CONTRAST SENSIBILITY OF THE EYE

By Enoch Karrer and E. P. T. Tyndall

CONTENTS

I. INTRODUCTION

The research reported in this paper was undertaken as part of the Bureau investigation of certain problems of searchlight illumination. One of the important aspects of searchlight illumination, such as the detecting of airplanes, is a matter of contrast, since the object illuminated by the search lamp must be seen in contrast to the diffused light in the path of the beam, or in contrast to other diffused light. The brightness of the path of the beam determines what the brightness of a target of any given size must be in order that it may be visible. This is a matter of the contrast sensibility of the eye, usually at low levels of illumination. To obtain data bearing upon this point, laboratory experiments were performed.

II. GENERAL METHOD

The general method followed was to illuminate a screen to a known amount so that its brightness might be comparable with that of the path of the searchlight beam. Upon this screen was projected a rectangular beam whose horizontal width could be varied at will.

The aspect then was that of a rectangular strip of light upon a light background. The length of the strip was varied from nothing to a length which enabled the observer at 26.3 m from

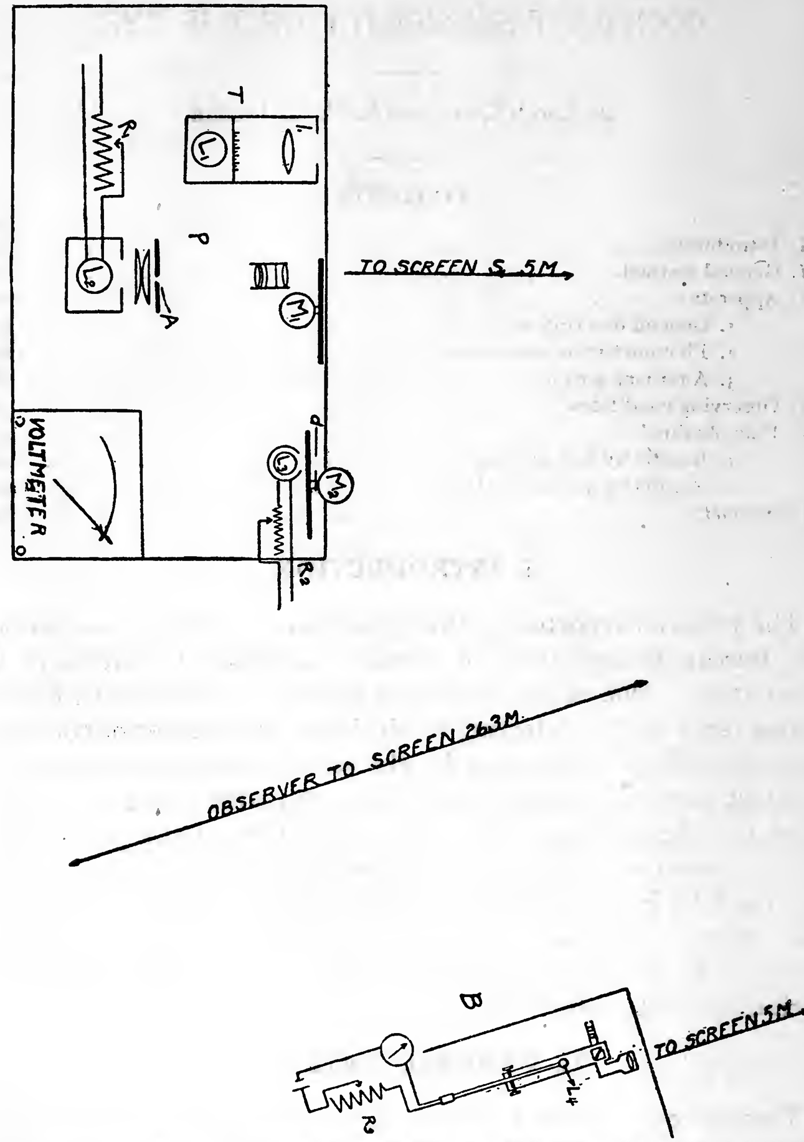


FIG. 1.—*Disposition of apparatus for contrast sensibility*

T, scale projector; *P*, lantern for projecting slit *A*; M_1, M_2, sectored disks; L_3, illumination for main screen *B*, photometer

the screen just to see the patch. This length, together with the brightness of the screen and the brightness of the strip, was recorded.

Two series of observations were made. In the first series the field illumination and strip illumination were varied by steps in the same ratio, so that a constant contrast between the two was maintained. In the second series the field brightness was kept constant, and the strip brightness was varied by steps thus giving a varying contrast.

