Stiles, W.S., (1928), Recent measurements on the effect of glare on the brightness difference threshold. Proc. International Committee on Illumination. Saranac Inn, New York, Vol. 7.

______________, (1928), The effect of glare on the brightness difference threshold. Proc. Roy. Soc., (London), ser. B., 104,322-351.

______________, (1929), The scattering theory of the effect of glare upon the brightness difference threshold. Proc. Roy. Soc., (London), ser. B., 105,131-146.

______________, (1949), The luminous efficiency of monochromatic rays entering the eye pupil at different points and a new colour effect. Proc. Roy. Soc., (London), ser. B., 123,90-118.

______________, & Crawford, B.H., (1933a), The luminous efficiency of rays entering the eye pupil at different points. Proc. Roy. Soc., (London), ser. B., 112,428-450.

______________, & ______________, (1933b), The liminal brightness increment as a function of wavelength for different conditions of the foveal and parafoveal retina. Proc. Roy. Soc., (London), ser. B., 113,496-530.

______________, & ______________, (1934), The liminal brightness increment for white light for different conditions of the foveal and parafoveal retina. Proc. Roy. Soc., (London), ser. B., 116,55-102.

______________, & ______________, (1937), The effect of a glaring light source on extra-foveal vision. Proc. Roy. Soc., (London), ser. B., 122,255-280.

Vintschgav, M. di., (1853), Richerche sulla struttura microscopica della retina dell'uomo degli animali vertegrati e dei cefalopodi. Sitzungsber d. K. Akad. Wiss., Wien, Mathem. Naturwiss. Gl, Vol. II, 943.

Walker, H.M., & Lev, J., (1953), Statistical Inference, New York, Henry Holt & Co.

Woodworth, R.S., & Schlosberg, H., (1958), Experimental Psychology. New York, Henry Holt & Co.

Wright, W.D., (1934), The measurement and analysis of colour adaptation phenomena. Proc. Roy. Soc., (London), ser. B., 115,49-87.

Wulfeck, J.W., Weisz, A., & Raben, M.W., (1958), Vision in Military Aviation. WADC Tech. Rep. No. 58-399. (Nov., 1958).

APPENDICES

APPENDIX I

Types of Glare

During the last few decades researchers have originated many words to describe the glare experience. In some cases the words describe the glimulus conditions rather than the experience; in other cases the impoverishment is emphasized. In most cases the various "types of glare" refer to some investigator's personal experience under given glimulus conditions. In order to help clarify this array of terminology the present appendix presents a discussion of various types of glare and associated glimulus.

It is generally agreed that Bell, Troland, and Verhoeff (1922) first differentiated glare into different forms. Their classic experiment distinguished the following three types of glare: (1) veiling glare, (2) dazzling glare, and (3) blinding or scotomatic glare.

Veiling glare is typified by fogging of a photographic plate or by "light uniformly superimposed on the retinal image which reduces contrasts and therefore visibility. This is typically seen in reading under the open sky." (Ibid.) In reports by Holladay (1926), Stiles (1928a) (1928b) (1929) (1949), and Stiles and Crawford (1933) (1934) (1937) veiling glare is consistently referred to in the following way, "it was as if the glaring source spread over the test field a luminous veil." Fry and Alpern (1955) point out that veiling glare is similar to a washing-out effect. Crouch (1955) explains that, "veiling reflections in glossy or semi-glossy tasks overlie the detail to be seen and reduce visibility." Luckiesh and Holladay (1925) suggest that it is due to a "diffusion of retinal processes."

The second type of glare, commonly called dazzling glare, has been defined by Duke-Elder (1942, p. 939) as, "adventitious light scattered in the ocular media so as not to form part of the retinal image...It is the most common type." The photic source used by Bell, Troland, and Verhoeff to obtain dazzle glare produced an intensity of 56.6 candles per square inch (equivalent to 110 ml when shown into S's eye through a small hole). They used an acuity test of a black "E" on a white background. It became difficult to see when the intensity was raised to 15,000 candles within a 10° circle and surrounded by a background intensity of 6.5 foot candles.

Both veiling and dazzling glare are actually forms of unwanted photic flux within the eye which is not a part of the target. Both are produced by stray illumination within the eye.

Blinding or scotomatic glare is the third type of glare proposed by Bell, Troland, and Verhoeff. It was claimed that this form of glare, "puts the retina temporarily out of business by exhaustion of its active material". Its effects typically disappear within several minutes. Both Duke-Elder (1942) and Luckiesh and Holladay (1925) believe that blinding glare is the "highest type of glare" and is due to a very intense glimulus which reduces, for some time, the retina's ability to respond normally to light. Graph II presents blinding brightness as a function of visual angle and background brightness ranging from 5 to 60 thousand ml as obtained by Holladay (1926). This classic study by Holladay was entitled "the fundamentals of glare and visibility". It studied glare and visibility chiefly by the method of least perceptible contrasts (brightness). It is interesting to note that the curves portrayed in Graph II illustrate that as background brightness increases the diameter of the test spot must also be increased to be just visible from the background at any given level of adaptation. Curve F = 1,000 represents an adaptation level of 929 lumen per square feet while curve $F = {}^{1}/_{10}$ represents an adaptation level of 0.092 lumen per square foot. It is apparent that the higher levels of adaptation do not require as rapid a change in visual angle (apparent size) of the test spot to be just visible as do lower adaptation levels.

