# Stray Light in the Eye

ROBERT M. BOYNTON, University of Rochester

THE deleterious effects of glare stimuli upon vision have long been recognized. Perhaps the most familiar modern example (and one which is obviously pertinent to the interests of those involved in highway safety) concerns the reduction of visibility caused by oncoming headlights during night driving. The present paper offers no solutions to the problem, but aims at an explanation of why the problem exists in the first place.

Why, for example, should oncoming headlights, which are imaged on the retina several degrees from the fovea (the area of most distinct vision) reduce the visibility of a pedestrian viewed dead ahead, whose image does fall in the fovea? One would suppose that, if the optic media of the eye were perfectly transparent, and, if there were no interaction between the impulses generated from one part of the retina and those coming from another, that the glare stimulus should have no effect on foveal visibility. The two hypotheses which have been invoked to explain the effects of glare stimuli state that the visual system is defective in one or another of these respects.

## Neural Interaction

According to one school of thought, the glare stimulus image initiates neural activity in the visual system which, either at the level of the retina, or perhaps in the brain, interferes with and reduces the information content of the foveal image, which, though still present, no longer results in a visual sensation. Thus, the pedestrian, once visible in your headlight beams, becomes invisible as the oncoming headlights approach. Actually, there has been little or no direct evidence to support this viewpoint, which will not be discussed further here.

## Stray Light

It is well established that the visibility of a dim object can be reduced, or that it can be rendered invisible when viewed through a veiling stimulus. For example, a vivid projected slide appears "washed out" and the details tend to disappear when the room lights are turned on. In general, as the level of adapting luminance is raised, larger and larger increments must be added to the prevailing level in order for them to be visible. (This is not to be confused with the fact that the percentage increase in the increment needed to be visible decreases with an increasing adapting luminance.)

According to the stray light interpretation (which, incidentally, has always been the most popular among illuminating engineers), the media of the eye are not perfectly transparent. The luminous flux incident upon the eye from the glare stimulus is scattered and reflected within the eye, so that large areas of the retina, including the fovea, are illuminated. There has been much support for this argument, such as the following:

1. The effects of glare stimulus can be duplicated by a veiling stimulus.
2. The stray light associated with an intense stimulus can be directly observed by anyone who cares to do so. Trying to see something in the presence of a glare stimulus is very much like trying to see through a fog.
3. An electrical response from the human eye, known as the electroretinogram, when elicited with small-area stimuli, has been shown to arise from stray light illumination of the retina, rather than from the focal component of the stimulus. A similar conclusion has arisen where the pupillary response is concerned.

By this view, then, a glare stimulus raises the general level of adaptation over wide retinal areas, and thus reduces to some extent, the visibility over the entire visual field. The research to be reported here attempts to further support the stray light viewpoint by an unusually direct procedure.

## Physical Measures of Stray Light

We took an eye from a living, anesthetized cat, and mounted it, cornea down, in an optical system capable of delivering a beam of light to the eye at any desired angle of incidence. In the back of the eye, we cut a small aperture, and placed a highly sensitive light detector (a photomultiplier tube) behind it. As the optical system was rotated, the reading on our recording meter sharply dropped, indicating, as one would expect, that the image had moved off the recording aperture. The instrument was sufficiently sensitive, however, to show that a considerable amount of stray light was still passing through the hole. As the angle of incidence was made progressively larger, the readings became smaller and smaller.

With the cat, we were able to begin our observations about seven minutes after the eye was removed. Systematic measurements were taken and certain changes were noted with time. Over a period of four hours, direct transmission through the eye decreased by about 50 percent, but at the larger angles of incidence, where the image was off the recording aperture, the readings, as a result of stray light, increased by more than 50 percent. As physiological changes go, these were slow, and it was possible to extrapolate backwards to find the "true" values which one would expect in the living cat eye. The data indicate that for a circular stimulus 4.76 degrees in diameter, the illumination of the retina by stray light at an angle of incidence of 5 degrees is about $1/10$ of that of the image itself, drops to about $1/100$ at 7 degrees, and trails downward to about $1/1000$ at 12 degrees.