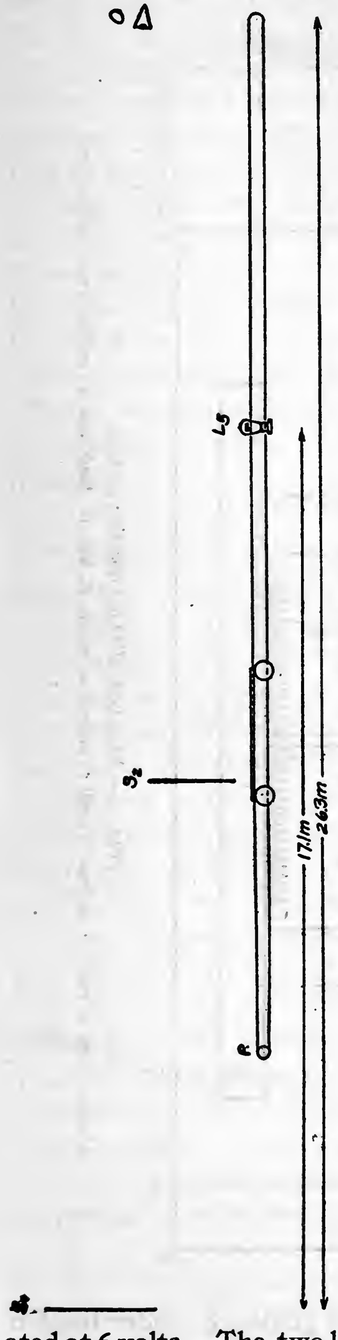


FIG. 2.—*Relative position of screens and observer*

S_1, main screen; S_2, auxiliary screen on carriage; P, pulley; L_5, illumination for S_2; O, observer

III. APPARATUS

1. GENERAL DESCRIPTION

The disposition of apparatus for these experiments is depicted in Figs. 1 and 2. The screen was coated with a white diffusing paint of magnesium oxide in water having dissolved in it a slight amount of white library paste as a binder. This screen was illuminated by means of the locomotive headlight lamp L_3, Fig. 1, operated at 29 volts. By means of sectored disks on the motor M_2 the intensity of the general illumination on the screen was regulated. The lamp, L_3, was inclosed by a metal cylinder with a suitable aperture. An additional black screen, *d*, was placed just beyond the disk. These precautions assured us that the screen received a negligible amount of illumination from the light-colored walls of the room. The screen was, furthermore, surrounded by a black-cloth border. The projection lantern by means of which the variable strip of light was projected upon the screen was equipped with a miniature signal lamp, L_2, operated at 6 volts. The two lamps, L_2 and L_3, Fig. 1, were operated on storage batteries, and voltage was kept constant to 0.1 volt.

The lantern was provided with a bilateral slit, whose construction is shown in detail in Fig. 3. Its chief parts were two jaws,