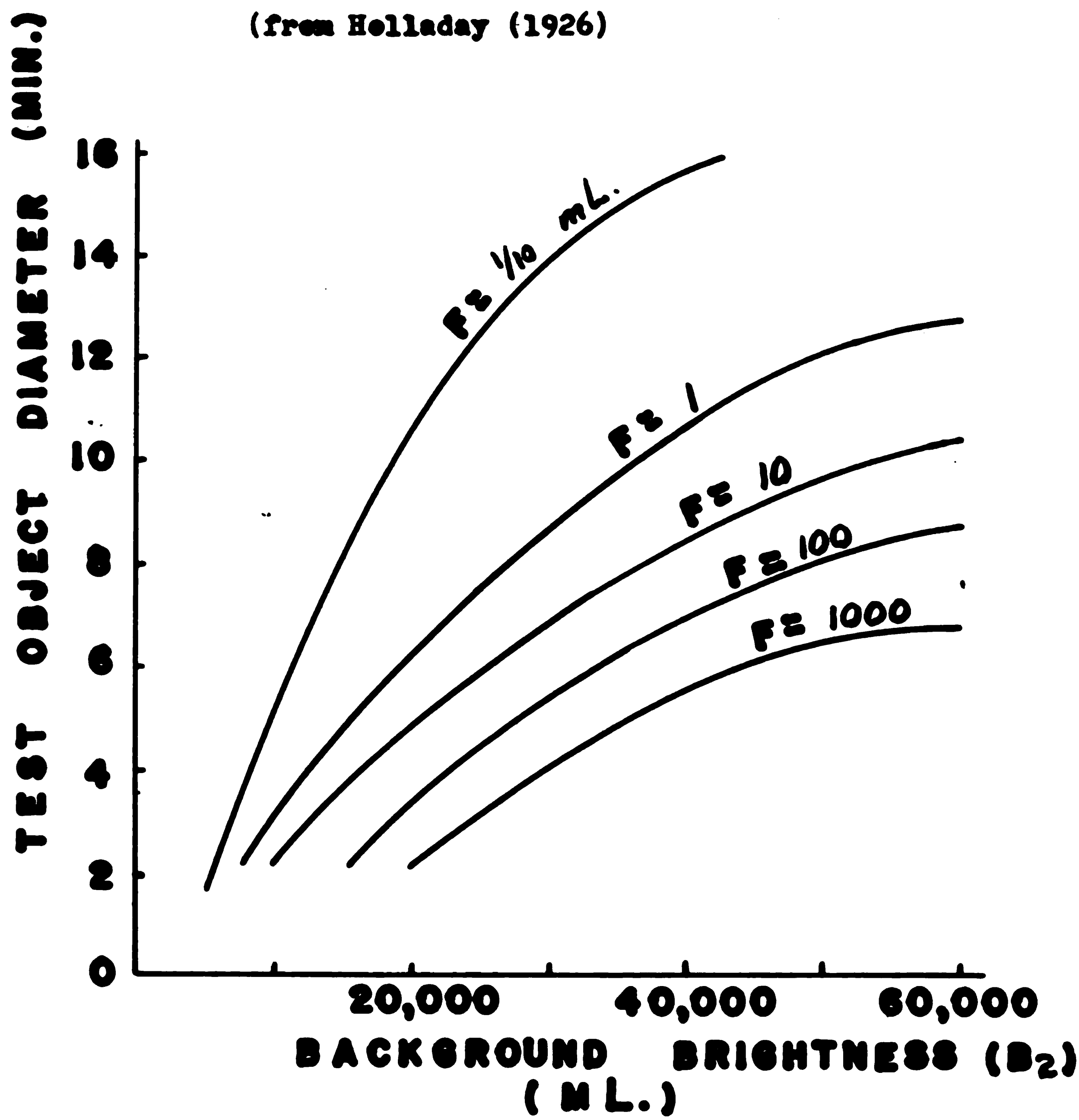
Indeed, it seems that because of the scarcity of research using high photic intensities, the difficulty in adequately describing the various phenomenon, and the lack of inter-observer validation these names for different forms of glare are of little actual value. Terminology used in the present report attempts to clarify this problem.

The IES Lighting Handbook (1947) discusses further forms of glare. <u>Disability glare</u>, it points out, has been found

Graph II

Blinding Brightness as a Function of Visual Angle and Background Brightness

(from Holladay (1926)



acceptable as a criterion for judging various glare phenomena. This kind of glare reduces contrast sensitivity or the contrast between a visual object and its background by increasing the observer's adaptation level. The same effect is observed if a veiling luminance is superimposed on both object and background. Both uniform and nonuniform field brightnesses are discussed (Ibid., pp. 2-18 to 2-19).

This source (Ibid.) also points out that discomfort has also been used as a criteria for judging certain glare phenomena. Discomfort is defined as, "the sensation experienced by an observer when brightness relationships in the field of view cause discomfort but do not necessarily interfere with seeing." (Ibid., p. 2-19). The above definition is obviously of little value to the researcher. Because a standardized procedure for evaluating this effect is lacking experimentation lacks direction, following one or more of five different theories. One such theory called the shock concept provides an empirical formula for determining the maximum brightness of a glimilus which may be viewed suddenly without discomfort.

$$B_g = \frac{K \times B_a^{0.3}}{W^{0.25}} \quad (6)$$

where: B_g = Maximum comfortable brightness of a potential glimulus (ft. L.)

K = 75.4 (Sometimes called the index of comfort)

B_a = Initial brightness level to which the observer was adapted immediately prior to encountering the potential glimulus (ft. L.)

w = Solid angle subtended by the potential glimulus assumed to be circular and centered on the optic axis (steradians)

The other theories will not be discussed here. Two remaining types of glare are discussed in the IES Lighting Handbook; direct and reflected glare. These catagories obvieusly refer to the glimulus rather than to the glare itself.

APPENDIX II

Theories of Glare

In almost every study dealing with glare there is at least implicit support for one of two theoretical explanations, i.e., the neural interaction theory and the entoptic stray light theory. Other explanations of glare have been proposed but only these two have gained consistent support. Each is discussed below.

Neural Interaction Theory

The neural interaction theory was first formally proposed by Schouten and Ornstein (1939). Their experiments showed that a glimulus, placed in the periphery of the field of view of one eye, decreased the apparent brightness of a foveally fixated test object when it was compared with a similar spot seen by the opposite eye. They felt that a physiological effect was initiated by the glimulus and was transmitted to the fovea from surrounding retina. That is to say, receptor impulses originating in parafoveal rods and cones passed into the "pure" cone area.

On the basis of known anatomical structure and physiological activity one can find many possible neural responses to a glimulus. Such receptor impulses could spread horizontally to neighboring retinal areas to be inhibited, facilitated, or possibly even delayed. To quote a previous investigator (Mackavey, 1959, p. 36), "The myriad neural interconnections which are known to exist within the retina form a tempting deus ex machina for the worker in vision. Although it may not be possible to predict the results of a given experiment based upon a knowledge of this structure, it may be possible to conservatively conclude that experimental results are consistent with such knowledge."

There is a certain amount of evidence behind the belief that separate cones within the fovea do interact with one another. (Bietel, 1934) (Granit, 1930) (Karn, 1936) (Kolliker, 1902). Studies by Ramon y Cajal (1894) have provided anatomical support for this line of reasoning. Beitel (1934) found a definite interaction between spatially separated subliminally stimulated areas in the fovea. He explains that (Ibid., p. 322), "The decrease in threshold intensity with a decrease in separation of stimuli is most easily interpreted as being due to an increased lateral summation which arises with an increased proximity of converging excitatory paths."

As is evident from findings presented in Appendix III there appears to be a 1:1 connection between cones and ganglion cells within the central fovea, however, amacrines and some horizontal cells have been demonstrated. (Ramon y Cajal,

1894) (Kelliker, 1902) With the wealth of information concerning the fovea and subretinal structure it is difficult to find evidence decidedly in favor of one view or the other.

