Effect of a Peripheral Glare Source Upon the Apparent Brightness of an Object

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THE PROBLEM — A given object or task, when viewed with a glaring light source nearby, appears less bright than when the glare source is removed. Let us use an example to explain how this can happen.

In Fig. 1, the bridge lamp introduces a glare source in the field of view. This glaring light is projected into the eye and causes stray or scattered light to fall over that area of the eye (the fovea) where the image of the music notes is recorded, thus producing a veiling glare or washing out effect and making the object look dimmer. This same veiling effect can be produced by a patch of brightness interposed between the object and the eye whose image overlays the image of the object being seen in the eye. If the effect of a glare source is the same as an overlaying veiling brightness, then one is led to believe in the principle that the combined effect of a number of glare sources in different parts of the visual field can be predicted by adding the *equivalent* veiling brightnesses falling on the fovea from the individual sources. This also lays the foundation for calculating the effect of any bright areas (even though not recognized as glare sources)in the field of view.

Figs. 1, 2 and 3 are examples of illumination accompanied by glare. Even though the glare source adds light to the retinal image of the object being seen, it decreases the apparent brightness of the object.

The Tests

Continuously Exposed Glare Sources — It has been shown previously[1] that a glare source in the visual field seems to reduce the brightness of an object viewed with one eye as compared to a similar object seen by the other eye. Since it has been concluded[2] that there is no communication from one area to another within the eye, this ,effect must

Why does an object viewed near a glare source appear less bright than it does if there is no nearby glare source? This question was studied as Project #17 of the I.E.S. Research Fund, and their findings reported herein, including a method of evaluating loss of visibility.

be the result of stray light or scattering of light in the eye media which lays a veil of light over the image of the object of interest.

In the first experiment a test object to be viewed by one eye was superimposed by a patch of veiling brightness and the object's actual brightness varied by an observer until it appeared to him to match a similar object with no veiling brightness, viewed by the other eye. The relative difference between the actual brightnesses of the two test objects was recorded as a *glare index*. This glare index was found to be a logarithmic function of the veiling brightness, as shown in Fig. 7.

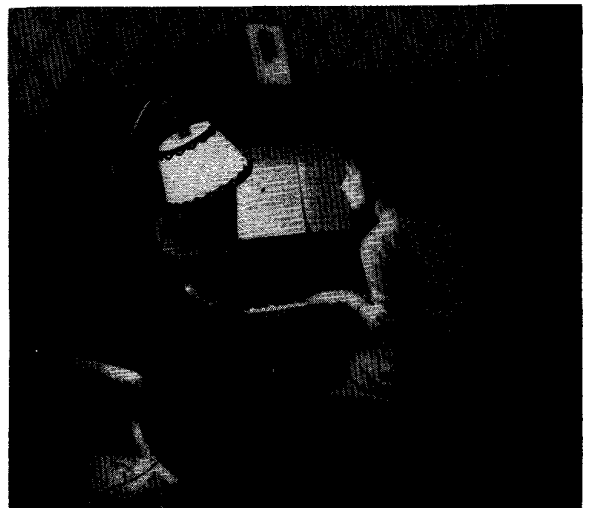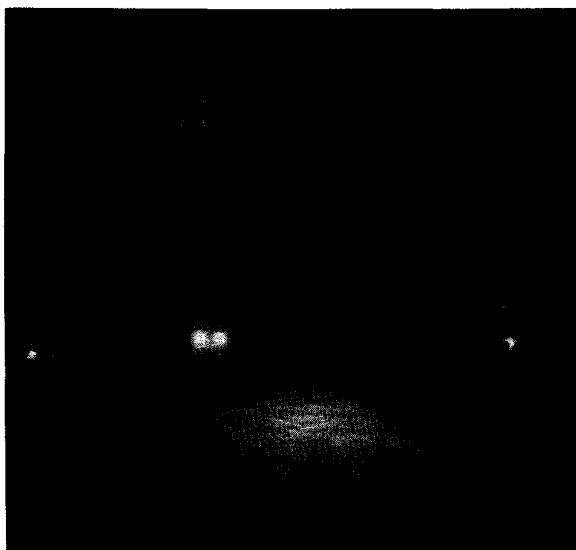In the second experiment the veiling brightness was replaced by two glare sources symmetrically

Figure 1. A common example of peripheral glare — a piano with a too bright lamp.

Figures 2 and 3. More common examples of peripheral glare — workman in front of window with direct sunlight in his eyes, and glare from opposing headlights on a highway.

spaced on each side of the test object. The same results were obtained, indicating that glare sources offset from the axis of vision have the same effect as an area of veiling brightness overlaying the seeing task. The experimental data show that

$$\beta_e = \frac{22.4 \, E}{\theta^{2.5}}$$

where β_e is the equivalent veiling brightness

E is the illumination produced at the eye from the glare sources

θ is the angular distance (subtended at the eye between the glare source and the test object).

