A DIRECT MEASUREMENT
OF
INTRAOCULAR STRAY LIGHT

by

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Introduction

Holladay[1] has described a comprehensive research in the effects of glare on visibility, and has indicated that a concentrated, bright source of light in an otherwise uniform visual field has an effect similar to an over-all "veiling-brightness" added to the entire field. Holladay's work involved the measurement of the contrast sensitivity of the eye, first with a glare source superimposed on a uniform field and, second, with a uniform veiling-brightness added to the uniform field. From these two experiments the effect of a glare source can be expressed in terms of an equivalent veiling brightness; equivalent in that it produces the same change in contrast sensitivity as does the glare source.

Bartley & Fry[2] have described similar experiments. Bartley[3] has also reported the results of direct photometry from the exterior of an excised rabbit's eye in an effort to measure directly the ratio of the amount of focused light to the amount of unfocused light incident on the retina.

Bartley[3] has also described a method for demonstrating the presence of intraocular stray light by the use of a small flickering source in an otherwise uniform field. Under these conditions not only the small source but the surrounding field appears to flicker, presumably because of stray light. Bartley measured the critical flicker frequencies for both the flickering source and the surround in an attempt to establish the reason for the field flicker and to measure its magnitude. On the basis of his experiments, Bartley concluded that the flicker in the surround is very probably due to stray light and not to some sort of retinal interaction.

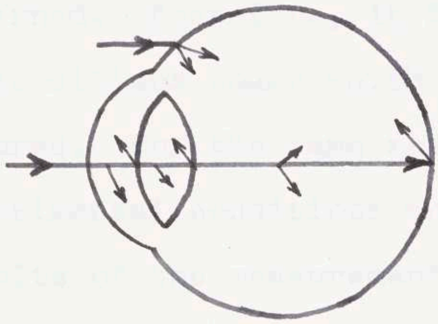
The contrast sensitivity and critical flicker frequency experiments are typical of the indirect methods for measuring intraocular stray light. Each consists essentially of two separate experiments in which some characteristic of the eye such as contrast sensitivity or critical flicker frequency is measured under two sets of conditions. The results of one experiment are used as a calibration of the visual apparatus, namely the eye, and the accuracy of the results of the other experiment depends on the assumption that the calibration holds also for the second experiment.

This means that such conditions as adaptation level, pupillary diameter, and fatigue must be carefully controlled in both experiments.

The purpose of this investigation was to develop a direct method of measuring intraocular stray light in one experiment. In contrast to the indirect methods, this direct method does not depend on the measurement of another property of the eye in order to evaluate the amount of stray light within it. Rather, the stray light is measured in terms of easily determined photometric quantities. The term "stray light" can be defined in several ways, so it is convenient to consider immediately the causes of what, in the most strict definition, might be called intraocular stray light.

The eye can be considered as an optical instrument which forms a real image on the retina of an object in the object space outside the eye. To simplify the discussion, it is convenient to choose as the object upon which the eye is focused an infinite plane perpendicular to the axis of the optical system. If the optical system were perfect, all of the light which enters the eye from an elemental area $d\sigma$ in the object would be imaged in the conjugate area $d\sigma'$ in the retinal image, and no light from other regions on the object would strike that area of the retina, either directly or after reflection from other parts of the eye.

For several reasons, some of the light entering the eye does not behave according to these conditions, and might, in the most general definition, be called stray light. For example, because of diffraction, a point on the object will always be imaged on the retina as an area. Also, even the normal eye is afflicted with the aberrations of geometrical optics, and these cause deviations from the point-to-point relationships given above. The effect of these two phenomena is relatively local in nature. They tend to cause part of the light from an area $d\sigma$ in the object to be spread over the region surrounding the conjugate area $d\sigma'$ on the retina. On the other hand, there are several causes of a more diffuse distribution of part of the light entering the eye. These are indicated in Figure 1.



Sources of Diffuse Stray Light

Figure 1

Some light is reflected at the boundaries between the components of the eye which have different refractive indices. There is also scattering within components which are not optically homogeneous. Some light enters the eye through the sclera which surrounds the cornea and therefore it is not focused. In addition, a portion of the light which strikes the retina, whether focused or not, is reflected and may strike the retina elsewhere. The net effect of these processes is to produce a diffuse distribution of some of the light from an area $d\sigma$ on the object over a considerable area of the retina.