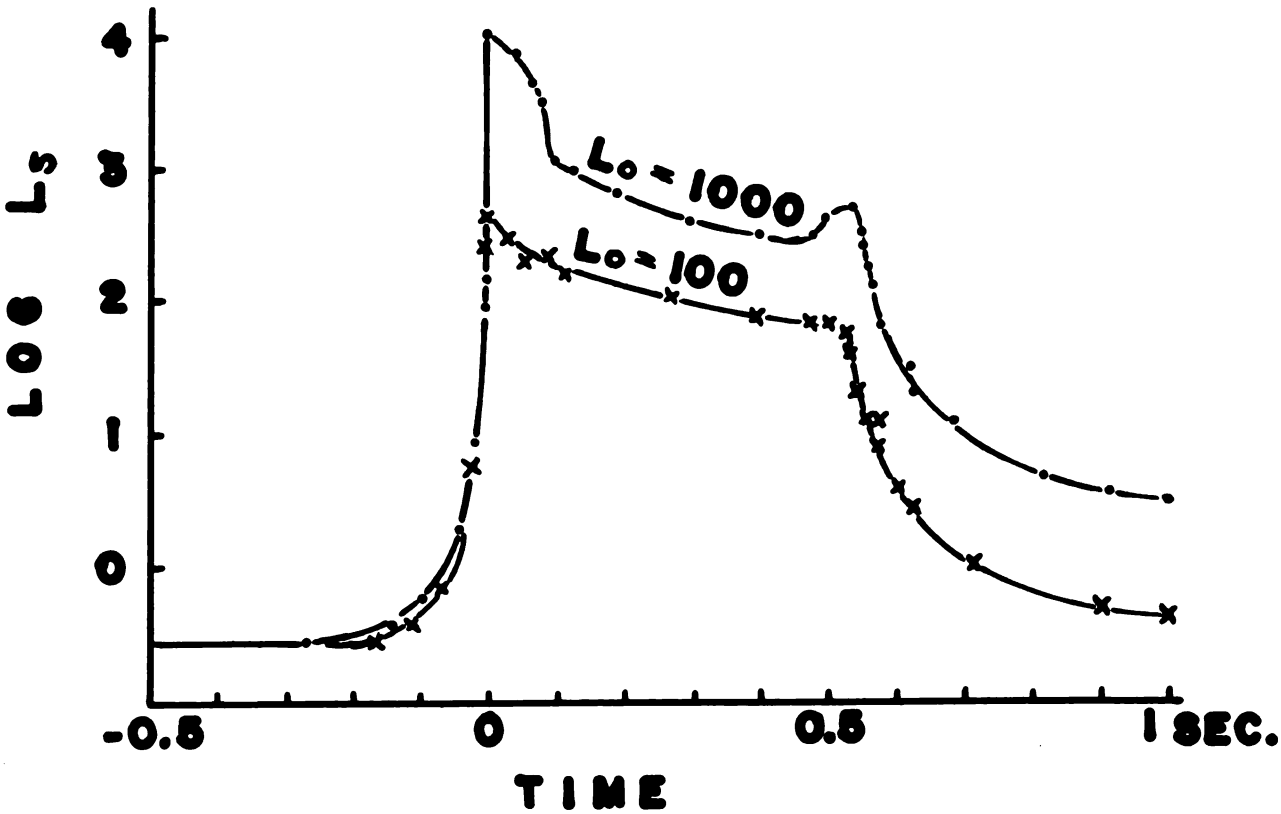
There are psychephysical experiments that appear to support a neural interaction point of view. Many studies (Hanes, 1951) (Luckiesh and Holladay, 1925) (Stiles, 1928b) (Stiles and Crawford, 1937) have found that apparent brightness tends to increase with an increase in the retinal area stimulated (and intensity held constant). Neural interaction provides a ready explanation. Le Grand (1957) stimulated the retina in two separate locations. He interpreted his findings as indicating "interactions" which sometimes reinforce, but more often take the form of inhibitions.

Crawford (1947) performed a study to determine the absolute threshold at the fovea (test spot diameter = 30' visual angle) before, during, and after it was surrounded by various luminances of 12° diameter. His findings are presented in Graph III. The fovea's absolute threshold (L_s) begins to rise about 200 msec. before the appearance of the surround luminance (L_o). Immediately after the surround luminance was turned off (see point +0.5 seconds on abcissa) the threshold fell, simply on account of the disappearance of the retinal inhibition. This effect has also been noted by Boynton, Bush, and Enoch (1954). Le Grand (1957) explains this rise in foveal threshold before the onset of surround luminance as being due to the fact that the "latent" interval for (L_o) is less than it is for (L_s).

The neural interaction theory is based upon the premise that some form of horizontal connections between fovea and

Graph III

Absolute Foveal Threshold as a Function of Surround Luminance (after Crawford (1947)



parafovea cause retinal impoverishment that is described as a halo or a veiling luminance surrounding the glimulus. The assumption is made that the glimulus ray retains its shape, as determined by the form of the distal target, all the way to the retina <u>and</u> <u>then</u> spreads out in sub-retinal structures. This view is physiologically, rather than physically, oriented. Evidence supporting this theory must speak for itself regarding its applicability to glimulus conditions.