This relationship is very nearly the same as ones determined previously by Holladay,[4] Stiles,[5] and Stiles and Dunbar.[6]

Momentary Exposure of Glare Sources—Earlier work[1] demonstrated that exposure to a glare source for various lengths of time before the test object was viewed had a constant effect, regardless of the duration of the pre-exposure after the first 200 milliseconds. The same study investigated also a momentary exposure of the glare source before the test object with a time interval between the glare source and exposure of the test object. The equivalent veiling brightness increased as the interval increased up to 50 milliseconds, and then decreased and disappeared completely when the interval between the two stimuli was as long as 150 milliseconds.

The present project involved a similar experiment using an area of veiling brightness, rather than the glare sources, exposed an interval of time before or after a 5-millisecond exposure of the test and comparison objects. The maximum glare effect was found to occur when the glare source preceded the test object by 50 milliseconds. The veiling glare affects the apparent brightness of the test object even when it follows the test object by as much as 100 milliseconds (Fig. 13).

The rate of recovery from adaptation to a peripheral glare source depends[1] on the length of exposure to the glare source despite the fact that the inhibitory (glare) effect reaches a constant level 200 milliseconds after the beginning of the exposure and retains this level during the rest of the exposure. Appendix C shows that this effect is the same as that obtained by direct adaptation to the equivalent veiling brightness.

Conclusions

Basic — The apparent decrease in brightness of a directly viewed test object produced by a nearby glare source (sometimes called "disability glare") can be accounted for in terms of the veiling glare produced by stray light falling on the fovea of the eye. The same effect can be produced by an overlaying patch of veiling brightness.

The changes in brightness that occur immediately following the onset of a peripheral glare source as well as the changes which occur following removal of the glare source can all be accounted for in terms of the veiling glare produced by stray light falling on the fovea.
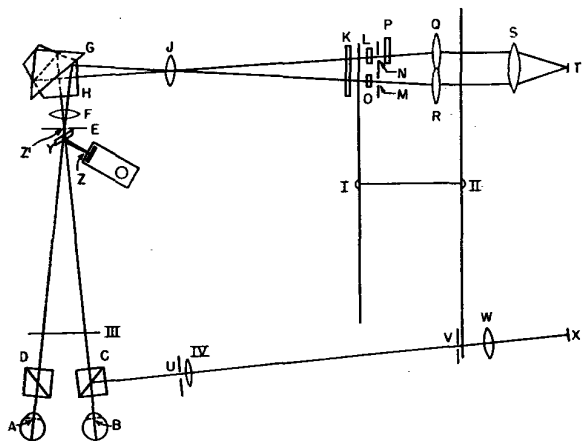
Figure 4. Apparatus for investigating Schouten-Ornstein effect.

A — center of entrance pupil of left eye

B — center of entrance pupil of right eye

C — beam splitting prism permitting right eye to see opening(s) in diaphragm U which are illuminated by light from aperture V

D — beam splitting prism making optical distance from A to E equal to that between B and E

E — diaphragm containing two rectangular openings, a and b as shown in Fig. 6

F, J — lenses forming a 2.2 mm diameter image of aperture M at A, and similar image of aperture N at B

G — right-angle prism; hypotenuse reflects light beam from aperture M to left eye ⎫
           ⎬ Arranged in two tiers with G above H

H — penta-prism; by means of two internal reflections directs beam from N to right eye ⎭

J — see F

K — Wratten neutral density filter

L, P — pair of cross polarized filters

M — see F and R

N — see F and Q

O — Wratten neutral density filter

P — see L

Q — lens which focuses image of filament T at N ⎫
        ⎬ The optical centers of Q and R are separated by an amount equal to the separation of the two apertures N and M

R — lens which focuses image of filament at M ⎭

S — collimating lens

T, X — ribbon filaments

U — diaphragm which can be adjusted to provide two rectangular openings c and c' as shown in Fig. 6, or a single circular opening e as in Fig. 5

V — aperture adjustable in vertical and horizontal direction so its image can be made to fall at exactly the same point as the image of N

W — lens forming an image of ribbon filament X at aperture in diaphragm V

X — see T

Y — horizontal mirror permitting each of the two eyes to observe the mirror image Z' of the bright spot Z. This mirror image Z' falls in the same plane as a and b and midway between them, as shown in Fig. 6

Z — see Y and Z'

Z' — fixation point, image of bright spot Z

I — rotating disk which exposes aperture e (see Fig. 5) for 5 milliseconds once each revolution, and has an opening to prevent it from interfering with the exposure of a and b

II — rotating disk on same shaft as I

III — diaphragm which screens the field of view so that each of the two eyes can see the fixation point Z', but the right eye sees only the rectangular opening b, constituting the test object, and the left eye sees only a, constituting the comparison object.

