Evaluating Disabling Effects of Approaching Automobile Headlights

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● AS long as the headlights of an approaching automobile are in the field of view of a driver, they will constrict his pupils and produce stray light in his eyes, interfering with his seeing. The constriction of the pupil will reduce the intensity of the useful retinal image and the stray light will produce a veiling brightness which covers the retinal image. The approaching headlights will also produce a marked effect upon the adaptation of the part of the retina on which their images fall, and the stray light in the eye will extend this effect on adaptation to all parts of the retina. After the approaching automobile has passed on by, the observer will still be faced with impaired vision because of the after effects on adaptation and pupil size.

The present paper is concerned primarily with the design of a device which can be used to measure directly the veiling brightness produced in the eye of an observer. The idea is to point the device in the direction in which the observer would be looking and have it measure directly the veiling brightness in the direction of the object looked at. In order to design such a device, it is necessary to know what effect a glare source at a given angle from the primary line of sight will have and how the effects of two or more glare sources add.

One can measure the effect of a glare source at a given angle from the line of sight by using the following procedure. The subject fixates a test object on a dark background and turns on a glare source, and varies the brightness of the test object until it is just visible (Fig. 1). One then turns off the glare source and introduces into the field of view a patch of brightness which covers the test object. The brightness of this patch is varied until the test object is again just visible. One can say then that the superimposed patch of brightness is equivalent to the veiling brightness produced by the glare source, and one can specify the amount of the veiling brightness in terms of the brightness of the equivalent superimposed patch. The effects produced by one or more glare sources can be shown to be strictly additive.

It is difficult to obtain data for small glare angles, and in order to design a meter which will apply to small glare angles as well as large ones, the writer is proposing that values for small angles be obtained by calculating them on the basis of the theory that the effect is mediated by stray light.

Stiles (1) pointed out two fundamental objections to the hypothesis that the effect of a peripheral glare source on foveal vision can be attributed to stray light in the eye: (1) in order to acount for the effect, it was necessary to assume that more light was scattered than was known to be lost in transmission through the media of the eye, and (2) the equation for stray light derived from theory did not conform to the effect produced by a peripheral glare source.

Since Stiles did his study, more-exact information about the transmission of the ocular media has become available and it is known that the transmission of the human eye is lower than that assumed by Stiles.

Furthermore, Stiles assumed as Holladay (2) had done that the scattering by the media of the eye conforms to Rayleigh scattering, which makes the amount of scattering inversely proportional to fourth power of the wavelength. It has been found since then that the effect of a glare source is more or less independent of the wavelength of light (3). This suggests that the scattering particles have a diameter greater than the wave length of light. If this is the case, one can assume a greater preponderance of forward scattering and thus bring the scattering theory into closer agreement with the facts.

It is hardly probable that one can overemphasize the importance of establishing the fact that the effect of a peripheral glare

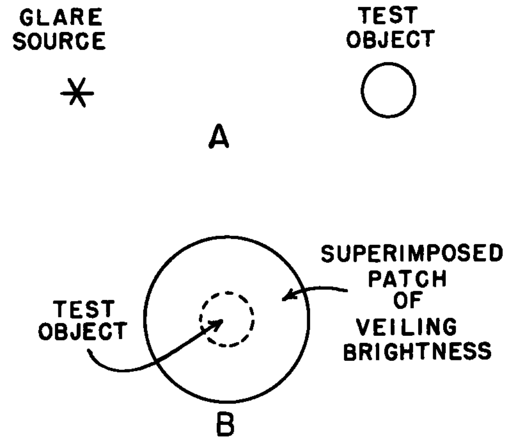

Figure 1. Stimulus patterns used for measuring the veiling brightness produced by a peripheral glare source.