Entoptic Stray Light Theory

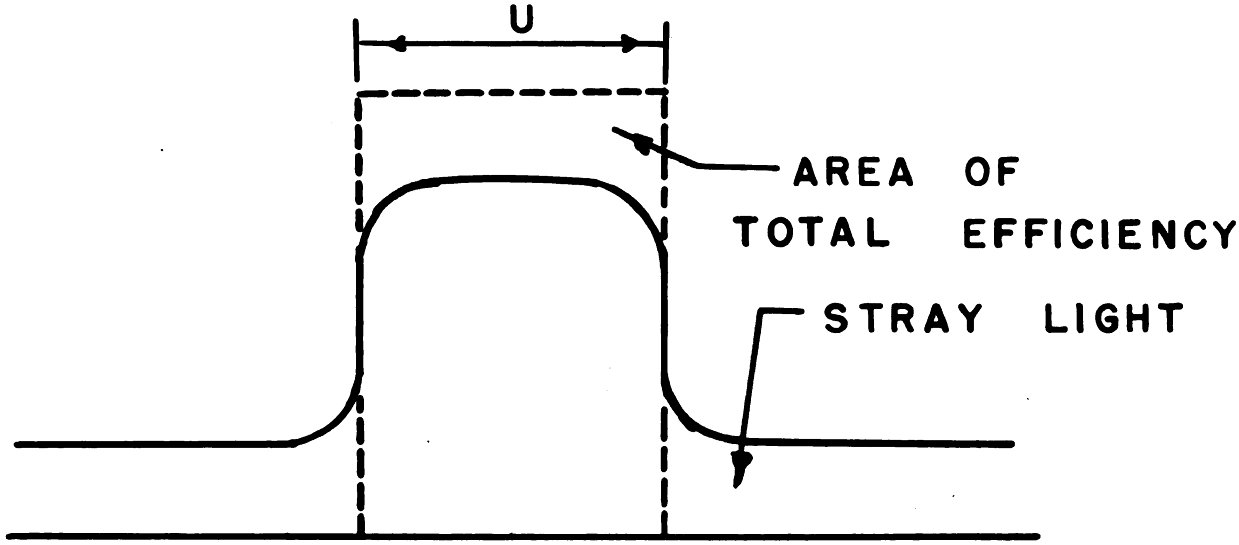
Even after a brief review of glare-related research one notices that the majority of evidence is in favor of the second of the two theories, namely, the entoptic stray light theory. In its simplest form the theory holds that glare is the direct result of scattering of incoming photic energy within the various media of the eye. Specifically, scatter means the change in direction of particles or photons owing to collision with other particles or systems due to the anisotropy of the transmitting medium (D. Van Nostrands Scientific Encyclopedia, 1958, p. 1460). For wavelengths much shorter than the radius of the particles causing the scattering, the scattered energy is nearly independent of the wavelength. For wavelengths much longer than the radius of the particles, the scattered energy falls off as the inverse fourth power of the wavelength and is called Rayleigh scattering. This fact will be touched upon later.

It is known that a glimulus produces a tapered distribution of photic radiation upon the retina. This concept is illustrated in Figure XIII (after Bartley, 1958, p.127). In this illustration the dashed line indicates the distribution of radiation under conditions where no scatter is possible; the solid line indicates the actual retinal distribution. Distance "U" represents the apparent width of the glimulus. This illustration points out that, under certain glimulus

Figure XIII

Entoptic Stray Illumination

(after Bartley (1958)



conditions, the focused radiation forming the glimulus' image is not the only retinal illumination present. The remainder of the retina receives radiation even when the visual field around the glimulus is dark. This remaining radiation is unfocused and is called stray or scattered illumination. Appendix V presents a detailed discussion of the sources of entoptic scatter. Di Francia and Ronchi (1952) and Boynton, Enoch, and Bush (1954) have determined the direction and magnitude of scattering for the eye. The reader is referred to Figure II once again.

Psychophysical experiments have been performed that appear to provide support for the entoptic stray light theory of glare. One such study by Bartley and Fry (1935) used a flicker technique. They positioned the glimulus' image on the blind spot where no neural interaction could take place. Field flicker was still present. A second test used two glimuli, equal in all respects, and presented alternately so as to hold the amount of stray light constant. Their results showed that field flicker is abolished, thus demonstrating its dependence upon actual intermittent illumination rather than upon neural interaction between portions of the retina stimulated and those not.

That same year Fry and Alpern (1953b) wrote that the decrease in perceived brightness of a foveal test spot produced by a peripheral glimulus can be accounted for in terms of a veiling luminance produced by stray illumination falling on the fovea. The same effect can be produced by an artificial patch of veiling luminance superimposed on the test spot. The reader is referred to pages 10 and 11 for a review of this study.

Further support for the entoptic stray light theory comes from a study performed by Boynton, Bush, and Enoch (1954) entitled "rapid changes foveal sensitivity resulting from direct and indirect stimuli". Ss had to match a flashing foveal test spot with either a direct or an indirect glimulus. Direct stimulation was produced by light shown on a large white screen. Indirect stimulation was produced by light shown on S's blind spot. The instantaneous change of retinal adaptation was recorded from the onset of the adapting glimulus to the state of steady adaptation. They found that when the two types of adapting luminances were equated at the start of adaptation for total luminous flux, sensitivity to each remained the same during the process of adaptation. Thus, they concluded that only stray light could account for such identical results. Neural interaction was ruled out as a factor on the basis that differential time effects would have occurred.

In 1954 Fry re-evaluated the scattering theory of glare. His report updated Stiles' (1929) objections that: (1) in order to account for the glare experience it was necessary to assume more light scattered than was known to be lost in the transmission process through the eye's media, and (2) the equations for stray light, derived from theory, did not conform to the effect produced by a peripheral glimulus. Stiles had found that flare and scattering by the media (see Appendix V) cannot account for the whole effect (glare), thus he assumed that part of the effect must be due to neural interaction. Because of more recently acquired knowledge of the eye's transmission qualities, Fry showed that stray light could account for the entire effect of a glimulus upon the brightness difference threshold. Stiles also assumed that entoptic stray light conforms to Rayleigh scattering functions. If this were true, scattering would be considerably greater for blue light than for red. Studies (Le Grand, 1937) (Luckiesh and Taylor, 1925) (Moon and Spencer, 1943) have shown that this is not the case. This suggests that the scattering particles are much larger than those involved in the Rayleigh type of scattering. Fry concluded that entoptic scattering may have a large pro-

portion of forward scattering. He also concluded that scatter by the optic media is sufficient by itself to account for the effect of a glimulus on the brightness difference threshold.

Another characteristic of entoptic stray light is that it has been found to be additive, i.e., if two or more glimuli are present in the field of view simultaneously the overall effect is the sum of all of them (Crawford, 1936) (Holladay, 1926). Rather precise predictions can be made of the effects produced by glimuli by using this fact. Such additivity could be due to neural interaction, however, it seems rather improbable that such a heterogeneity of retinal inter-connections could lead to such an effect. (Duke-Elder, 1942) (Polyak, 1941) (Woodworth and Schlosberg, 1958). Psychophysical experiments also tend to support this point of view (Crampton, 1956) (Kruger and Boname, 1955) (Pieron, 1929).

Electroretinogram studies have also been used to investigate entoptic stray light (Boynton, 1953) (Crampton, 1956) (Fry and Bartley, 1935). The E.R.G. record does not differentiate between the activity of one part of the retina and that of another. As Bartley (1941, p. 268) put it, "This is due to the fact that under most conditions enough stray light falls on the retina in general to produce a considerable action-potential, despite the common belief that the retinal action-potential is determined for the most part by the elements in the focal area of the retina receiving the image."