IV — lens which focuses 2.3 mm diameter image of aperture V at B.

Practical — The implications of this study for practical problems of illuminating engineering are as follows:

The effect of a glare source on any aspect of foveal vision is dependent upon stray light. This lends support to the principle that the combined effect of a number of glare sources in different parts of the field can be predicted by adding the increments of stray light falling on the fovea from the individual sources. This lays the foundation for calculating the effect of any brightness areas or brightness distribution in the field of view. A procedure for doing this has already been outlined by Moon and Spencer.[10, 11]

Visualizing these conclusions in terms of everyday practice one can see where the results can be used to evaluate the loss of visibility of objects or people on the street or highway due to the glare of opposing headlights. (The more the overlaying veiling brightness is built up the less one can see the object of regard.) The same idea would also apply to low mounted floodlights on an athletic field, to theatrical spots and floods on theatrical stage or TV studio, to certain types of industrial lighting, and possibly to some extent to interior office and school lighting, if the luminaire or daylighting fenestration directs a large proportion of light toward the eyes. In fact, the concept would apply to large non-uniformities of brightness anywhere particularly if one is looking at darker detail surrounded by or adjacent to markedly lighter areas. Since the tests disclose a continuance
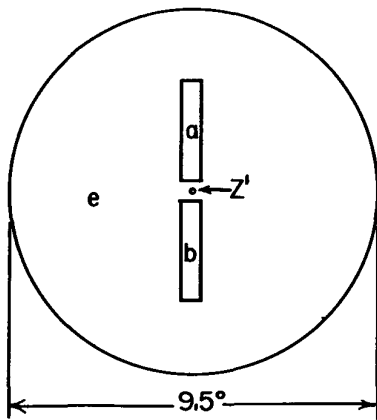
Figure 5 (left). Pattern for investigating the effect of a patch of veiling brightness.
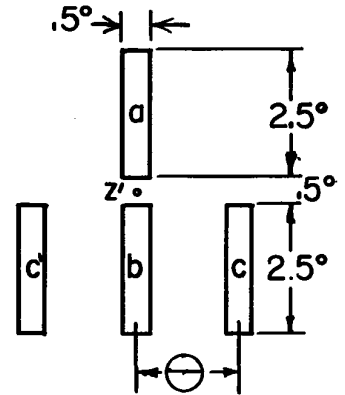
Figure 6 (right). Pattern for investigating the effect of glare sources.

of the veiling glare effect for a time after the removal of the stimulating source, the idea can be applied to eye movements in a room as one looks away from the brightness of the task to darker detail or looks back from a high brightness area in the room to the lower brightness task again.

APPENDIX A.—APPARATUS AND ITS OPERATION

Fig. 4 shows the apparatus used for the experiments described in the subsequent parts of this report. The details of the apparatus have been described in a previous paper.[12] The subject sinks his teeth into a previously prepared biting board, bringing his head into an approximate position. He is then directed to fixate the fixation point Z'. The biting board which controls the position of the head is then adjusted until (1) the center of the entrance pupil B of his right eye coincides with the images of N and V, (2) the center of the entrance pupil of the left eye lies in the same horizontal plane as that of the right eye and (3) the cornea of the left eye lies at an equal distance from Z' as the cornea of the right eye. To aid this operation, a diaghragm containing a small circular hole for the right eye and a horizontal slit for the left is mounted between diaphragm III and the beam-splitting prisms, C and D. The assembly supporting the right angle prism G and the penta prism H is then rotated until the image of M falls at the center of the entrance pupil A of the left eye. The rotation of H does not affect the position of the image of N.

Lens W forms an image of ribbon filament X at the aperture in V. The rays from ribbon filament T are collimated by S, and Q focuses an image of T at aperture N; R focuses an image of T at the aperture M. The optical centers of Q and R are separated by an amount equal to the separation of the two apertures N and M.*

Experiments involving simultaneous momentary exposure of a and b preceded or followed by a momentary exposure of e (see Fig. 5) were made possible by means of electromagnetic shutters and rotating disks. The rotating disk II exposes e for 5 milliseconds once each revolution. By adjusting disk I with respect to II, a and b can be made to precede or follow e by any interval up to 300 milliseconds. A cam on a shaft rotating one-fourth as fast as the shaft

carrying the two disks controls the two electromagnetic shutters which permit exposure of the targets once every four revolutions of disks I and II. A system of relays was also worked out to permit the operator to give a single exposure by pressing a key.

The brightness of the targets seen by reflection at C was varied by Wratten neutral density filters and by a pair of crossed polaroids placed at V. The brightness of b seen by transmission through beam-splitter C can be varied independently from that of a seen through beam-splitter D by a pair of cross polaroid filters L and P. The brightness of the target as seen through D can be varied independently of that of b seen through C by Wratten neutral density filters O. The brightness of targets a and b can be varied together by means of Wratten neutral density filters K. The entire apparatus is supplied with suitable baffles so that no extraneous light can enter the eyes.