Thus, it is possible to consider two types of stray light, local and diffuse. Depending on the distribution of light in the scene being viewed, it is possible that one type of stray light might be more important than the other in affecting the appearance of the scene, just as it is possible that the effect of stray light of either type may or may not be important as far as the appearance of the scene is concerned. Therefore, it is important to state explicitly the conditions under which the quantity of stray light is measured. For the same reasons, it is important to choose experimental conditions which approximate those to which the results of the measurement are to be applied.

The Method Used in this Investigation

A. General

In general terms, the method of measurement used in this investigation is as follows. Consider the eye to be fixated on a small, uniformly bright area on a plane in the object space. Let the size of this area be such that its image on the retina falls within the fovea. The remainder of the object plane may have any brightness distribution desired, but the brightness of this surround varies in time as $A \sin^2 wt$. Some of the light from the surround will be scattered to the area of the fovea on which the fixation spot is imaged. If the quantity of stray light from the surround is sufficient and if $\frac{w}{2\pi}$ is below the critical frequency of flicker, the fixation spot will appear to flicker as $A' \sin^2 wt$. If now the fixation spot is illuminated by additional light whose intensity varies as $B \cos^2 wt$, the conjugate area on the fovea will receive light flickering as $B' \cos^2 wt$. By setting the amplitude of the $\cos^2 wt$ component of the foveal illumination equal to that of the $\sin^2 wt$ component, the flickering of the fixation spot will cease, since $A' \sin^2 wt + B' \cos^2 wt = A'$ if $A' = B'$. A measurement with an ordinary photometer of the average value, $\frac{B}{2}$, of the brightness of the fixation spot gives the apparent increase of brightness of that area due to stray light from the surround.

In this investigation the illuminated portion of the field of view consists of a uniformly bright circular area in a plane normal to the line of sight and with a small test spot in the center. The method of illuminating the field is shown in the accompanying diagram of the apparatus, (Figure 2).

The light source is a 500-watt projection lamp operated on the 115 volt, D.C. power circuit. The condensing lens L_1 forms an image of one-half of the lamp filament on the projection lens L_2 directly. The mirror M_1 reflects about one-half of the light from L_2 through the Polaroids P_3' and P_4' and the lens L_2'.

P_1 is a Polaroid which rotates about an axis through its center and normal to its surfaces. It is driven by means of a motor whose speed can be varied over a wide range by the observer. P_2 is a fixed Polaroid, and P_3 is another Polaroid whose plane of polarization can be set at any angle with respect to that of P_2. The combination of P_1, P_2, and P_3 provides a means of illuminating the screen with light whose intensity varies as $A \sin^2 wt$, where w is just the angular velocity of P_1. By rotating P_3, the amplitude of the screen illumination can be varied without changing its phase. P_2' is a Polaroid fixed with its plane of polarization at 90° with respect to that of P_2, so that the light reflected by the mirror M_1 varies in intensity as $B \cos^2 wt$. Since a portion of the light reflected from M_1 is depolarized in the process of reflection, a Polaroid