In 1953 Boynton investigated "stray light in the human electro-retinogram". He concluded that stray illumination on peripheral retinal areas , where the rods predominate are thought to cause the beta portion of the E.R.G. wave. He also concluded that the beta portion is a scotopic response to high intensity stimulation (for small areas) but that it also represents a summated response of receptor activity all over the retina. These results agree with others showing that the average retinal illumination, due to stray radiation, is of small absolute magnitude. An extremely weak, scotopic, full-field stimulus was capable of eliciting as large a beta wave response as the stray radiation associated with a very high intensity, small, glimulus. Furthermore, the directional sensitivity of the cones (Stiles and Crawford, 1933) (Stiles and Crawford, 1934) may aid in suppressing the perception of what stray radiation there is.

Crampton (1956) suggested that the E.R.G. is not an accurate indicator of the effects of a glimulus because a psycho-physical response is made to the focal area of the stimulus alone while the E.R.G. involves the whole retina. From this one might assume that psycho-physical experiments tend to over-estimate glare and that E.R.G. records are more representative of certain aspects of glare. His point is well taken ...to the extent that the given impoverishment can be measured and that glare and glimulus are kept strictly separated.

By shining a glimulus first on the blind spot (called indirect adaptation), and then on a large, full visual field, screen (called direct adaptation), Crampton's E.R.G. patterns indicated that both kinds of retinal stimulation lead to the same result. Holladay (1926) found similar findings. Crampton explains these results as being due to stray illumination upon the retina. He also found that the greater the glimulus intensity, the greater the diameter of the effective distribution of the nonfocal light. The present dissertation has provided a quantification of similar findings.

Finally, Bartley (1941, chpt. 3) discusses various means of actually measuring entoptic stray radiation: (1) direct photometry in freshly excised eyes, (2) by using a peripheral glimulus to determine its effect upon the differential threshold of a foveal test spot, (3) by using flicker methods in which the critical flicker frequency (c.f.f.) curves of the test spot and that of the field at a given distance from the fovea are compared, (4) by using apparent movement study techniques, and (5) by studying blurredness of the retinal image.

To summarize the position of both theories of glare; it is not yet possible to find any element decidedly favorable to either theory, yet one must acknowledge that the entoptic stray light theory offers the advantage of supplying a physical relation (see formula (2) on page 13) by which the effects of a glimulus may be foreseen through calculations and empirical measurement.

APPENDIX III

Anatomy and Physiology of the Central Human Retina

This appendix is included because of its central importance to the neural interaction theory of glare (see Appendix II) and to discussions of the role played by the *fovea centralis* under present glimulus conditions.

The retina is a light-sensative neural layer and forms part of the wall of the vitreous chamber of the eyeball. It receives radiant energy and changes it into nerve impulses, among other functions. These impulses are transmitted to the higher centers of the brain to yield a sensation of "light". Certain photo-sensative elements called cones and rods make up part of the retina and transform the incoming photic energy into neural impulses. Many different sub-retinal structures carry these neural impulses to higher nervous centers via the optic nerve, chiasma, and optic tract.

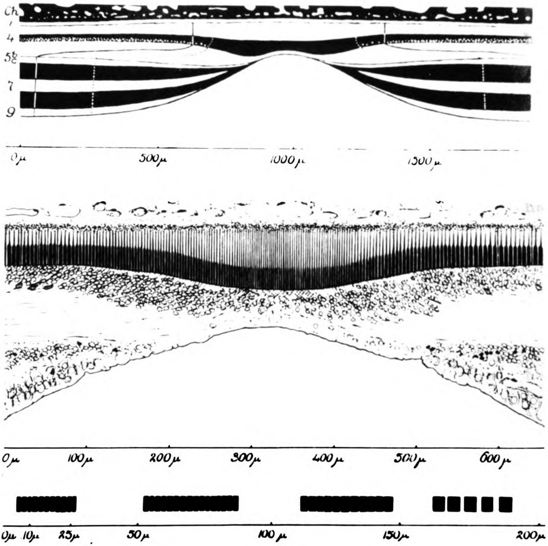
The beautiful complexity of the human retina should not make one shy away from studying it; rather this complexity should be unraveled and this beauty enjoyed. When one studies the portion of the retina that receives the focused incoming

radiation one is studying the <u>fovea centralis</u>. The present appendix attempts to bring this area into clearer focus.

Different values are given for the exact location of the

Figure XIV

The Fovea Centralis in Cross Section
(after Polyak (1941)



<u>fovea centralis</u>. This is due primarily to individual differences in the subjects studied. Polyak's (1941, p. 197) excellent work locates it somewhat over 4mm. lateral to the optic papilla in man.

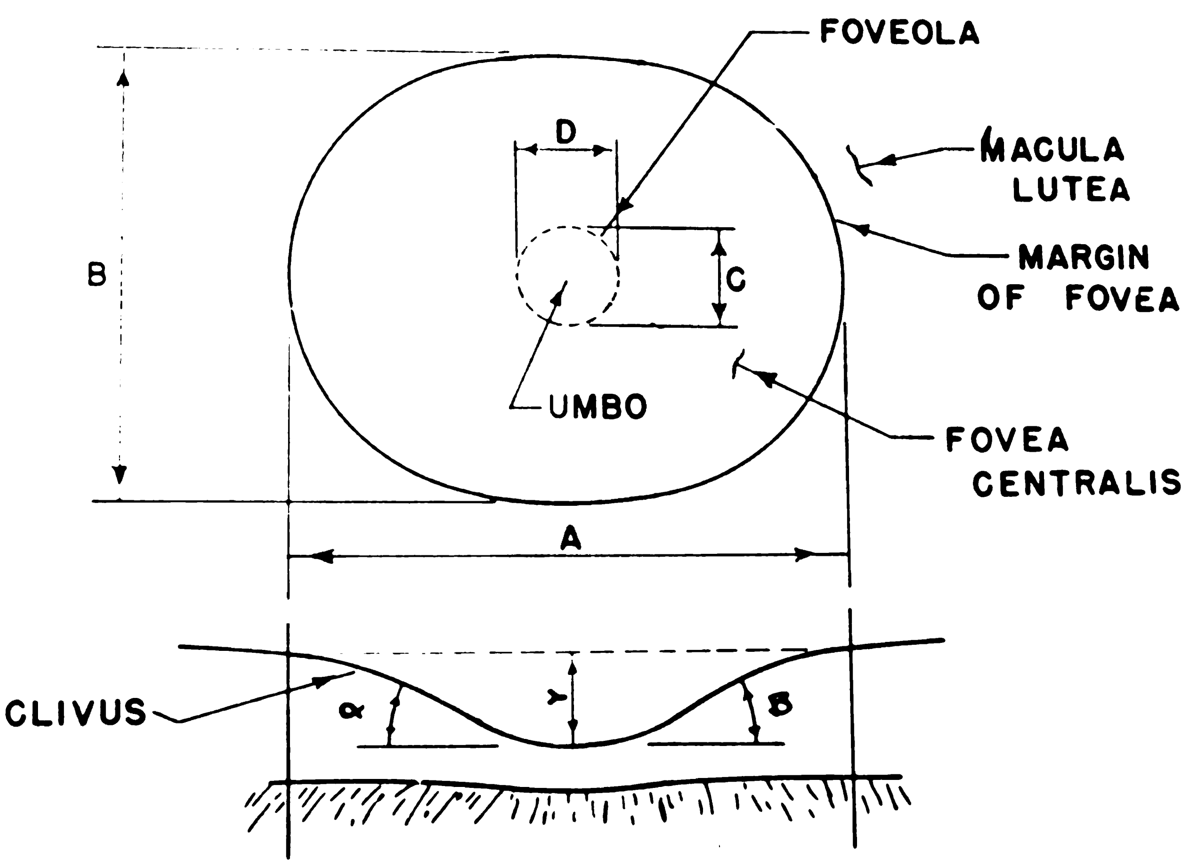
Its shape in man...both in freshly enucleated and in well-fixed specimins, is round. O'Brien and Miller (1953, p. 5) assert that the _fovea centralis_ corresponds to the, "small depression lying in the center of the _macula lutea_ (yellow spot)". Only cone vision is involved in clearly focused vision.