APPENDIX B.—DETAILED PROCEDURE

B-1 — *Effect of a Patch of Veiling Brightness Upon the Apparent Brightness of the Test Object* — The stimulus pattern for this experiment is shown in Fig. 5. A patch of veiling brightness e having a diameter of 9.5 degrees is superimposed upon the test object b with its center falling at the fixation point Z'. The fixation point, test object b, and the patch of veiling brightness superimposed upon it are seen by the right eye. The left eye sees only the fixation point and the comparison stimulus a. The brightness β_a of a is kept fixed; the brightness β_b of b is varied in order to make it match a in brightness. For various levels of brightness for the veiling glare β_e one of the subjects (TH) made five settings of β_b. The results are presented in

TABLE I.—Data for T. H. obtained with the stimulus pattern in Fig. 5 showing the effect of varying β_e. β_e and β_b are expressed in footlamberts.

β_e	β_b	Υ	β_e	β_b	Υ
0	4.98*	0	55.8	17.06	2.42
1.116	5.30	.064	111.6	22.26	3.47
2.49	5.22	.048	223.0	22.12	3.42
4.70	5.86	.18	335.0	25.0	4.03
11.16	7.28	.46	558.0	39.4	6.93
22.32	9.68	0.94	1245.0	61.0	11.25
27.9	10.62	1.13	2350.0	110.5	21.2

*Value for β_a used in computing values for Υ.

*In some of the early experiments both N and M were illuminated by a piece of opal glass which in turn was illuminated from the rear by a single lamp. Also, in some of the early experiments a 100-watt inside-frosted lamp was used at X instead of the ribbon filament lamp.
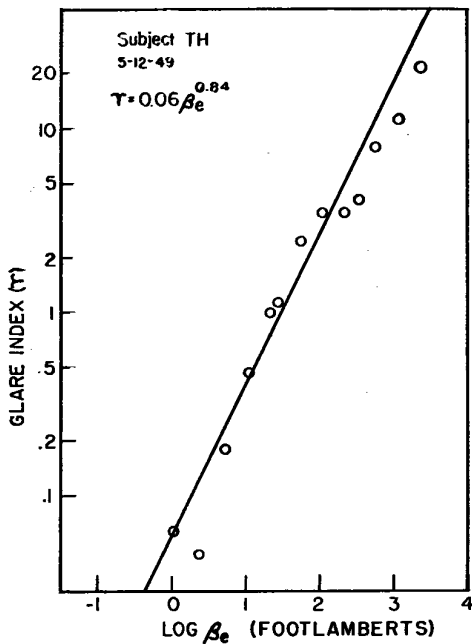
Figure 7. Results for subject T. H. obtained with the stimulus pattern in Fig. 6, showing the effect of varying the brightness of the patch of veiling glare, e.

Table I and Fig. 7. In Fig. 7 the data are expressed in terms of Υ and β_e. The symbol Υ represents a quantity which is called the glare index by Schouten and Ornstein[1] and is defined as follows:

$$\Upsilon = \frac{\beta_b}{\beta_a} - 1 \qquad (1)$$

The important point is that β_b continually increases as β_e increases. If one begins with a match between β_a and β_b and then increases the veiling glare, this cuts down the perceived brightness of b in spite of the fact that it adds to the original brightness of b, and the brightness of b must be further supplemented to reestablish the match with a.

With much simpler equipment, this type of experiment was carried out with three other subjects who obtained the same type of result. The slope of the best fitting straight line varies from day to day between about 0.7 and 1.0. The value used for β_a in calculating Υ is based on a binocular match between b and a when the veiling glare is off, and

TABLE II.—Data for G.A.F. obtained with the stimulus pattern in Fig. 6 showing the effect of varying θ and β_c on the actual brightness of b required to make b match a. Brightness β_a of a constant. β_b and β_c are expressed in footlamberts.

β_c	c and c' Removed	β_b					
		θ					
		0.75°	1°	1.5°	2.5°	3.5°	4.5°
2350.0	6.74	126.00	53.8	30.0	16.94	10.76	10.64
1245.0	6.34	65.0	32.7	22.3	15.78	11.5	9.42
558.0	7.34	47.5	21.4	13.04	8.96	8.68	8.2
335.0	5.83	33.0	17.3	12.95	7.95	6.6	6.95
223.4	6.48	30.1	14.94	11.0	7.77	6.66	8.52
111.7	5.78	19.3	10.2	9.14	7.98	7.62	6.2
55.8	5.46	11.48	9.6	8.16	7.3	6.14	5.98
27.9	6.24	13.2	7.66	6.06	6.56	7.02	5.34

any error in the determination of this value produces a marked effect on the slope of the best fitting straight line. Values of Υ are practically meaningless for small values of β_e where the difference between β_a and β_b is no longer significant. Variations in the relative sensitivities of the two foveas will also affect the results.

