Effect of Exposure to Sunlight On Night-Driving Visibility

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SUNGLASSES have been used for about 300 years; yet almost no research has ever been undertaken concerning their usefulness. In fact, these devices have developed almost spontaneously. They are used, because they are comfortable when the wearer is exposed to excessive sunlight. Since persons habitually living on the beach, at sea, or out-of-doors do not use sunglasses, and apparently do not need them, they seem to be devices for city slickers and sissies to wear. They are a luxury item.

During World War II the attitude of the armed services towards sunglasses was shifted from one of considering sunglasses to be a luxury item to the recognition that sunglasses were a necessary part of the uniform allotment. A group consisting of scientists meeting with representatives of the armed services (1) based its conclusions about sunglasses upon the researches of Hecht (2) and of Clark (3). In individual studies, Hecht, and later, Clark demonstrated that the effect of exposure to sunlight during the day resulted in a loss of seeing at night. Hecht demonstrated that about twice the amount of light is necessary for night vision after exposure to sunlight without sunglasses. Clark showed that the use of sunglasses effectively prevented this loss.

Follwing the war, Peckham and Harley (4,5) studied the effect of similar exposures upon civilians, performing their experiments upon life guards of the Atlantic City Beach Patrol. These investigators wished to determine if a comparable effect to that found by Hecht and Clark, could be observed under conditions of moderate photopic illumination (the moderate artificial light used for reading, working, and night driving).

Figure 1 shows the curve of visual response to brightness. It can be shown that at high levels of illumination there is very little or no improvement in vision with increasing illumination, but that at lower levels visual performance decreases rapidly with decrease in brightness (6).

This is a schematic figure designed to compare two subjects whose response to brightness is slightly different, as represented by the constant brightness shift, $\triangle B$. At very low levels, a large difference in response, $\triangle R_1$, is found for the brightness shift. In the middle of the curve, near the cusp of the rod-cone transition, a constant shift of brightness causes a smaller shift in response, $\triangle R_2$. At very high levels of brightness, there is only a negligible change in response, $\triangle R_3$. Peckham and Harley worked near the region shown by $\triangle R_2$. Measurements in this region, of visual acuity or contrast perception, tend to be erratic and undependable. Nevertheless, Peckham and Harley showed that exposure to excessive illumination at the beach resulted in the loss of photopic, or low-level daylight, visual performance, and that this loss can be expressed quite adequately as a factor of reduced effective illumination. The value of this factor was found to closely agree with those previously determined by Hecht and Clark.