The shape of the _fovea centralis_, in cross-section, is presented in Figure XIV. The scale is shown directly in microns under the drawing. Cones predominate in this drawing by Polyak although a few rods have been included near the edges. This illustration clearly emphasizes the depression which contains many layers of neural structure (see top portion of Figure XIV). The shape of the _fovea centralis_, in plan view, varies according to: (1) which boundary definition one uses for his histological studies, and (2) which subject is used. Figure XV helps to clarify various portions of the foveal region. Letters refer to a research review on the size of the _fovea centralis_ and density of cones therein which is presented as Appendix VI. This review summarizes the experimental findings of 29 investigators concerning these foveal dimensions.

In the present research, as well as in most research that deals with human vision, the size of the fovea is of great importance for its size will often determine the size of the visual targets used. Few references agree, however, on its absolute size. Adler (1950, p. 530) claims that the rod-free area of the retina measures about 0.3 mm. in diameter, corresponding to a visual angle of about 1°. Woodworth and Schlosberg (1958, p. 366) use the values, "2° horizontally and a little less

Figure XV

A Schematic Representation of the Foveal Area



vertically. They point out that the place where rods begin to appear outside the foveal area (called the rod line) begins at about 130 microns or 26.6' visual angle from the center of the fovea. Bartley (1941, p. 86) states that, "The central area of about $1\frac{1}{2}^{\circ}$ is entirely rod-free, while a slightly larger area, 2° in diameter, contains so few rods that it may be considered virtually rod-free." If 1 mm. distance on the retina equals 3.4° visual angle then Bartley's central pure-cone area equals 0.44 mm. in diameter. Polyak (1941, pp. 198-203) gives

a margin to margin dimension (of the foveal depression) of 1.5 mm., or somewhat more corresponding to 5^{o} visual angle on both sides of the fixation point. The region of the fovea yielding most direct vision corresponds approximately to 1^{o} 20' visual angle (400 microns). The rod-free area measures about 1^{o} 40' visual angle (500 microns).

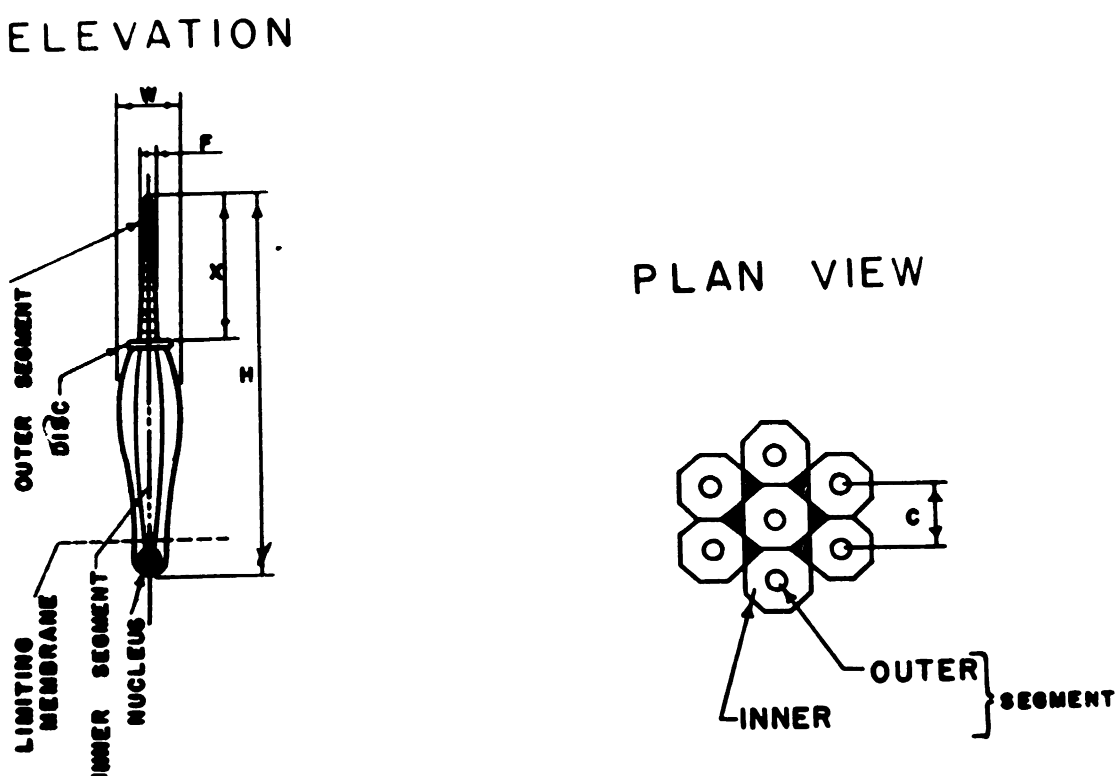
Referring to Polyak's drawing of the foveal area (Figure XIV), a nominal <u>longitudinal</u> dimension would be somewhat over 600 microns. Wulfeck, et al. (1958, p. 32) claim that the, "fovea's entire area is approximately 1.50 mm. in diameter and subtends about 5^{o} of visual angle." Other references (Guyton, 1961) (Southall, 1961) give still different values.

For the present experiment an <u>almost</u> circular <u>fovea centralis</u> is assumed having a horizontal dimension equal to 0.5 mm. (1.70^{o} visual angle) and a vertical dimension equal to 0.4 mm. (1.36^{o} visual angle). These values were chosen because they were conservative estimates of previous reliable findings. Horizontal and vertical refer to meridians on the back of the inner eyeball when the head is erect.