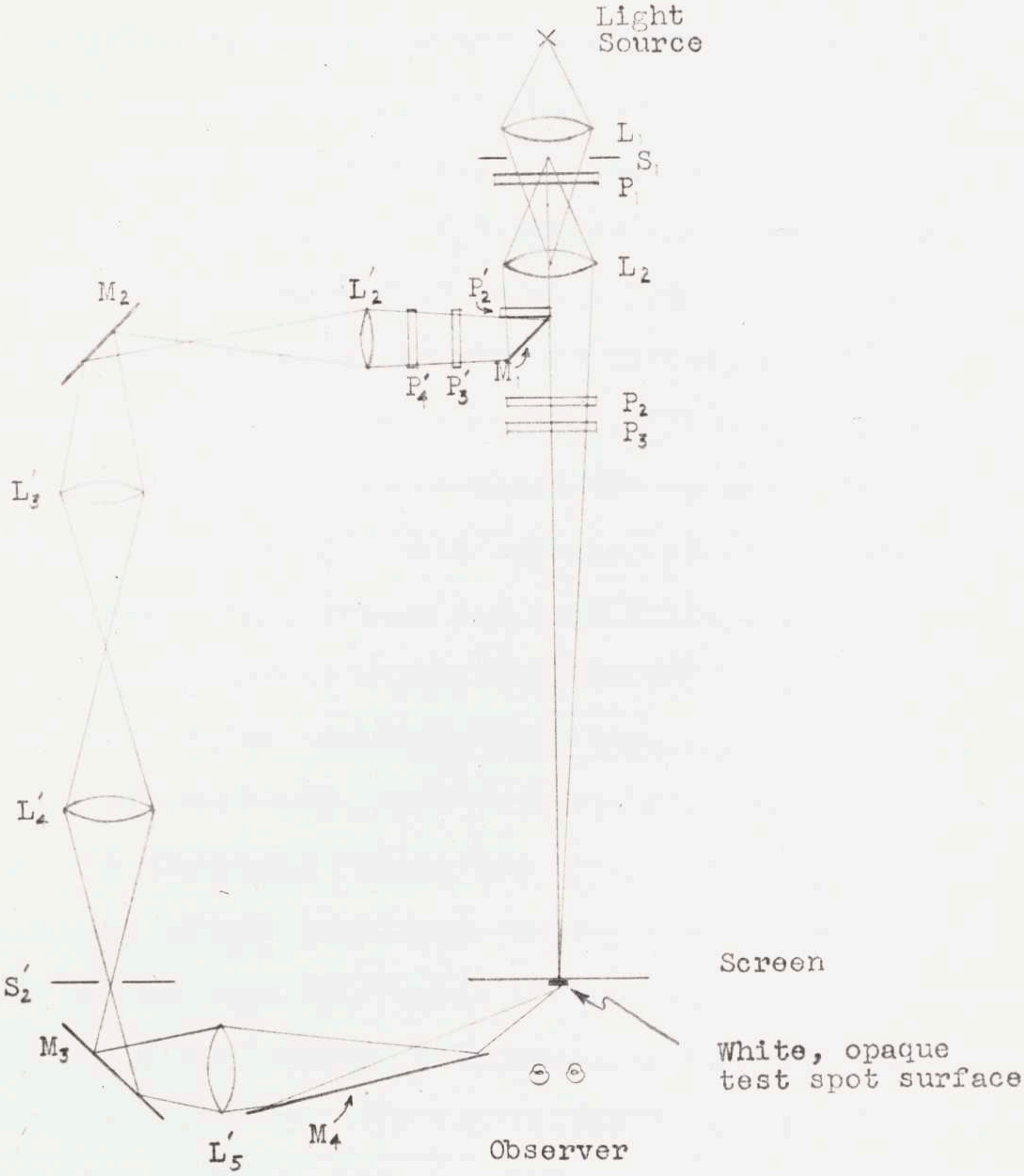

Light
Source
L_1
S_1
P_1
L_2
M_2
L'_2
P'_2
M_1
P'_4
P'_3
P_2
P_3
L'_3
L'_4
Screen
S'_2
M_3
White, opaque
test spot surface
L'_5
M_4
Observer

Figure 2

P_3', with its plane of polarization parallel to that of P_2', is used to insure that only plane-polarized light strikes P_4'. The latter Polaroid is rotatable by the observer about an axis normal to its surfaces and its position is read on a divided circle. The combination of P_1', P_2', P_3, and P_4' causes the intensity of the light beam which passes through the lens L_2' to vary as B $\cos^2 wt$, and the value of B is varied, without changing the phase, by rotating P_4'. The light from L_2' passes through the second optical train, which includes a rectangular stop S_2' with variable dimensions. An image of S_2' is focused on and just fills a white, opaque, matte surface which is attached to the screen on the side of the observer. The screen itself is a sheet of flashed opal glass with the flashed side turned toward the observer. These two optical systems provide a uniformly bright field surrounding a small test spot at its center, the brightness of the field varying in time as A $\sin^2 wt$ and the brightness of the test spot varying as B $\cos^2 wt$. The amplitudes of the flicker in both field and test spot are variable continuously from zero to the maximum value.