An explanation of how a patch of veiling brightness can reduce the apparent brightness of an object has been attempted in a previous paper.[3]

B-2—*Effects Obtained with Glare Sources* — The stimulus pattern for this part of the investigation is illustrated in Fig. 6. In this pattern the two rectangles c and c' constitute the glare sources and these are symmetrically placed on opposite sides of test object b. The distance from the center of b to the center of either of the glare sources is θ. For several different fixed values of θ the subject made five separate settings for the actual brightness of b which made the apparent brightness of b equal to that of a which is seen by the opposite eye. In each run the order of θ values was from large to small. Prior to each run, a set of data was obtained with the inhibiting stimuli removed from the field of view.

The data for two separate subjects are summarized in Tables II and III and are plotted in Figs. 8 and 9.

In order to compare this type of data with that shown in Fig. 7 values of glare index Υ were computed for the data shown in Fig. 9 in accordance with Equation (1).

The values of Υ for observer T. H. are summarized in Table IV. Values of Υ less than 0.1 have little meaning because of the indeterminateness of the data. It should be noted that the value of β_a was determined by making a binocular match between β_b and β_a when the glare sources are removed from the field. This makes the results independent of any imbalance which might exist between the
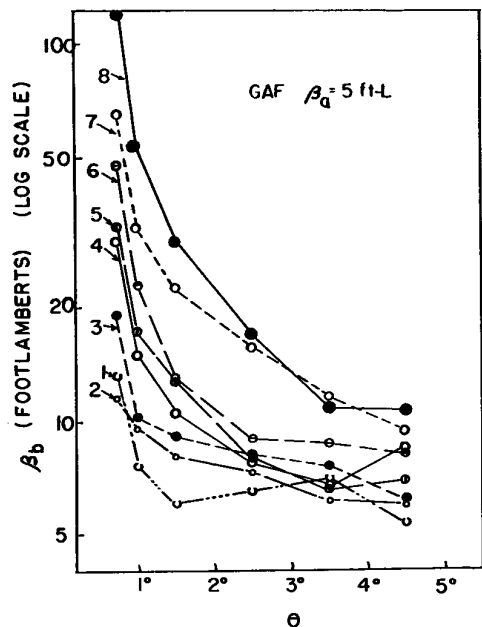

Figure 8. Results obtained by subject G. A. F. with the stimulus pattern shown in Fig. 6. The different curves represent different values of β_c in footlamberts as follows: 1 = 27.9; 2 = 55.8; 3 = 111.7; 4 = 223.4; 5 = 335; 6 = 558; 7 = 1245; 8 = 2350.

TABLE III.—Data for T. H. obtained with the stimulus pattern in Fig. 6 showing the effect of varying θ and β_c on the actual brightness of b required to make b match a in brightness. Brightness β_a of a constant. β_b and β_c expressed in footlamberts.

| β_c | c and c' Removed | β_b | | | | | |
| | | 0.75° | 1° | 1.5° | 2.5° | 3.5° | 4.5° |
		θ					
6.65	5.81	5.04	4.92	6.28	6.46	5.74	5.5
16.63	4.71	5.84	5.22	4.7	4.66	4.72	5.1
33.25	4.73	9.96	8.38	7.36	6.3	6.06	5.74
66.5	5.07	8.94	6.06	5.28	4.8	4.89	5.54
166.3	4.68	7.12	5.3	5.16	4.84	4.95	4.80
332.5	4.67	9.68	6.7	5.46	5.1	4.93	4.64
665.0	4.74	13.2	8.54	6.56	5.72	5.28	5.4
1,663.0	5.12	22.6	16.06	11.32	8.74	8.56	6.98
3,325.0	4.75	18.74	11.34	9.14	7.68	6.08	5.08
6,650.0	4.76	35.6	25.5	20.26	15.04	9.96	7.04
16,630.0	4.73	62.2	42.2	28.8	18.62	12.46	9.82
33,250.0	5.36	95.4	64.6	40.4	31.8	20.18	15.92
74,100.0	5.6	684.0	91.8	58.8	39.4	30.0	18.24
139,900.0	5.47	—	678.0	107.8	99.8	58.2	30.0

Mean — 5.0

two eyes. The balance between the two eyes varies considerably from observer to observer and from one experimental session to another. A redetermination of β_a was made for each brightness level and these varying values of β_a were used in computing values of Υ.