Regarding the size and shape of the <u>foveal cones</u>, again, many different values have been determined. Cones are typically measured from center to center...averaged across any small group of four or five. In order to better picture the foveal cone and related dimensions Figure XVI presents a schematic, labelled, diagram in both plan and elevation view. Labelled dimensions refer to those in Table XIV. This table gives a

Figure XVI

A Schematic Representation of a Foveal Cone in Plan and Elevation View



review of foveal cone dimensions obtained by various researchers. Rather large differences in these dimensions can be ascribed to several factors: (1) the rapid change in cone diameter with location in the retina and differences in the depth of histological section, (2) different amounts of shrinkage during preparation (Duke-Elder, 1942) (Hartridge, 1950) (Helmholtze, 1924), and (3) differences inherent in retinas of different subjects.

The shape of foveal cones varies with position in the retina (Duke-Elder, 1942, pp. 89-90). It is apparent from

Figure XIV that the central cones are longer and thinner than those at the periphery (Helmholtze, 1924, p. 28) (O'Brien, et al., 1953).

Table XIV

Foveal Cone Dimensions
(microns)

Investigator	Reference	W	F	H	X	C
Bartley, S.H.	(1962)	3				
Fritsch, G.	(1908)	1.8-4.5				
Greff	———	2.5				
Hartridge, H.	(1950)					2
Heine	———	4				
Helmholtze, H.	(1924)	4.0-6.0		63		
Kolliker, A. von	(1854)	4.5-5.4		15-20		
Koster	———	4.4-4.6				
Krause, C.	(1842)	3.0-5.0				
Le Grand, Y.	(1957)				0.5	
Müller, H.	(1852)		1.5-4.0			
O'Brien & Miller	(1953)			75		2.02-2.32
Polyak, S.	(1941)	1.5	1.5	70		
Rochon-Duvigneaud	———	2.02-2.50				
Schultze, M.	(1866)		2-2.5			
Southall, P.C.	(1961)	2-3				2.6
Vintschgau, M. di.	(1853)	3.4-6.8				
Welker	———		3.1-3.6			

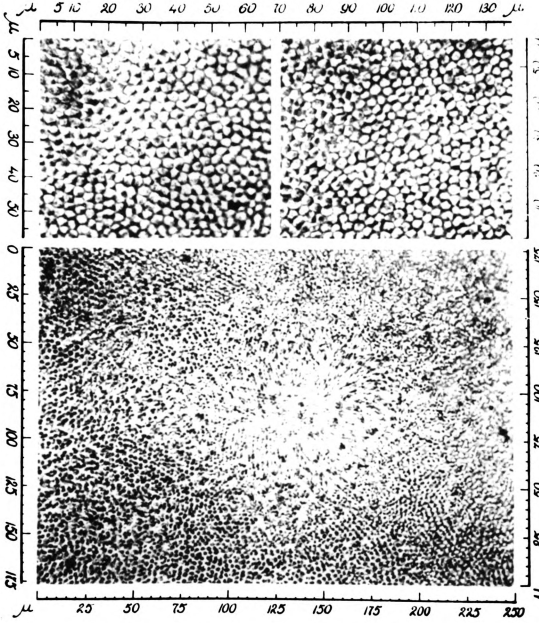
(Osterberg, 1935) (Pirenne, 1948) (Schultze, 1866).

The foveal cones lie within a depression or pit in the back of the eyeball. (see Figure XV) Some investigators feel

Figure XVII

Photomicrograph of the Foveal Region

(after Polyak (1941)



that the foveal clivus (slope) acts to spread the image over a larger number of receptors than would otherwise occur. (Polyak, 1941, pp. 199-203) Another prominent view is that the thinning of blood vessels and other retinal layers in the foveal region make it easier for light to reach the cones. (Guyton, 1961, p. 711) (Polyak, 1941, p. 201) Figure XVII is a photomicrograph of the foveal region showing, in the lower portion, the foveal depression. Note that the lighter portion is out of focus.

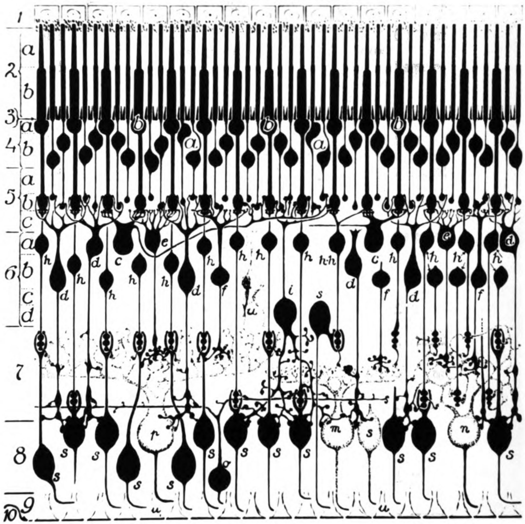
The following section deals with certain neurophysiological relationships existing between foveal receptors and the optic nerve. It is well known that cones within a certain area of the fovea are connected individually, by way of a monosynaptic bipolar, to an individual ganglion cell. (Adler, 1950, p. 633) (Anderson & Weymouth, 1923) (Bartley, 1941, p. 86) (Bartley, 1962, pp. 928-929) (Le Grand, 1957, p. 347) (Polyak, 1941) (Woodworth and Schlosberg, 1958, p. 386) (Wulfeck, et al., 1958, pp. 32-33) In parafoveal regions other paths are possible, in fact the great number of interconnections between the various layers of retinal structure enable rod and cone discharges to interact in many ways. This is illustrated in Figure XVIII which is an enlarged "hand-drawn" diagram of retinal neurology according to Polyak (1941). The ten layers are shown along with many of the possibilities for convergence, divergence, and even loop (storage or delay) activity of receptor impulses.

Numbers on the left side of Figure XVIII refer to the following layers: (1) choroid (pigment layer), (2) rods and

cones (photic receptors), (3) external limiting membrane, (4) outer nuclear layer, (5) outer fiber layer, (6) inner nuclear layer, (7) inner fiber layer, (8) ganglionic layer, (9) nerve

Figure XVIII

Enlarged Schematic Cross-Section of the Retina



fiber layer, and (10) internal limiting membrane. (Helmholtze, 1924) (Le Grand, 1957, chpt. 16) (Müller, 1852) (Polyak, 1941) This illustration is of a portion of the parafovea; it contains two rods for every cone. Within the pure cone area different synaptic relationships are found.