The viewing conditions which were finally used were influenced by expediency. The apparatus was first designed for a viewing distance (observer's eye to screen) of ten inches and with a circular screen of such dimensions that the diameter of the illuminated surround subtended a plane angle of 90 degrees at the eye. Because the screen illumination is limited by the size of the Polaroid discs and the f/numbers of the lenses, it was found that the available apparatus did not permit a sufficiently great screen brightness. Accordingly, the diameter of the bright surround was reduced and its brightness increased by moving the screen closer to the lens L_2. It was necessary to reduce the plane angle subtended at the observer's eye by the diameter of the field to 36 degrees. Although this restriction of the size of the surround limits the usefulness of the measurements made with this particular apparatus, it in no way affects the validity of the method itself. The viewing distance finally used was ten inches. The observer's head can be fixed in position by means of a biting board, and arrangements can be made for the use of either binocular or monocular vision. Since the observer's eye is only ten inches away from the test spot, some of the light from the screen will be reflected to the test spot from the face and clothing of the observer. To determine the effect of this reflected light on the measurements made, a black cloth with two holes for the eyes was placed over the observer's head and chest. Measurements taken under these conditions showed no systematic variation from those made without the cloth, and the latter was dispensed with.

In making an observation, the observer takes the biting board in his teeth and fixates his eye on the square test spot at the center of the screen. The side of this spot subtends an angle of $1\frac{1}{2}$ degrees at the eye, insuring that the image of the spot on the retina lies within the area of the fovea.

If the Polaroid P_4' is turned to extinction the illumination of the test spot is zero, but if the surrounding screen is sufficiently bright and if the frequency of rotation of the Polaroid P_1 is properly adjusted, not only the surround but also the test spot will appear to flicker. The observer now rotates the Polaroid P_4', by means of a shaft coupled to the Polaroid, until the test spot ceases to flicker.

Let the average brightness of the screen (one-half of the maximum brightness) be B_s and let the average brightness of the test spot at balance (no flicker) be B_{ts}. Consider now a circular area (diameter equal to that of the flickering surround) of uniform brightness B_s and in a plane normal to the line of sight of an observer whose vision is fixated on a small area (equal to the area of the test spot) at the center of the field. Because of intraocular stray light, a fraction of the apparent brightness of the fixation area will be due to light from the surround, and this fraction is given by the ratio B_{ts}/B_s.

The average screen brightness B_s was measured with a Macbeth illuminometer by increasing the flicker rate above the critical flicker frequency. To the eye, the screen brightness is then constant and equal to the average value obtained when the flicker is visible. The divided circle of the balancing Polaroid P_4' was also calibrated at a super-critical frequency. This was done by setting the circle at the experimentally determined balance point and reducing the brightness of the surround by rotating Polaroid P_3 until the brightnesses of the test spot and surround matched. The brightness of the surround was then measured with an illuminometer.

B. Viewing Conditions

In the course of building and testing the apparatus described above, a number of experiments were made in an attempt to find the viewing conditions that would give the observer the most comfort and yet allow him to make an accurate determination of the no-flicker balance point.

The most marked difficulty comes when the observer attempts to concentrate on the small area in the center of the large, bright, flickering surround. Qualitatively, the annoying effect of the surround is greatest (even to the extent of being painful) at very low frequencies, of the order of 2 or 3 cycles per second. At relatively high frequencies which are still less than the fusion frequency the flickering of the surround is only slightly objectionable. However, the brightness of the test spot near balance is only a small fraction of that of the surround, and hence the critical flicker frequency for the test spot is much lower than that of the bright surround. This means that the flicker frequency must be below the critical frequency for the test spot. Several tests for balance were made at relatively high frequencies, and the results were not nearly so consistent as at lower frequencies. As a compromise, a frequency was chosen which was low enough to give satisfactory accuracy in balancing but high enough to give sufficient comfort for the observer. It was found that a flicker frequency between twelve and fifteen cycles per second was the best value.

Many of the preliminary trials with the apparatus were made in a darkened room, with special attention being paid to the shielding of the observer's eyes from all light except that from the screen containing the test object and the surround. Later it was found that it was easier to make observations if the normal room illumination from tungsten lamps was used during the experiments. Precautions were taken to shield the observer's eyes from extraneous bright sources of light and also to prevent the illumination of the test spot by flickering light of the same phase as that of the surround. On the other hand, both the ground glass screen and the test spot were illuminated by the unmodulated room lights, and the flickering field was surrounded by a sheet of white cardboard. This was in marked contrast to the earlier situation in which the brightnesses of both the test spot and the surround were completely modulated and the field of view outside the flickering surround appeared very dark. The results obtained under these conditions showed no systematic variation from those obtained when the room lights were turned off. This is not unexpected, since it is only the modulated light which is effective in determining the balance point for no flicker in the test spot. Of course, it is reasonable to expect that there is an optimum value at which the increase in ease of viewing obtained by thus diluting the flicker of the surround and by making the exterior field of a brightness comparable to that of the surround would be balanced against the loss in the ability to detect flicker in the test spot, as a result of the lowering in the percentage of modulation of the test spot brightness.