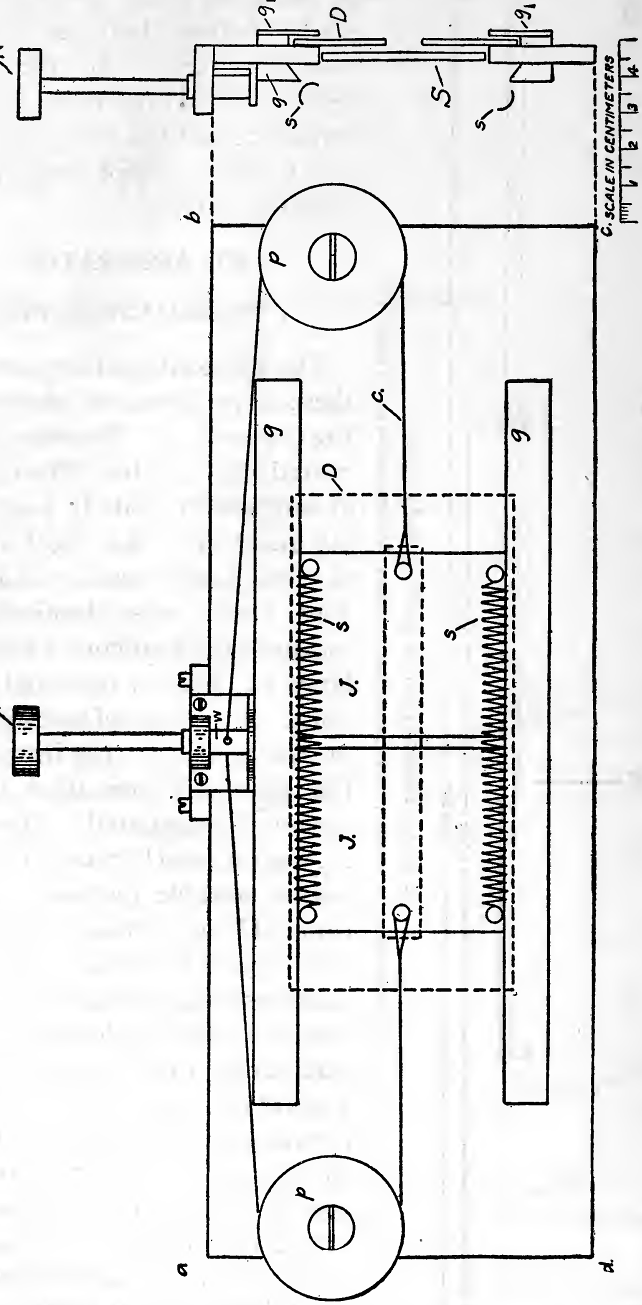


Fig. 3.—*Adjsutable slit for projection lantern*

J, sliding jaws; *g*, guides; *s*, springs; *c*, cord; *p*, pulleys; *w*, winch; *K*, key; *D*, diaphragm; g_1, guides; *S*, equalization screen

J, smoothly displaceable horizontally in guides, *g*, under tension of two springs, *s*. The displacement of the jaws—that is, the opening of the slit—was varied by means of a cord, *c*, attached to the jaws and passing over pulleys, *p*, to the winch, *w*, operated by the key, *k*. To limit the aperture vertically to a required height, a diaphragm, *D*, of any desired width could be inserted into guides, *g*. This simple slit mechanism when in good condition gave entire satisfaction for the purpose in hand. A second sectored disk, M_1, Fig. 1, was placed before the projection lantern to control the brightness of the variable strip. To determine the length of a strip projected upon the screen a scale, *T*, Fig. 1, was projected alongside of the strip by means of the lens, *l*. When measurements of the length of the strip were made, the light from lamp, L_3, was eclipsed by means of a screen operated by a lever which simultaneously closed the circuit with lamp L_1, causing only the strip and the scale superimposed to be visible. All the manipulation of the sectored disks, the variable slit, and the reading scale, as well as the recording, was done by one operator.

2. PHOTOMETRIC MEASUREMENTS

The brightness of the screen and of the strip were measured by means of a photometer (Macbeth) equipped with a lens, and calibrated to read in microlamberts. The lamp in the lantern and the lamp illuminating the screen, and that in the photometer were adjusted for a color match.[1] Measurements of the brightness of strip and screen were made twice in each night, viz, at the beginning and end of the observations. The calibration of the photometer was usually checked once during the night by comparison with a secondary standard. The screen was explored for uniformity of brightness over its entire area, and was found satisfactory over the portion of it that was actually used.

It was somewhat more difficult to obtain uniformity of brightness across the entire maximum length of the strip because of the slight obliquity of the projection. This was accomplished in the following manner: A photograph was taken of the screen illuminated by means of the projection lantern with the variable slit entirely extended, and the diaphragm, *D*, Fig. 3, removed. The size of the picture was made about the size of the aperture in the lantern. The negative was then cut down to fit into the slide, as shown by *S* in Fig. 3. The resultant distribution across the strip was very uniform. The exposure of the negative was short so that its absorption at the densest parts was probably no more

[1] It may be pointed out, however, that when the strip was very small a slight physiological color difference appeared.

than 15 per cent. This was necessary not only to economize the light but to avoid appreciable changes in the brightness when the strip length was varied. Within experimental errors the brightness of the center of the strip when entirely extended and when almost closed was the same.

3. AUXILIARY SCREEN

It has been stated above that the general illumination on the screen was cut off when the length of the strip was read. This was, of course, subjecting the eye of the observer to a variable and uncertain state of adaptation. To avoid this an auxiliary white diffusing screen was used upon which the eye of the observer was fixed whenever the illumination on the main screen was cut off or seriously changed, as during the time of adjusting the sectored disks. The relative position of the screens and observer is shown in Fig. 2, where S_1 is the main screen and S_2 the auxiliary screen mounted upon a carriage which could be moved to or from the observer at O, until the brightness of it due to illumination from the lamp, L_5, Fig. 2, whose voltage was also controlled by the observer at o, was equal to the brightness of the screen S_1. The lamp, L_5, was turned out by the observer during the time that he was observing the strip upon the screen.