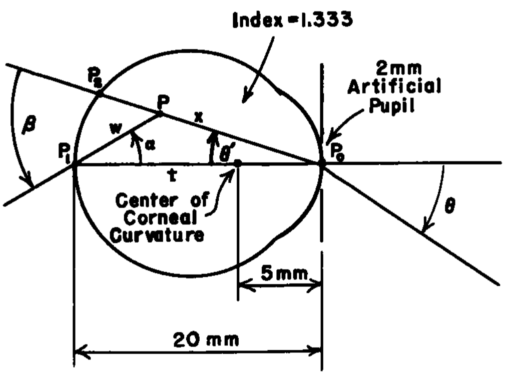

Figure 2. Reduced eye used in computing scattered light in the eye.

source on foveal vision is mediated by stray light. It not only makes it possible to use stray light theory for computing veiling brightness, but it also simplifies the evaluation of the effect of peripheral glare sources on pupil size and adaptation at different parts of the retina. It means that the problem of adaptation can be formulated in terms of pupil size and the adaptation of individual photoreceptors at different parts of the retina.

The facts relating to stray light in the eye may be summarized by noting that stray light may be produced by approaching automobile headlights in several different ways: (1) diffuse transmission through the iris and sclera; (2) flare, produced by multiple reflections at the different refracting surfaces; (3) specular reflection from the front surface of the retina; (4) halation produced by reflection at the pigment epithelium, choroid and sclera; (5) light reflected through the vitreous from one part of the retina to another; (6) fluorescence of the crystalline lens; (7) bioluminescence; and (8) scatter by the media of the eye.

The major source of stray light is scatter by the media and this is true to the extent that the other sources of stray light may be ignored in computing the effects of stray light in the typical observer.

Figure 2 illustrates the geometry involved in computing the scattered light in the eye which is produced by a glare source and which interferes with the visibility of an object which one is looking at. In the figure the glare source is located at an angle, θ, from the object looked at. The object looked at forms an image on the retina at the center of the fovea.

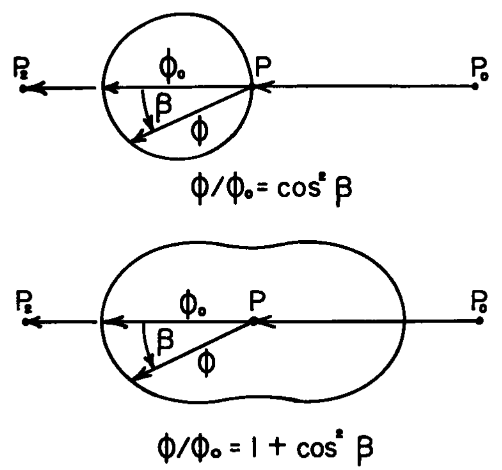

Figure 3. Polar diagrams of scattered light.

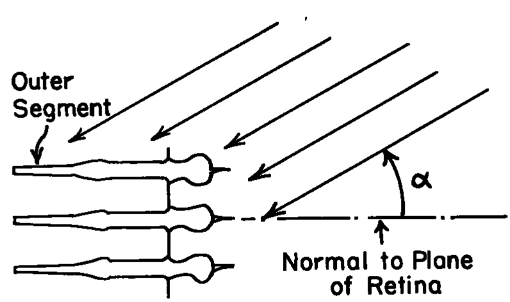

Figure 4. Relation of the angle of incidence to the absorption of light by the photoreceptors.

In order to simplify calculations, it is satisfactory to assume that the eye of a typical observer is equivalent to an eye which has one refracting surface and a single homogeneous medium. It may be further assumed that the pupil of the eye lies in the plane of the cornea. The glare source projects a beam of light through the pupil to a point on the retina. In the calculations about to be described, it has been assumed that the stray light falling on the retina at the fovea is produced by first order scattering at the various points along the beam between the cornea and the retina, and that the stray light produced by flare, reflection at the retina and other sources is negligible. It is assumed further that the amount of scatter is independent of the wavelength.