The discomfort which arises from viewing the flickering surround received considerable attention in the course of the investigation. The final apparatus contains a third optical train which is not indicated in Figure 2. Light from the projection lamp passes through an optical system which is similar to the system described above for illuminating the test spot. By means of another motor and rotating Polaroid the light in this auxiliary beam is modulated at a frequency different from that used in the other two beams. The auxiliary beam is used to provide additional illumination of the test spot.

Suppose that the brightness of the surround varies as $A \sin^2 w_1 t$ and the test spot illumination varies as $C \sin^2 w_2 t$, where w_1 and w_2 are different angular velocities. If w_1 and w_2 are chosen properly, the stray light from the surround and the light from the test spot will combine in the well-known manner to produce beats. That is, the resultant illumination of the fovea will be equivalent to a modulated illumination of frequency $\frac{1}{2\pi}(w_1 + w_2)$ but of a variable amplitude modulated at a frequency $\frac{1}{2\pi}(w_1 - w_2)$.

For the moment, suppose that the observer actually observes that the illumination of the test spot appears to vary with a frequency $\frac{1}{2\pi}(w_1 - w_2)$. Now let there be added to the test spot illumination varying as $B \cos^2 w_1 t$. If the amplitude of this illumination is adjusted to the proper value, the light of frequency $\frac{w_1}{2\pi}$ from the test spot will combine with the stray light (which varies as $A \sin^2 w_1 t$) from the surround to produce a constant illumination of the fovea. Thus the total illumination of the fovea will consist of an unmodulated component, plus a modulated component varying as $C' \sin^2 w_2 t$. In other words, the balance point is indicated by the disappearance of the beat frequency $\frac{w_1 - w_2}{2\pi}$.

This method of illumination was undertaken because, if practical, it would allow the use of a relatively high flicker frequency in the surround, thus increasing the ease of operation, while the frequency under observation in the test spot would be relatively low, thus allowing accuracy in determining the balance point. Accordingly, the following mathematical investigation of the necessary conditions for the observation of a beat frequency in the test spot was made.

Let the apparent brightness of the test spot due to stray light from the surround be $b_1 = B_1 \sin^2 w_1 t$. Let the test spot be illuminated simultaneously by two beams such that the components of the brightness of the test spot due to the separate beams are $b_2 = B_2 \sin^2 w_2 t$ and $b_3 = B_3 \cos^2 w_1 t$. For the moment, let $B_3 = 0$. Then the apparent brightness of the test spot is,

$$b = b_1 + b_2 = B_1 \sin^2 w_1 t + B_2 \sin^2 w_2 t.$$

This equation can be rewritten as,

$$b = b_1 + b_2 = \frac{B_1}{2} \cos 2w_1 t + \frac{B_2}{2} - \frac{B_2}{2} \cos 2w_2 t + \frac{B_1}{2} + \frac{B_1}{2} \cos 2w_2 t - \frac{B_1}{2} \cos 2w_2 t .$$

Rearranging terms,

$$b = \frac{B_1 + B_2}{2} - \frac{B_1}{2}\left[\cos 2w_1 t + \cos 2w_2 t\right] + \frac{B_1 - B_2}{2} \cos 2w_2 t .$$

Since $\cos \alpha + \cos \beta = 2 \cos \frac{\alpha + \beta}{2} \cos \frac{\alpha - \beta}{2}$,

$$b = \frac{B_1 + B_2}{2} - B_1 \left[\cos (w_1 + w_2)t\right]\left[\cos (w_1 - w_2)t\right] + \frac{B_1 - B_2}{2} \cos 2w_2 t.$$