Fig. 10 shows values of log Υ plotted against log β_c for various values of θ. The variation in the slopes of the best fitting straight lines may be dependent in part upon the variations in balance between the two eyes or a small error in the determination of β_a. If the variation in Υ were completely determined by stray light falling on the fovea, the slope of the line in these graphs as well as those in Fig. 7 should be the same.

By using the graphs in Fig. 10 to interpolate the data, one can determine for the various values of θ the value of β_c required to yield a constant value of Υ. In Fig. 11 are shown the values of β_c for different values of θ which are required for a value of Υ equal to unity. This means that the amount of stray light falling on the fovea is constant, and according to Fig. 4 the equivalent veiling brightness β_e is equal to 30 footlamberts. From the data in Fig. 11

$$\beta_e = \frac{\kappa \beta_c}{\theta^\nu} \qquad (2)$$

where $\kappa = 0.00545$, and $\nu = 2.5$. The illumination at the

TABLE IV.—Data from Table III expressed in terms of Υ.

| β_c | θ | | | | | |
	0.75°	1°	1.5°	2.5°	3.5°	4.5°
6.65	—	—	.0812	.112	—	—
16.63	.219	.1082	—	—	.0021	.0828
33.25	1.106	.763	.557	.333	.282	.214
66.5	.762	.195	0.41	—	—	.0927
166.3	.522	.1327	.1005	.0342	.0577	.0256
332.5	1.072	.435	.169	.092	.0557	—
665.0	1.78	.8	.384	.2062	.114	.139
1,663.0	3.41	2.13	1.21	.707	.6725	.363
3,325.0	2.95	1.38	.925	.617	.280	.0695
6,650.0	6.48	4.35	3.25	2.16	1.091	.479
16,630.0	12.12	7.94	5.09	2.94	1.632	1.074
33,250.0	16.82	11.04	6.53	4.94	2.76	1.97
74,100.0	121.0	15.38	9.49	6.04	4.36	2.26
139,900.0	—	122.8	18.9	17.25	9.63	4.46
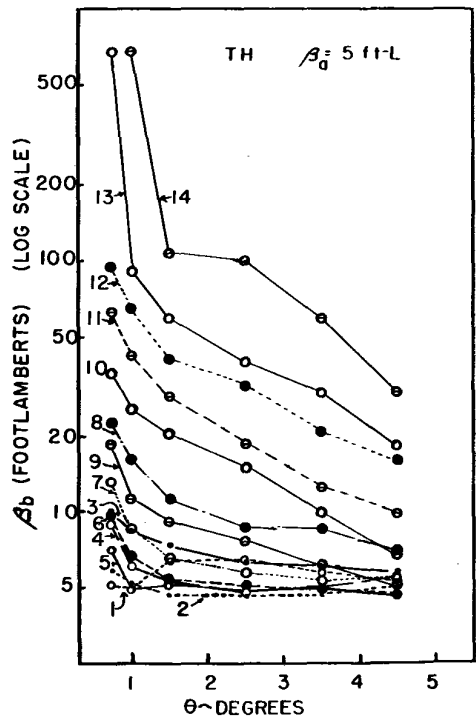
Figure 9. Results obtained by subject T. H. with the stimulus pattern shown in Fig. 6. The different curves represent different values of β_c in footlamberts as follows: 1 = 6.65; 2 = 16.63; 3 = 33.25; 4 = 66.5; 5 = 166.3; 6 = 332.5; 7 = 665; 8 = 1663; 9 = 3325; 10 = 6650; 11 = 16,630; 12 = 33,250; 13 = 74,100; 14 = 139,900.

eye E produced by the two glare sources is given by the following equation

$$E = \frac{\beta_c}{\pi} \omega \qquad (3)$$

where ω is the solid angle (in steradians) subtended by the two rectangular glare sources, and where E is expressed in footcandles and β_c in footlamberts.

Since $\omega = 7.656 \times 10^{-4}$ steradians,

$$\beta_e = \frac{22.4 E}{\theta^{2.5}}, \qquad (4)$$

where β is expressed in footlamberts and E in footcandles.

It should be noted that the form of Equation (4) is identical with that of the equations used by Holladay,[4] and Stiles,[5] and Stiles and Dunbar[6] to express the relationship between the intensity of the glare source, the glare angle, and the equivalent veiling brightness. The values of the constants are also in reasonable agreement with those found by these investigators when allowance is made for the units used. The equation given by Stiles and Dunbar is

$$\beta_e = \frac{10 E}{\theta^2} \qquad (5)$$

where β_e is expressed in candles per unit area and E in lumens per unit area.