IV. OBSERVING CONDITIONS

The observer was seated in a room at a distance of 26.3 m from the screen and test strip. This room could be darkened but was not entirely light-tight. Skylight and moonlight were always present to a very small extent. However, since the observations were, perforce, made after nightfall and before dawn, the effects of the small amount of stray light from external sources were, undoubtedly, smaller than the corresponding effect of the light from the lamp, L_5, and from the two screens, for there was some general illumination in the observer's room at all times from both of the screens. The walls of this room as well as the walls of the adjoining room containing the auxiliary screen and lamp were all of very light tint.

It is of interest to point out that additional illumination other than from the main screen entering the observer's eye, did not necessarily decrease the sensibility. It was noticed, for example, that when the auxiliary screen was illuminated while the strip was observed, the strip became more visible. This phenomenon is similar to that observed by Nutting, that when the field was stopped down with black the threshold was raised.[2]

The observer used his right eye only, having the natural pupil. The left eye was covered by a dark card over the left spectacle lens in case of one observer (E.K.) who wore glasses. A similar method sufficed for the second observer (E.P.T.T.) by the use of a spectacle frame without glasses. Both observers have had considerable experience in photometric measurements. Before the subject began to observe he remained under the test conditions from 10 to 15 minutes with the eye exposed to the screen of the brightness desired to begin the observations. To keep the observer alert, particularly at the lower contrasts and at low field illumination, "blank" settings were made as follows: The slit was entirely closed as when starting all observations; then it was announced to the observer that he look for the strip as customarily. The slit, however, was not opened, so that any strip seen by the observer was imaginary. Such checking was made at the pleasure of the operator at irregular intervals. When several imaginary strips were reported for any condition of the brightness or contrast and of the physiological condition of the observer, the observations were discontinued and resumed on some succeeding day, if it was desired to extend or repeat the observations.

The amount of the surface of the screen and the maximum length of the test strip seen by the observer were limited by intervening doorways. The maximum length of strip was about 125 cm. The area of screen actually used was approximately 125 by 125 cm.

The rooms in which these experiments were made were not available for this purpose during the daytime. As a consequence the observations were usually made after the observers had been performing other active duties for 8 or 10 hours previously. The disposition to manifest fatigue, at times very markedly as noted below, was, undoubtedly, due to this fact.

V. DATA OBTAINED

The two methods by which the two series of observations previously mentioned were obtained are as follows:

1. The illumination on the screen (this will be referred to as the field brightness) is kept constant, while the illumination on the strip (strip brightness) is varied by known amounts by means

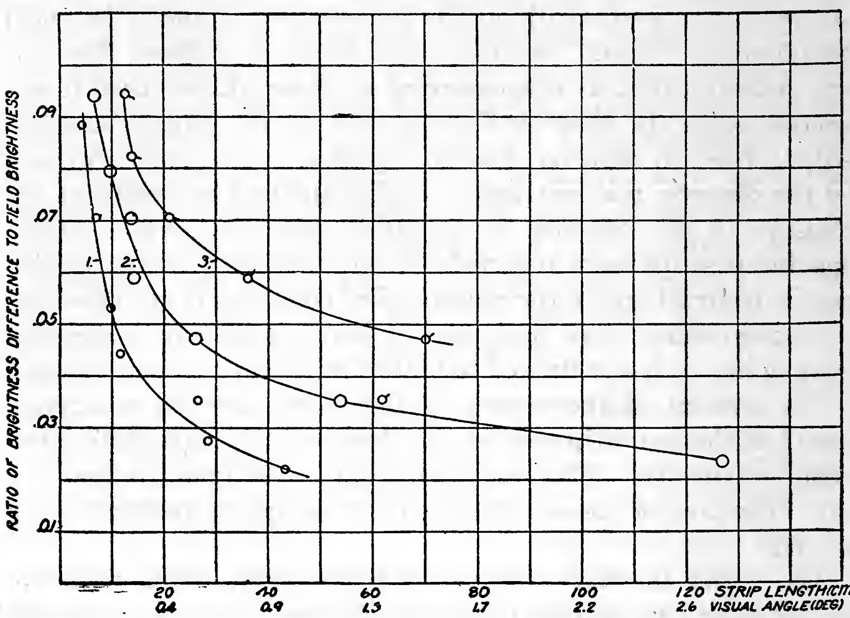
---

[2] Trans. Ill. Eng. Soc. 11, p. 1; 1916.

of sectored disks. By this method a relation is directly obtained between the length of strip and contrast between the field and strip for any desired field brightness.