At any point, P, along the path of the beam, a certain fraction of the flux is scattered in various directions. The lower part of Figure 3 illustrates a polar diagram which shows the relative amounts of light scattered in various directions in the case of Rayleigh scattering. As much light is scattered in a backward direction as in a forward direction. The upper part of Figure 3 is a polar diagram which illustrates the type of scattering which the writer has assumed to exist in his calculations of veiling brightness. This is characterized by a predominance of forward scattering. Scatter at all points along the beam from the cornea to the retina contributes to the stray light falling on the retina at the fovea. The stray light falling on the fovea produces an effect which is equivalent to that produced by a patch of veiling brightness.

In using scatter theory to compute the effect of a peripheral glare source, it has been assumed that the retina is equivalent to a smooth curved surface. The lumens of stray light per unit area falling on such a surface has been computed and compared to the lumens per unit area produced by an external patch of veiling brightness. This comparison implies that the effect of light on photoreceptors is proportional to the cosine of the angle of incidence (cos α).

It is known for example from the Stiles-Crawford effect that this is not always the case. The theory of scattering will have to be modified at this point when the facts are known. Figure 4 illustrates the nature of the problem. The photosensitive substance lines the inside of the outer members of the cones. The problem is further complicated by the extension of processes from the pigment epithelium between the photoreceptors.

As indicated above it is possible to measure the amount of veiling brightness. The straight line designated Equation 13 in Figure 5 represents Stiles data for glare sources located between 1 deg. and 10 deg. from the object looked at. The straight line designated Equation 14 represents Holladay's data for glare angles between 2½ deg. and 25 deg.

The curves designated Equation 12 and Equation 22 are the curves calculated from scatter theory. The curve designated

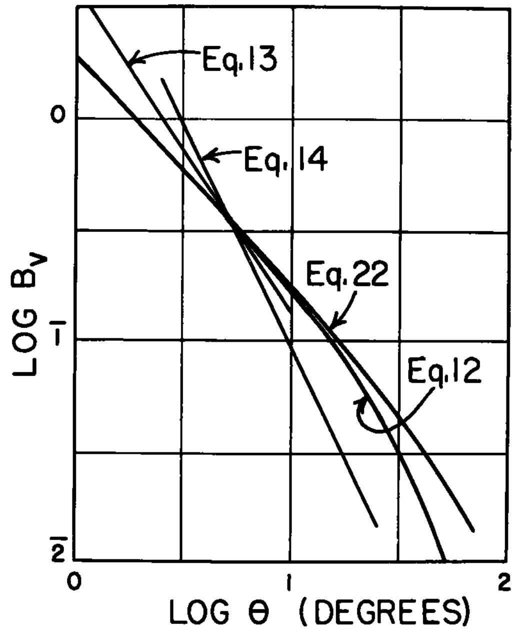

Figure 5. Comparison of theoretical and empirical curves for veiling brightness (B_V) for various glare angles (θ); E = 1 c/m².

Equation 22 is based on Rayleigh scattering and the curve designated Equation 12 is based on the scatter diagram in the upper part of Figure 3, which is characterized by a predominance of forward scattering. Although the fit to the empirical data is better for Equation 12 than for Equation 22, neither is very satisfactory. It should be noted, however, that for small angles for each of the theoretical curves, the veiling brightness is inversely proportional to the glare angle. This would also be true for most any reasonable assumption that one might make about the nature of the scattering.

It would appear that complete agreement cannot be achieved merely by changing the form of the scattering function, or by making a different assumption about how the absorption of light by photoreceptors is affected by the angle of incidence.