The second term on the right hand side of this equation represents a cosinusoidal variation in brightness of frequency $\frac{1}{2\pi}(w_1 + w_2)$ and of variable amplitude of frequency $\frac{1}{2\pi}(w_1 - w_2)$. If B_2 is set equal to B_1, the last term on the right vanishes, and the only variation in brightness is that represented by the second term. If the sum frequency $\frac{1}{2\pi}(w_1 + w_2)$ is below the critical frequency for the conditions used, the second term indicates that the brightness of the test spot will appear to vary about the value B_1 as $B_1 \cos (w_1 + w_2)t$ with a beat frequency $\frac{1}{2\pi}(w_1 - w_2)$ superimposed. When $B_1 = B_2$ the beat frequency will be most easily observed, since the third term of frequency $\frac{w_2}{\pi}$ is then absent. It should be noticed that if $w_1 + w_2$ is too great the eye will be unable to detect the $\cos (w_1 + w_2)t$ variation in the brightness, but will rather see the average value, which is zero. Thus the phenomena of beats would not be present and the test spot would appear to have a constant brightness. Now let B_3 have some value other than zero. This increases the brightness of the test spot by the amount $b_3 = B_3 \cos^2 w_1 t$, and the apparent brightness is given by,

$$b = b_1 + b_2 + b_3 = B_1 \sin^2 w_1 t + B_2 \sin^2 w_2 t + B_3 \cos^2 w_1 t.$$

These three components can be treated in the manner above, but it is easily seen that when B_3 is set equal to B_1, $b = B_1 + B_2 \sin^2 w_2 t$. If B_2 has previously been set equal (or approximately so) to B_1, the beat frequency $\frac{1}{2\pi}(w_1 - w_2)$ which was observed will disappear when B_3 is also set equal to B_1. It is only necessary to measure B_3 at the point where the beat frequency disappears in order to obtain B_1. $\frac{B_1}{2}$ is then the average value of the contribution which the surround makes to the apparent brightness of the test spot.

Under some conditions it may prove that the observation of the beat frequency depends critically on the value of B_2. In that case, B_2 is also a good measure of B_1, since the beat frequency is most noticeable when $B_2 = B_1$.

Not only is it necessary to choose w_1 and w_2 in conformity with the conditions outlined above, but it is also necessary, from an experimental standpoint, that they be carefully maintained as constants.

When the method was tested experimentally the phenomenon of beats was observed, but the necessarily accurate frequency control requires more elaborate apparatus than was available in order to maintain the beat frequency constant. The tests made were encouraging, however, and indicate that the method merits further investigation at a time when the materials and shop time to construct the apparatus can be obtained.

In referring to the fixing of the observer's eye in position before the screen, it was stated that arrangements were made for either monocular or binocular viewing of the test spot and surround. Whenever only one eye is being used the other can be covered by a small black screen (held in place by a band about the observer's head) so that the observer can keep both eyes open.

C. Balancing

In setting the Polaroid P_4' for the condition of no apparent flicker in the test spot, it was customary to approach the final test spot brightness from both higher and lower values. No significant differences between the two sets of values obtained in this way was noticed.

D. Effect of Wave Form

If the light transmitted by the Polaroids is completely plane-polarized, the wave forms of the modulated light used are $A \sin^2 wt$ and $B \cos^2 wt$. The trigonometric identities $A \sin^2 wt = \frac{A}{2} - \frac{A}{2} \cos 2wt$ and $B \cos^2 wt = \frac{B}{2} + \frac{B}{2} \cos 2wt$ indicate that each of these wave forms may also be thought of as equivalent to a constant plus (or minus) a cosinusoidal wave of twice the original frequency. This latter fact was strikingly illustrated in the first model of the apparatus. This was built as indicated in Figure 3, which is a diagram showing it as a modification of the current apparatus. The light from P_3 is reflected into the lens L_3 and the subsequent optical train by the mirror M_5. The pinhole stop S_2 (about 1 mm in diameter) is imaged on the pupil by the lens L_4. The diaphragm S_3 next to L_4 is of such a diameter that its image on the retina falls within the blind spot. The position of the image of S_3 on the retina can be altered by swinging the arm on which the optical system M_5, L_3, S_2, L_4, S_3 is mounted and which is pivoted about a vertical axis under the observer's eye.