2. The relative brightness of the field and strip is fixed, and the brightness of both is reduced in known steps by sectored disks. A relation is thus obtained directly between the length of strip and the field brightness for any desired contrast between field and strip.

Both of these methods differ materially from the method by which Reeves [3] obtained his excellent results, and also differ from that of Koenig.[4]



Observer, E. P. T. T., June 20, 21, 1919

FIG. 4.—*Relation between strip length (visual angle) and ratio of brightness difference to field brightness*

Average of decreasing and increasing brightness difference: 1, F. B.=427 microlamberts; 2, F. B.=320 microlamberts; 3, F. B.=160 microlamberts

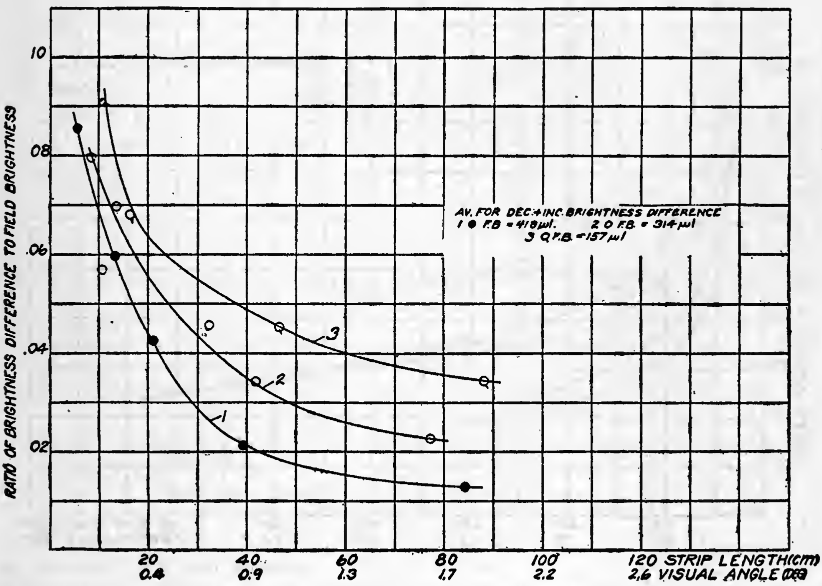
1. RESULTS BY FIRST METHOD

The data obtained by the first method for each of the two observers are given in curves of Figs. 4 and 5 where the strip length is indicated along the axis of abscissae in centimeters, and in terms of the angle which this length subtended at the observer's

[3] J. Opt. Soc. Amer., **1**, p. 148; 1917.

[4] Physiological Optics, p. 135. The results of Blanchard should also be noted, obtained by a similar photometric method and confirming the results of Koenig, when the intensity unit of the latter are properly evaluated. These are reported by Nutting in Trans. Ill. Eng. Soc., **11**, p. 939, 1916; and in J. Frankl. Inst., **183**, p. 287; 1917.

eye. The contrast condition is indicated along the axis of ordinates in terms of the Fechner fraction; that is, the ratio of difference between strip brightness and field brightness to the field brightness. A series of observations, Fig. 4, for three different values of the field brightness, viz, 427, 320, and 160 microlamberts (μl) were made by one observer (E. P. T. T.). Similar observations, Fig. 5, were made by the second observer (E. K.) with field brightness of 418, 314, and 157μl. For each value of the field brightness, observations were made both on decreasing and increasing the strip illumination. The curves of Figs. 4 and 5 are the average