It has been assumed that the medium of the eye is uniform from the cornea to the retina. This is only an approximation. It is known that the lens for example has a much higher attenuation coefficient than the aqueous or the bitreous. So far as the lens is concerned the values of both α and β are small for first order scattering and the

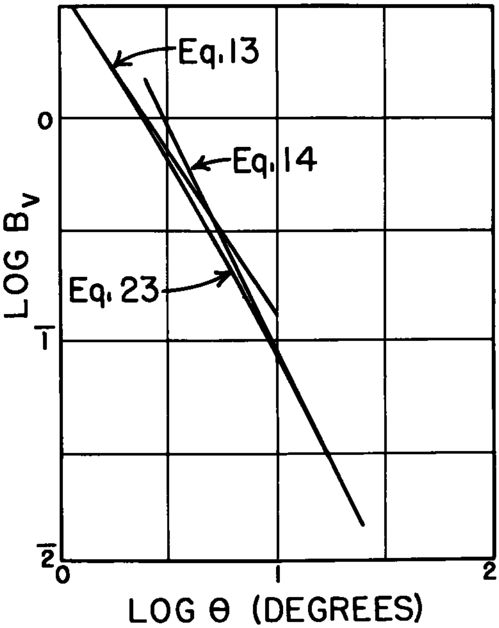

Figure 6. Proposed Equation 23 for computing veiling brightness for various glare angles and its relation to the equations of Stiles (13) and Holladay (14); $E = 1$ c/m².

scattering function determines for the most part the distribution of light on the retina. If the lens alone were considered, it would be necessary to assume an unreasonable amount of forward scatter. Hence all of the media of the eye should be considered with different scattering functions and attenuation coefficients for each. This gives the scattering theory the flexibility it needs to bring it within the range of experimental facts and permits one to make whatever assumption that needs to be made in regard to the effect of angle of incidence upon the light absorbed by a photoreceptor. It seems unnecessary therefore to postulate a mechanism in the retina to help account for the effect of a peripheral glare source on foveal vision, except in the case of glare angles of two degrees or less.

In Figure 6, the curves designated Equations 13 and 14 again represent the empirical data of Stiles and Holladay. The curved line designated Equation 12 represents an approximate fit to both sets of data and at the same time provides for the extrapolation of the data to a zero angle of glare. This curve conforms to the equation,

$$B_V = \frac{8.2\, E}{\theta\,(1.5+\theta)}$$

where B_V is the veiling brightness (candles per square meter), E the illumination (lumens per square meter) in the plane of the pupil which is assumed to be normal to the primary line of sight, and θ is the angular displacement (in degrees) of the glare source from the primary line of sight.

The extrapolation of the data to zero angles of glare is based upon calculations of veiling brightness made from scatter theory and conforms to the proposition that for small angles of glare the veiling brightness is inversely proportional to the glare angle.

It is recommended that this equation be used in calculating the veiling brightness produced by a glare source in a given situation. It is also recommended that this equation be used in the design of a meter for predicting the veiling brightness which must exist for a typical observer in a given situation.

A typical situation is illustrated by two cars passing each other at night when the driver of one car is faced with the necessity of seeing a pedestrian who is located in his path at a slightly greater distance than the approaching automobile. One can compute the brightness of the surface of the highway which forms the background for the pedestrian and the brightness of the pedestrian and the veiling brightness produced by the approaching headlights. With this information, one can determine preciselv how much the contrast of the pedestrian against his background will be affected by the veiling brightness. Furthermore, if the pupil size and the state of adaptation of the photoreceptors in the central portion of the retina were known, the chances of seeing the pedestrian could be predicted.

The devise described above could be used to measure the veiling brightness and it is conceivable that with the addition of continuous recording and computing equipment the state of adaptation at any given part of the retina at any given moment might be determined.

SUMMARY

Evidence has been presented to show that the effect of a peripheral glare source on foveal vision is mediated by stray light.

It is difficult to measure the veiling brightness for small angular displacements of the glare source from the line of sight, but the empirical data can be extrapolated to zero angles of glare by the use of stray light theory.

It is possible therefore to design a device which will measure directly the veiling brightness produced by the headlights of an approaching automobile.

It is also probable that such a device can also be used to determine the state of adaptation of the central region of the retina, at various moments during the approach, and after the approaching automobile has already passed by.

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