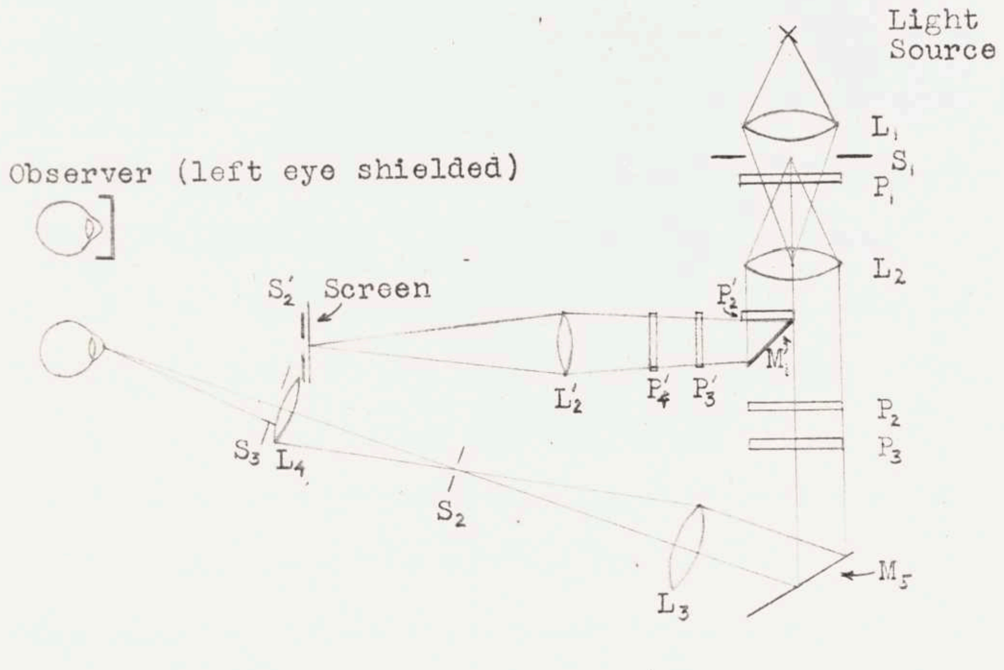

Light
Source
L_1
S_1
P_1
Observer (left eye shielded)
L_2
S_2' Screen
P_2'
M_1'
L_2'
P_4'
P_3'
P_2
P_3
S_3 L_4
S_2
M_5
L_3

Figure 3

When making an observation, the observer uses only the right hand eye, the other one being shielded with an opaque screen. His head is held in position by means of a biting board so that he views the screen of opal glass ten inches from his eye. He fixates on the center of the area, which is determined by the stop S_2' so that its image on the retina falls within the fovea. The intensity of the light from S_3 varies as $A \sin^2 wt$, while the brightness of the opal glass varies as $B \cos^2 wt$.

In the tests that were made with this apparatus, the stop S_3 was imaged on the blind spot on the observer's retina, and therefore was not visible. But some of the light from L_4 struck the fovea as stray light (actually, it was observed that a large part of the retina was illuminated by stray light which was most intense around the blind spot) and its effect in illuminating the fovea was matched by varying the brightness of the fixation spot until there was no flicker apparent in the latter.

Knowing the average brightness of the screen at balance and the average amount of flux in the beam which is imaged on the blind spot, it is possible to compute the effect on the apparent screen brightness of the stray light in terms of the flux entering the eye from L_4,

This earlier model of the apparatus was discarded before any quantitative results were obtained with it, in favor of the previously described method which gives a more useful evaluation of the stray light. However, it was possible, with this apparatus, to introduce enough light into the eye by means of L_4 to provide a rather high level of illumination of the fovea by stray light. Under these conditions it was possible to study closely the appearance of the test spot as balance was approached. It was noted that near the balance point the frequency of flicker increases markedly. This indicates that for the higher amounts of modulation the eye sees the light which varies as $A \sin^2 wt$ as having a flicker frequency of $w/2\pi$. For lower modulation the eye records the frequency $\frac{w}{\pi}$, corresponding to the interpretation of the $A \sin^2 wt$ variation as one of the form $\frac{A}{2} - \frac{A}{2} \cos 2wt$. Cobb[4] has reported a similar effect for modulated light with a rectangular wave form. He showed that for some cases the flicker perceptible just before the critical frequency is reached is due to the harmonics above the one of lowest frequency in the Fourier series representing the rectangular wave.

Results of Measurements

The results given here are for one observer (E.T.L.) using binocular vision, and they serve to show the order of magnitude of the effect of stray light under the conditions that have previously been described.