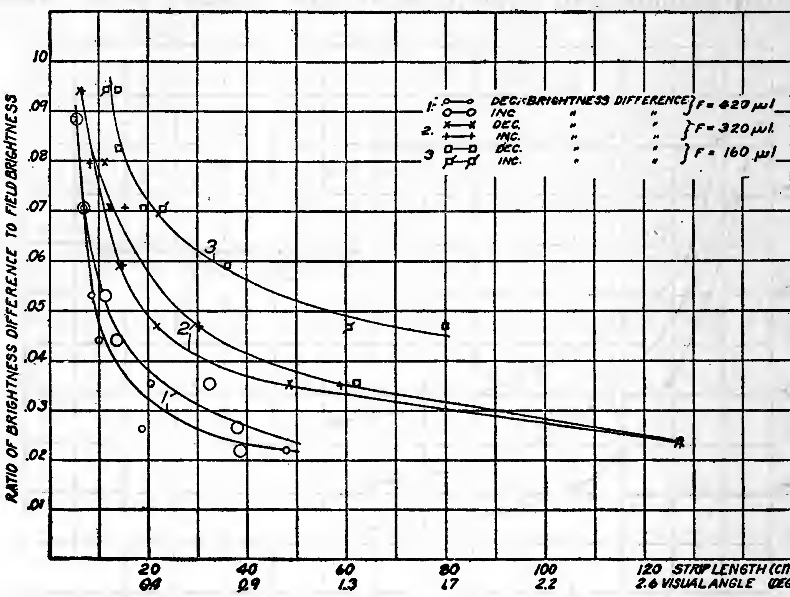


E. K., June 24, 25, 1919

FIG. 5.—*Relation between strip length (visual angle) and ratio of brightness difference to field brightness*

curves. The values of the strip length obtained on decreasing the strip illumination usually were smaller at any given contrast than those obtained on increasing the illumination. At times this "lag" was very marked. It was related to the general physiological condition of the observer as well as to the immediate condition of the eye due to prolonged functioning. These differences are the fatigue effects referred to previously. The time required to make a complete series of observations both for decreasing and for increasing the strip illumination for a given field brightness was approximately 1.25 hours.

It is of interest to record some typical cases of this fatigue, as those in Fig. 6 for one observer (E. P. T. T.); and in Fig. 7 for the second observer (E. K.). For the latter is given one extreme case of this fatigue for a field brightness of 418μl. A second series of curves is given in Fig. 8 for one observer (E. K.) picturing the data taken at an earlier date. The field brightness was 432, 324, and 162μl. These curves are of the same general nature as those given in Fig. 5 above, and lie fairly consistently with them. In all respects the external conditions were approximately the

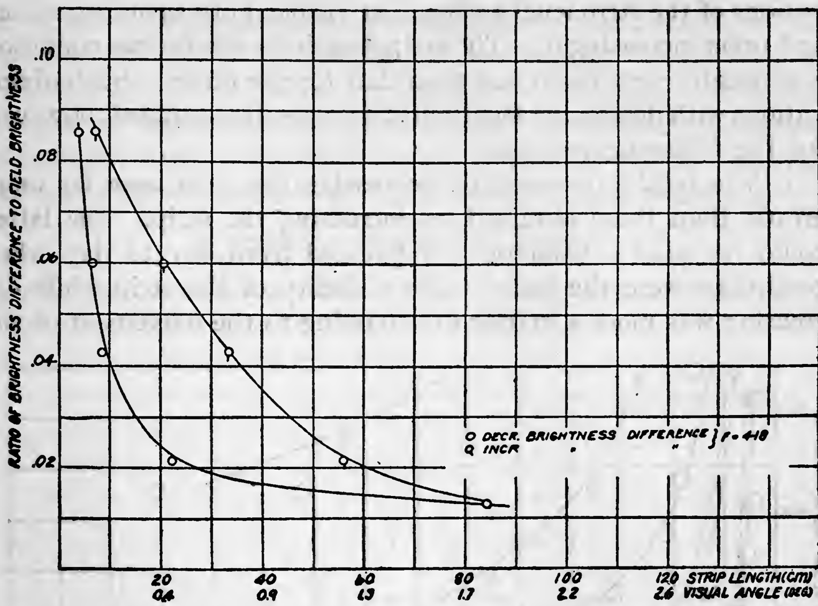


Observer, E. P. T. T., June 20, 21, 1919

Fig. 6.—*Relation between strip length (visual angle) and ratio of brightness difference to field brightness*