In the experiment described above, the beam of light entering the eye was confined to an area smaller than the pupil and was not affected by variations in pupil size. In
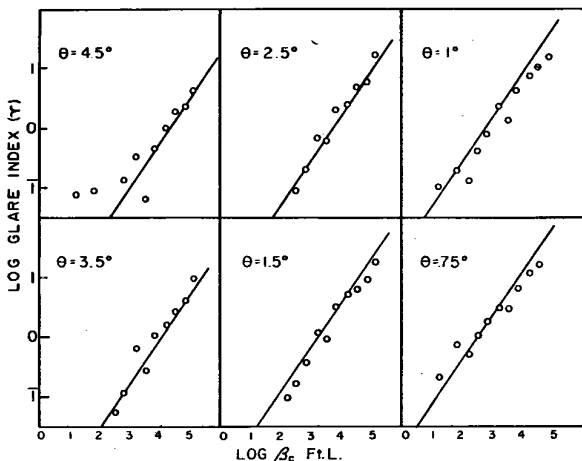
Figure 10. Results obtained by T. H. with the stimulus pattern shown in Fig. 6.

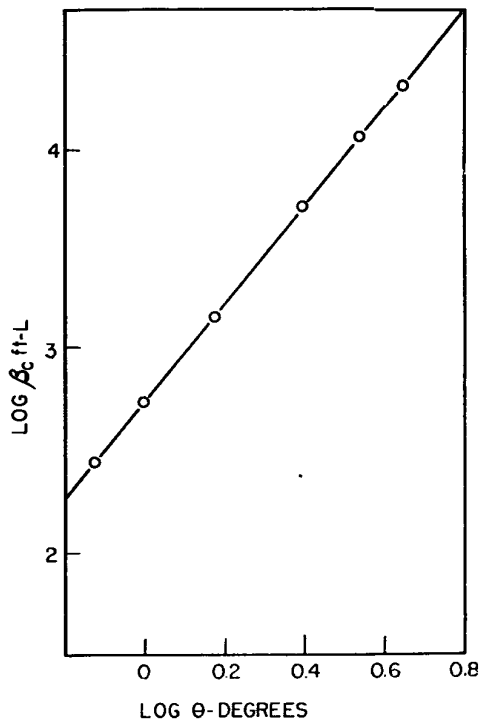

Figure 11. Values of β_c required to yield a value of unity for Υ for various values of θ. Data interpolated from the curves in Fig. 10.

this respect the experiment differs somewhat from those performed by the previous investigators. It should also be noted that the data presented by the authors are limited to glare angles from ¾ to 4.5 degrees, and the data presented by Stiles and Holladay[4] and Stiles and Dunbar[6] cover much larger glare angles.

B-3—*Changes in Foveal Sensitivity Immediately Following the Onset of a Glare Source* — Schouten and Ornstein[1] used the stimulus pattern shown in Fig. 12 for studying the changes in foveal sensitivity which occur immediately after the onset of a glare source. They exposed the glare source for various durations and during the last 10 milliseconds of this exposure also exposed a' and b'. The semicircle b' and the glare source were seen by the right eye, and a' was seen by the left eye. The brightness of a' was kept constant and that of b' was varied from exposure to exposure to make b' match a'. In this way they demonstrated that the sensitivity falls gradually during the first 200 milliseconds and after this remains constant. No overshooting occurs.*

The maintenance of a constant level after the first 200 milliseconds they designate as the *law of constant level*. This empirical law is of great theoretical significance in formulating and testing hypotheses concerning the mechanism subserving the effect, but the practical bearing upon the present investigation is that the finding of Schouten and Ornstein can be used as justification for using glare sources continuously exposed and making measurements without reference to the duration of exposure. Care has been exercised, however, in starting off each experimental session with the subject dark adapted and working always from the lower to the higher brightness levels.

B-4 — *Effects Obtained with Asynchronous Momentary Stimuli* — Schouten and Ornstein[1] used the stimulus pat-

*Schouten and Ornstein attached a great deal of significance to the fact that no "overshooting" occurs. This points to the possibility that the effect may be tied up with component III of the retinal potential as analyzed by Granit. However, if stray light falling on the fovea is responsible for the loss in sensitivity, one would expect this to be brought about by a lowering of the concentration of the photosensitive substance in the photoreceptors until this concentration reaches its equilibrium. No overshooting is to be expected in this process.[7]

tern shown in Fig. 12 also to study the effects of a momentary exposure of the glare source. They exposed the glare source for 10 milliseconds and after an interval exposed a and b simultaneously for 10 milliseconds. They reported that the inhibitory effect of the glare source on b increases as the interval increases up to about 50 milliseconds and then decreases and disappears completely when the interval between the two stimuli is as long as 150 milliseconds.