In Table I, θ represents a series of settings of P_4' (angles measured from extinction) for no flicker in the test spot. The first column gives the direction in which the brightness at balance was approached; i.e. from higher values or lower values. The next two columns give $\sin\theta$ and $\sin^2\theta$. The latter values are averaged and the mean deviation from the average is calculated.

Table I

Results of A Series of Measurements

θ is the setting of the Polaroid P_4' at balance, the angles being measured from the position for extinction of the test spot illumination.

Brightness values from which balance was approached	θ (degrees)	$\sin\theta$	$\sin^2\theta$	Deviation from mean of individual values of $\sin^2\theta$
lower	26	.438	.192	.053
higher	18	.309	.095	.045
lower	23	.391	.153	.014
higher	20	.342	.117	.022
lower	17	.292	.085	.054
higher	19	.326	.106	.033
lower	29	.485	.235	.096
higher	19	.326	.106	.033
lower	24	.407	.166	.027
		Ave.=	.139	Ave.=.042

Average $\sin^2\theta$ = .139

Mean deviation from average $\sin^2\theta$ = .042.

The average brightness of the screen was B_s = 13 ft-lamberts and the average (actual) brightness of the test spot at arc $\sin^2$ [average value of $\sin^2\theta$] was determined to be B_{ts} = 0.17 ft-lamberts. The ratio $\frac{B_{ts}}{B_s}$ is 0.013, with a mean deviation of $\pm$ .004.

This ratio gives the contribution of light from the surround to the apparent brightness of a small area in the center of the surround (the diameter of the latter subtending an angle of 36 degrees at the eye and having a brightness of 13 ft-lamberts). The natural pupil was used in all measurements. Most of the settings were made in about twenty seconds of viewing time. Fixating the eye on the test spot for periods as long as one minute apparently does not increase the ease or accuracy of setting. Any increase in adaptation of the fovea to the brightness of the test spot is presumably overbalanced by the fatigue due to the flickering surround.

The results given above can be compared with those of other investigators who have measured the effect of stray light on minimum perceptible contrast, minimum perceptible visual angle, and similar characteristics of the eye. Moon and Spencer [5,6] have formulated equations, based on the work of Holladay, Stiles, and others, which give the effect of light from the surround on the adaptation of the fovea. Before giving the results of Moon and Spencer it is convenient to explain their procedure. If a scene of any arbitrary brightness distribution is viewed, the fovea (as well as the other areas of the retina) finally reaches a steady state of adaptation which can be specified in terms of the brightness of a large uniform field (specified by Moon and Spencer as one whose radius subtends an angle of 1 radian at the eye) which would produce the same steady state of foveal adaptation. This brightness is called H_a. If the field is of uniform brightness H_s, and if its radius subtends an angle of one radian at the eye, then $H_a = H_s$. On the other hand, if the radius of the outer edge of the field is reduced (the area in the object space which lies outside this outer edge of the uniformly bright field is assumed to have zero brightness), the amount of stray light from the surround which strikes the fovea is reduced; and therefore the fovea adapts itself to a lower brightness. The brightness of a large uniform field that would produce the same foveal adaptation might be called H_a'. Then, $H_a' < H_s$. If now a small area at the center of the field, of such a size that its image falls within the fovea, has zero brightness, the fovea will receive even less light and its new state of adaptation, on the basis of the above convention, might be called H_a''. Thus, $H_a'' < H_a' < H_s$. The ratio $\frac{H_a''}{H_s}$ gives the contribution of the light from the surround to the foveal adaptation.

Using the equation of Moon and Spencer, and setting the angle subtended at the eye by the radius of the outer edge of the bright surround equal to the value used in this investigation (18 degrees), the calculated value of $\frac{H_a''}{H_s}$ is 0.060. This result is of the same order of magnitude as the value of $\frac{B_{ts}}{B_s}$ obtained for the author's eyes.

Conclusions

A method has been proposed and developed for measuring directly, in one experiment, the amount of intraocular stray light. Measurements made by this method indicate that approximately 1% of the apparent brightness of a small area at the center of the uniformly bright surround is due to stray light from the surround. These results are for one particular set of viewing conditions, but the method can be extended by the use of non-uniformly bright surrounds and also surrounds of sizes and shapes other than those used in this investigation.

A means of improving the method of measurement through the use of a beat frequency has been proposed, and preliminary tests of the principle have been made. Further investigation of this phase of the subject should be made, when the equipment necessary for accurate frequency control is again available.

References

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