In the very center of the foveal depression (called the foveola) there are from 10,000 to 187,000 cones per square millimeter according to Fritsch (1908, p. 17). The value most commonly cited is 147,000 cones per square millimeter (Osterberg, 1935) and agrees with values obtained earlier (Anderson and Weymouth, 1923) (Fincham, 1925) (also see Appendix VI). Supposedly, the great majority of these 147,000 cones have their own "individual" pathways to the optic nerve and thence to higher centers. On this basis one would expect that interaction would be at a minimum in this retinal area. There is considerable experimental proof that this is the case (Adler, 1950, p. 554) (Illum. Engr. Soc., 1924) (Woodworth and Schlosberg, 1958, p. 386).

Bartley (1962, p. 928) points out that there are no diffuse ganglion cells in the fovea. There the mop bipolars are also absent. The cone impulse is conducted to a midget bipolar, then to a midget ganglion cell, without lateral or transverse overlapping. Many researchers feel that this is the basis for the good visual acuity found in this region (Adler, 1950, p. 633) (Guyton, 1961, p. 710) (Helmholtze, 1924, pp. 26-27) (Le Grand, 1957, p. 250) (Oatman, 1913, p. 13) (Polyak, 1941) (Woodworth and Schlosberg, 1958, p. 386).

The present appendix has provided a brief review of what is known about the central human retina. On the basis of this review a foveal dimension was accepted which appeared to be consistent with previous foveal measurements. This appendix also provides a basis for further discussion of experimental findings and will provide the reader with a ready source of information on the *fovea centralis*.

APPENDIX IV

Experimental Instructions

"This experiment is meant to uncover some of the processes involved in looking at different shaped lights. You are already familiar with the experimental method to be used (Note: all subjects had taken an introductory experimental psychology course) but the apparatus is new. You will sit in this chair (point to chair) and bite into this wax biting board (point to adjustable wax biting board). I will adjust this board until you can see the mirror (S.G.S.) centered in the viewing hole (artificial pupil). Remember, it must be exactly centered. (E also checked S's head position visually).

"To begin the task you will observe two separate things. The first is an intense object, the second is a small moving light. You are to hold your fixation on the center of the intense object (S.G.S.) at all times. While you are fixating you will also see the smaller light move in a straight line toward the intense object. Actually it will pass behind the intense object (point out the M.T.S.). When you see the moving light completely disappear from view simply press the button (point to button) and hold it down until you are told to release it. During the time you are holding it down I will be recording the place at which you stopped the moving light. When I tell you to do so again direct your attention to the center of the intense object and release the button. The moving light will reappear from behind the intense object. When the moving light comes completely into view once more simply press and hold the button down again. Are there any questions?

(Note: All subjects readily understood these instructions. In several cases all of the apparatus was described in detail because these subjects (B.N.) (B.M.) (J.M.) also served as experimenters.)

APPENDIX V

Detailed Discussion of the Sources of Entoptic Scattering

Entoptic stray illumination arises from many sources. The detailed listing below includes the known sources-with relevant references for each.

Entoptic stray illumination arises from: (1) diffusion through the sclera and iris (Bartley, 1941, p.58), (2) flare in the optical system (Kris, 1958, pp. 201, 241) including the light reflected from the iris to the cornea and thence through the pupil to the retina, and also part of the light diffusely reflected by the retina which may be reflected back toward the retina by one of the refracting surfaces. Normally, flare refers to light reflected at the boundary surface between media in its course through the optical system, (3) scatter by the media (Duke-Elder, 1942, p. 801) (Fry, 1954, p. 98) (Fry and Alpern, 1955, p.879) (Holladay, 1926, pp. 271-319) (Kris, 1958, pp.201, 241) (Schultze, 1866, p. 131) including the halos (Duke-Elder, 1942, p. 801) produced by the diffraction associated with the microstructure of the lens and cornea, (4) diffuse reflection from the pigment epithelium, choroid, and sclera (Di Francia and Ronchi, 1952, p. 782) this light stimulates the photoreceptors in passing back through the retina (called halation by Duke-Elder (1942, p.774), and then passes through the vitreous to the other parts of the eye. After it reaches some other part of the retina a part of the light may by further reflected, (5) flourescence of the lens (Duke-Elder, 1942, p.820) and retina (Ibid., p. 821) when exposed to ultraviolet light, and (6) bioluminescence in the photoreceptors (Judd, 1950, p. 2).

APPENDIX VI

Dimensions of the *Fovea Centralis*

The review to follow presents dimensions of the human *fovea centralis* obtained by the researcher noted. The identifying letters refer to those given in Figure XV. The "umbo" or foveola is the area of most acute vision. Cones within this small area exhibit extremely fine ability to respond to detail. Angles α and β have been found to range from approximately 15° to 25° (Polyak, 1941) depending upon which side of the fovea one is considering. All measurements are in millimeters or as otherwise noted.

Investigator	Reference	Density	A	B	C	D
Adler, F.H.	(1950)		0.3	0.3		
Bartley, S.H.	(1941)		$0.44mm^2$		1.5°	1.5°
Dimmer	———				1.4-2	1.4-2
Dub. Reymond	———	$15,200/mm^2$				
Duke-Elder,	(1942)	4,000 in fovea 13,000 in macula				
Fritsch, G.	(1908)				1-1.5	1-1.5
Guyton, A.C.	(1961)		1.22mm			
Hartridge, H.	(1950)		(26.6' radius to rod line)			
Henle, J.	(1866)				0.2	0.2

Investigator & Reference		Density	A	B	C	D
Kolliker, A.	(1854)		3.24	0.31	0.18-.225	0.18-.225
Koster	—				0.2-.4	0.2-.4
Krause, C.	(1842)	4,000 (foveola)	2.25			
Kuhnt	—				0.15	0.20
Le Grand, Y.	(1957)	25,000	2-3	2-3	1.3-1.5	1.3-1.5
Michaelis	—				0.2-.4	0.2-.4
Oatman, E.L.	(1913)		2	2		
Osterberg, G.	(1935)	147,000/mm^2				
Perera, C.A.	(1949)		1-2	1-2		
Pirenne, M.H.	(1948)				0.3	0.3
Polyak, S.	(1941)	25,000 (fovea) 34,000 (rod-free area)			0.4	
Salzer	—	12,622 to 13,234/mm^2				
Schafer	—	16,000/mm^2				
Schultze, H.	(1866)				0.2	0.2
Southhall, P.C.	(1961)		0.2			
Wadsworth	—				0.4-1.0	0.4-1.0
Weber, E.H.	—		0.76			
Welker	—		1.75			
Woodworth & Schlosberg	(1958)		$<2^\circ$	$<2^\circ$		
Wulfeck, J.W.	(1958)		1.5	1.5		