Since the glare angle employed was 10 degrees it appeared to us that this effect might depend upon stray light superimposed upon the test object and its immediate surround. If this is true one should be able to produce the same effect with a patch of artificial stray light. In order to study this type of effect first hand, the stimulus pattern illustrated in Fig. 5 was employed. The artificial stray light e was presented for an exposure of 5 milliseconds, and at a certain interval of time prior to or succeeding this
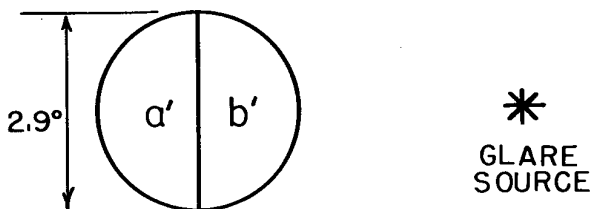

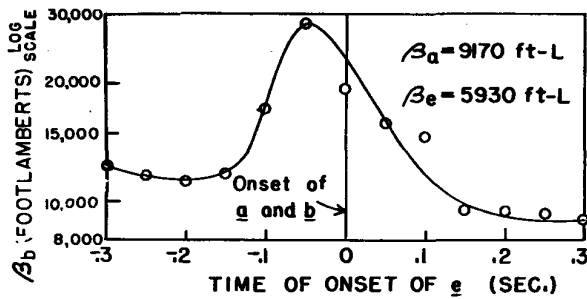Figure 12. Stimulus pattern employed by Schouten and Ornstein.

$\beta_a = 9170$ ft-L

$\beta_e = 5930$ ft-L

Figure 13. The effect of a synchronous exposure of e and a-b (Fig. 6). Zero on the time scale represents the onset of a and b which are exposed simultaneously for 5 milliseconds. The patch of veiling glare e is also exposed for 5 milliseconds. When e is turned off, b matches a when $\beta_b = 9170$ footlamberts.

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exposure of e, a and b were exposed simultaneously for 5 milliseconds. This cycle of exposures was repeated once every three seconds. The effect of e upon b was determined by varying the brightness of b to make it match a in brightness. The subject started with the brightness of b at a level which made it appear brighter than a and from one cycle to the next reduced the brightness of b until it appeared to match a. He then started with a brightness of b which made it appear darker than a and increased the brightness of b to obtain a match. This procedure was repeated three times and an average of the six settings was taken as representing a match.

Similar matches were made for other time intervals between the exposure e and the exposure of a and b. The results are shown in Fig. 13 and are summarized in Table V.

It should be noted that after 300 milliseconds the retina is just recovering from the veiling glare. The maximum inhibitory or adaptation effect occurs when the glare source precedes the test object by 50 milliseconds. It should be noted also that the veiling glare can affect the test object even when it follows the test object by as much as 100 milliseconds. A similar effect upon the threshold of visibility has been noted by Crawford.[8]

APPENDIX C.—ANALYSIS OF RECOVERY FROM INDIRECT ADAPTATION

Schouten and Ornstein[1] showed that the rate of recovery from adaptation to a peripheral glare source depended upon the length of exposure of the eye to the glare source in spite of the fact that the inhibitory effect reaches a constant level 200 milliseconds after the beginning of the exposure and retains this level during the rest of the exposure. They showed that the effects were analogous to those obtained by direct adaptation.

As a matter of fact, it is possible from the data presented in Figs. 9 and 10 in their paper[1] to show that the recovery curve following direct adaptation for 60 seconds to a surface having a brightness of 270 c/m² (79 footlamberts)

TABLE V.—The effects on T of asynchronous flash (5 milliseconds exposures of e and a-b (see Fig. 6). $\beta_e = 5930$ footlamberts. β_a constant. β_b varied from one cycle of exposures to the next to obtain a match with a. β_b in footlamberts.

	milliseconds	β_b
No veiling glare		9,170
e precedes a-b by	300	12,510
	250	11,800
	200	11,220
	150	11,700
	100	17,200
	50	28,290
e and a-b together		19,400
e follows a-b by	50	15,800
	100	14,630
	150	9,570
	200	9,550
	250	9,410
	300	9,200

would be approximately the same as the recovery curve following indirect adaptation for 60 seconds to a glare source at a glare angle of three degrees and producing an illumination of 130 lux (12 footcandles) at the eye.

According to Equation (5), a glare source at a glare angle of three degrees and producing an illumination of 12 footcandles at the eye should produce an amount of stray light equivalent to a veiling brightness of 42 footlamberts. This calculated value is close enough to the empirical value of 270 c/m² (79 footlamberts) to lead one to suspect that indirect adaptation is dependent upon stray light falling on the fovea.

If this is true, the mechanism of adaptation is essentially the same in both direct and indirect adaptation and can probably be explained in terms of the primary photochemical mechanism in the photoreceptors.

APPENDIX D.—EFFECT OF WAVELENGTH COMPOSITION

Schouten and Ornstein[1] and Ivanoff[9] have investigated the effects of varying the wavelength composition. If the effects are dependent indirectly upon stray light in the eye, the differential reflectance of the retina and the differential transmittance of the sclera and choroid for the various wavelengths would contribute to the variations that have been found.

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