Actually, most of our work has been done with steer eyes, because they are larger and more easily obtained. These are usually about one hour old by the time we start measurements, and we have made corrections for the age of the eye by employing the data from the cat. Here we have established that the stray light illumination falls off as a function of angle of incident illumination about the same way as for the cat, and that the variability from one steer to another is reasonably small. It is also easy to show that stray light illumination increases directly with an increase in the area of the glare stimulus (which one would expect on physical grounds). In other words, it is the total amount of incident flux incident upon the eye which is important, regardless of its luminance-area distribution.

One day, we rather unexpectedly obtained a human eye, and subjected it to the same sorts of measurements. Although the man was 63 years of age at death, and had been dead for more than two hours before we were able to obtain our first measurement, the results (corrected for time) were surprisingly in accord with those for the cat and steer. We thus have no reason to suppose that the human eye is exempt from the effects of stray light.

## Sources of Stray Light

We are currently in the process of trying to pinpoint the sources of stray light in the eye. We have been able to look into the steer eye both from below (through the cornea) and from above (by cutting a large hole in the back). What one sees, looking from the back, are the following: (1) a bright spot at the corneal surface; (2) a very faint yellowish beam transversing the aqueous; (3) a bright spot at the anterior surface of the lens; (4) a good deal of scattering as the beam is transmitted through the lens; (5) another bright spot at the posterior surface of the lens; (6) moderate scatter, though much less than in the lens, as the beam goes through the vitreous. At large angles of incidence, one can also see the image upon the fundus of the eye, which is obviously bright enough to reflect some light to other retinal areas. We are currently trying to photograph and quantify these phenomena. Work with the steer eye has established that at least under one set of conditions, reflection from the fundus is not important. We cut a second hole in the back of the steer eye to "let the image out" and it caused no measurable change in our readings. We currently believe, but cannot yet prove, that scattering in the cornea and the lens are the two prime factors, and that their relative contributions vary, depending upon angle of incidence and pupil size (for example, scatter from the cornea is blocked by the iris under many conditions, but not others).

## Comparison with Glare Experiments

A favorite way to measure the effects of glare stimuli has been to introduce them at various angles of incidence (glare angles) and measure the threshold of visibility for a foveal test stimulus. When this is done, one obtains a function much like those that we obtain by our direct procedures, showing that the effects of glare stimuli fall off rapidly as the glare angle is increased. Our curve, however, is higher, suggesting that there is more than enough stray light in the eye to account for observed glare effects. Some of this may be due to defects in our procedure, such as the age of the eyes after death. However, it seems probable that the effects of stray light are less than the amount, and that the difference may be accounted for in terms of the directional sensitivity of the cones in the eye, since scattered light strikes the cones, for the most part, at large angles of incidence.

## ACKNOWLEDGEMENTS

This research has been made possible only with the splendid cooperation of several persons and agencies. I would like to expressly thank the following: Drs. Jay M. Enoch and William R. Bush, and Donald DeMott, who have assisted in the experimental work; Prof. George Smelser of the Columbia University College of Physicians and Surgeons, for the loan of the photomultiplier unit which we used for our original research on this problem; Dr. James Harrington, Assistant Resident in Opthalmology, Strong Memorial Hospital, who made the human eye available to us; The Rochester Independent Packing Corporation, which furnished the steer eyes; and the Office of Naval Research and the National Institute for the Prevention of Neurological Diseases and Blindness, United States Public Health Service, for finanancial support of this research.

Part of this research has been published in detail, in the Journal of the Optical Society of America, November 1954, vol. 44, page 879. Reprints may be obtained upon request by writing Dr. Robert M. Boynton, Department of Psychology, University of Rochester, Rochester, New York.