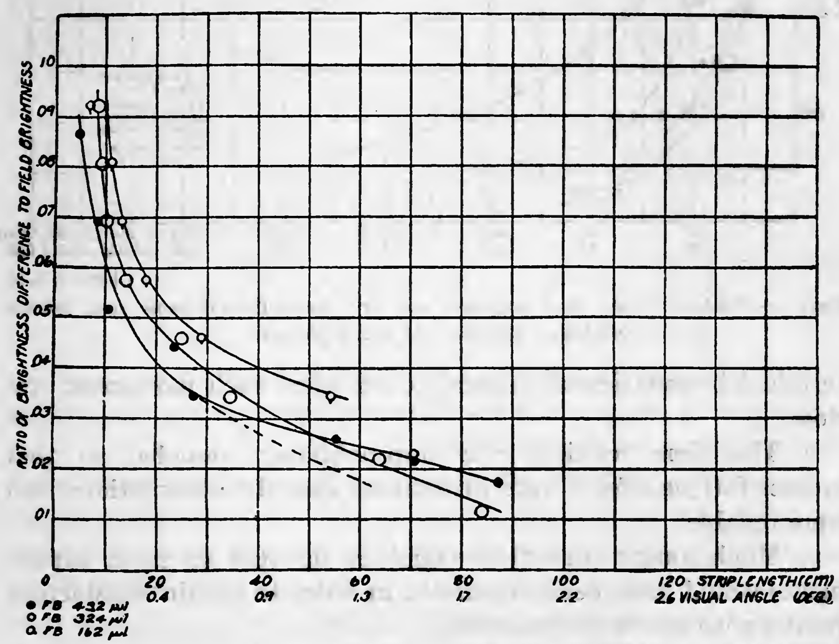
same in the two cases. The crossing of the two curves for the higher field brightness is a result of fatigue and lack of control of the factor of time. When fatigued the eye required a longer time to distinguish the test strip.

In both methods six observations and frequently more were made for each setting of the sector disk. The time between two adjustments of the strip was approximately uniform. The slit was opened at a rate such that the motion of the boundary of the strip of light was imperceptible to the observer. In this connection it may be noted that, in the beginning of the experiments upon the contrast sensibility, it was attempted to record obser-



Observer, E. K., June 24, 25, 1919

FIG. 7.—*Relation between strip length (visual angle) and ratio of brightness difference to field brightness*

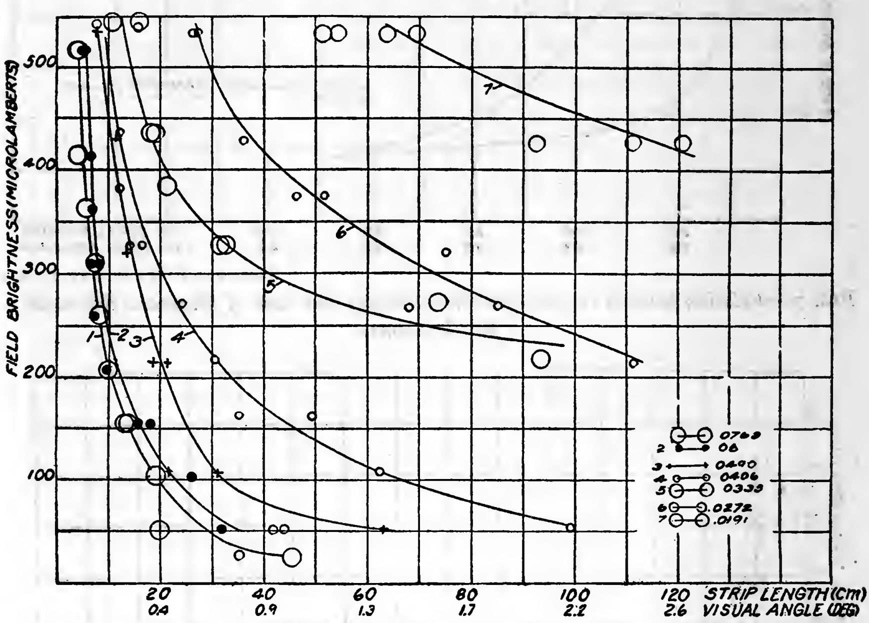


Observer, E. K., June 21, 22, 1919

FIG. 8.—*Relation between strip length (visual angle) and ratio of brightness difference to field brightness*

vations of the strip length when just visible, both upon decreasing and upon increasing it. The strip length for the former condition was usually very much less than that for the latter. Such observations with decreasing length of strip were discontinued, however, for the following reasons:

1. The results obtained on decreasing the strip were far more erratic than those obtained on increasing the strip. The latter could be quite satisfactorily duplicated from day to day when conditions were the same. The visibility of the strip while decreasing was more a matter of attending to the movement of the



Observer, E. K.

FIG. 9.—*Relation between field brightness and strip length (visual angle) ratio between brightness difference and field brightness*

terminal boundaries of the strip even when such movement was slow.

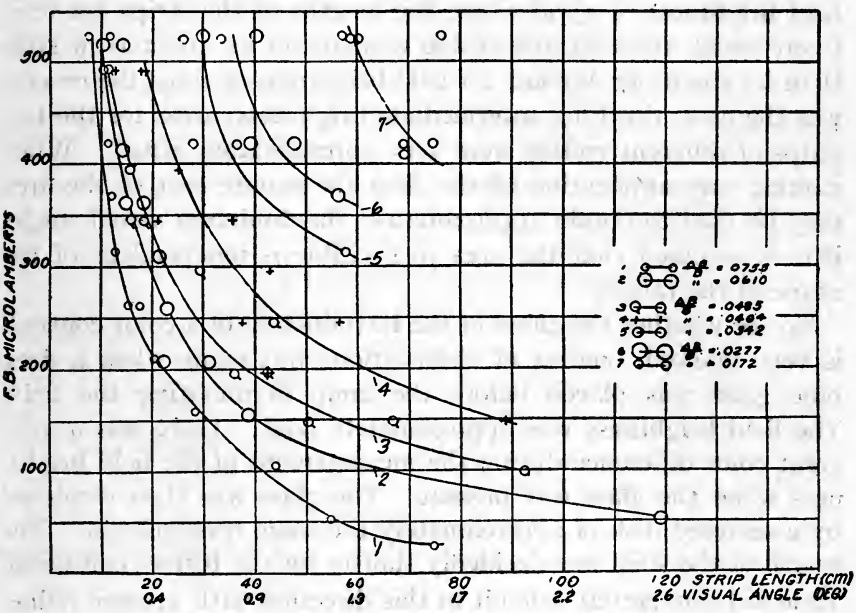
2. The time required was approximately doubled so that greater fatigue effects were introduced into the observations that were reliable.

3. Much longer time than could be devoted to these experiments would have been demanded in order to obtain satisfactory results with the strip decreasing.

The curves of Figs. 4 and 5 are similar, and are somewhat suggestive of hyperbolas, but by test are shown not to be such. These curves are typical of curves that are obtained under approximately the same external conditions. These data should not be generally applied, but similar curves obtained for a large number of observers would be applicable. The necessity of a large number of observers is to eliminate not only differences between individuals but also to eliminate the variations for each individual that depend upon the physiological conditions of the eye.

2. RESULTS BY SECOND METHOD

The data obtained by the second method are somewhat more extensive. These are represented by the curves of Figs. 9 and 10. Ordinates are values of field brightness, in microlamberts;



Observer, E. P. T. T.

FIG. 10.—*Relation between field brightness and strip length*

abscissas are lengths of the strip in centimeters with the equivalent visual angle subtended at the eye of the observer. The relation is given between the visual angles and field brightness, for ratios of difference in brightness to field brightness of 0.0762 to 0.0191 for one observer, Fig. 9, and from 0.0755 to 0.0172 for the second observer, Fig. 10. The curves for the two observers are very similar. The exact location of the individual curves may change with the physiological condition of the observer, but they are always of the same type. Under favorable conditions the curves could be very closely duplicated at different times. The data in the curves were obtained in an interval of 10 nights.

Several of the curves are repetitions of curves originally obtained that were obviously out of proper place for reasons of fatigue.

The curves giving the relationship between the visual angle and brightness or contrast show that, under certain conditions, a very small change in the size of the target demands a very great change in contrast or field brightness. This relationship is such as to suggest the possibility of adapting it to the measurement of distances.

The data given in the curves were obtained with a strip whose width was fixed (19.5 cm). Only a few observations were made with a strip of 8.5 cm wide. These indicated that, first, for a field brightness of 533μl where the lengths of the strips are relatively small, the area just visible was greater for the narrow strip than for the wider; second, for field brightness of 200μl the reverse was the case; third, for intermediate brightness, areas for the two strips of different widths were very approximately equal. When making any application of the data the square root of the area may be used to obtain approximately the minimum visual angle, if it is assumed that the area just visible is independent of the shape of the target.

To see whether the effect of the introduction of a color contrast is very marked, one set of observations was made when a deep blue glass was placed before the lamp illuminating the field. The field brightness was approximately 90μl. There was a very great color difference during the measurement of the field brightness when the glass was present. The glass was then displaced by a sectored disk of approximately the same transmission. The length of the strip was decidedly shorter for the former condition. Time did not permit pursuit in this direction with greater refinement and detail.

VI. SUMMARY

1. Data on the contrast sensibility of the eye is fundamental in searchlight and similar illumination.

2. The relations between visual angle, contrast, and field brightness for two observers are represented in groups of curves which lie consistently with each other.

3. For practical applications mean values obtained from a large number of observers should be employed.

WASHINGTON, August 4, 1919.