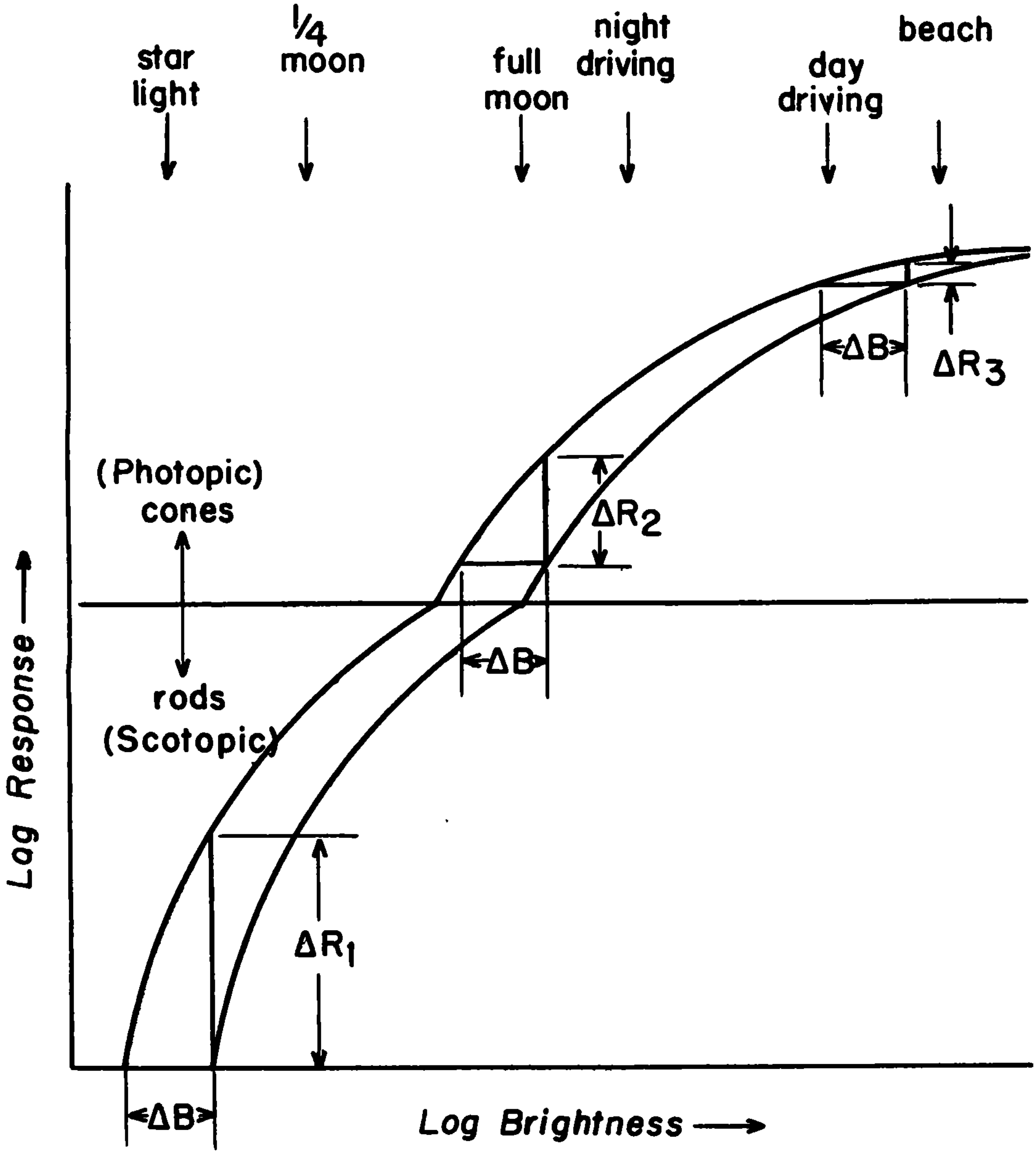

Figure 1. Schematic diagram of visual response: The curves represent the visual response after a constant shift in effective brightness, △ B. The change in response at △ R_1, the threshold, will be greatest. The change, △ R_2, at low brightness is much less. The change at high brightness, △ R_3, may be too small to be reliably measured. Responses below the cusp are scotopic, or night-vision, responses, those above the cusp are photopic, or day-vision, responses.

Since the vagaries of visual acuity at low contrast and low brightness render such measurements extremely difficult, another method of estimating effective visual brightness is needed. Such a function is found in the critical flicker frequency (CFF) at photopic levels. Such flickering objects are frequently found in everyday experience. For instance, in the old motion pictures, and in some home movies, the effects of flicker caused the picture to shimmer and to be very disagreeable. In those parts of the country served by 25-cycle alternating current instead of 60-cycle alternating current, lamps seemed to flicker. In an experimental situation, the flicker can be produced by having a rotating shutter pass rapidly in front of the lamp, thus alternating the light. Or it can be produced by using a gaseous-discharge light source activated in a series of flashes. With such apparatus, if we start it at a low flicker rate, the object will appear to jump, shake, and shimmer. But if the rate of flicker is increased sufficiently, the flickering will disappear. The point at which the flickering disappears is called the critical flicker frequency. It has been shown by several investigators, for instance Hecht (7, 8) and Crozier (9), that a change of brightness results in a change of critical flicker frequency, and that the relation of flicker frequency is linear to the logarithm of the brightness. This means that it would be possible to measure retinal sensitivity directly by determining the critical flicker frequency for a standard brightness.

In Figure 2 the relationship between the critical flicker frequency and the brightness of the flickering object is shown by the line AB. When we change the brightness of the light we will find that the flickering disappears at a low speed with a dim light but will not disappear until a high speed is reached with a bright light. Now suppose that we take a different subject, giving us a series of measurements along the line CD, indicating that this subject responds differently in critical flicker to the variation of brightness. If we compare these two curves at a certain standard brightness, indicated as B_1 in the figure, we notice that subject CD loses the perception of flicker at the rate R_2, which is slower than subject AB, at R_1. If we draw a line parallel to the base from R_2 on CD, it intersects curve AB at the brightness level B_2. Thus, if we wish to compare the first and second subjects, we could say that the brightness B_1 for the second subject was only as effective as the lower brightness B_2 for the first subject. This means that the constant illumination within our apparatus was not as effective for the second as for the first subject. Since this illumination has not changed, we are in effect comparing directly and very accurately the retinal sensitivities of these two subjects. By this means we have conquered an epistemological problem. Although, when using a comparison photometer, both subjects would have reported the same absolute brightness, by means of this visual response to flicker, we can determine individual differences between them. This means of measuring the sensitivity of subjects can be directly applied to the problem of sunglasses. We have here a means of determining the relative sensitivities of a single subject in the morning and again in the evening by comparing his critical flicker frequency for a standard brightness. We could equally well make the same measurement by measuring the brightness required for a standard critical flicker frequency. In either case, our results would be expressed in terms of the logarithm of effective retinal response. This was done upon a group of life guards in Atlantic City (5). It was done again upon a group of automobile drivers in Phoenix, Arizona (12).

In this latter study, a group of 24 young men were required to drive automobiles along country highways for about 6 hours per day for five days without sunglasses. The study was undertaken in the spring of 1951, and illumination measurements show that the brightnesses of the road were no higher than that of country roads in the northern half of the United States during the summer.

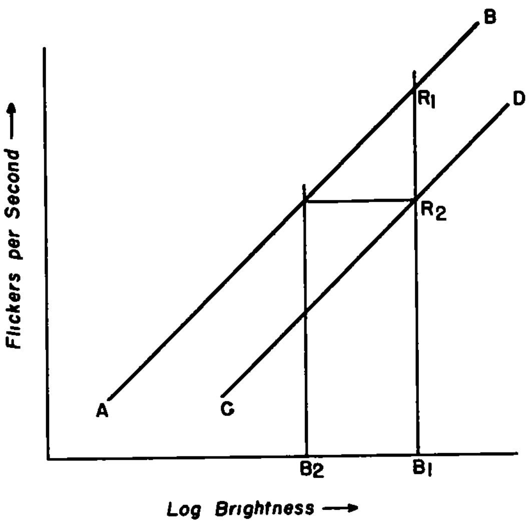

Figure 2. Relationship between critical flicker frequency (CFF) and brightness: CFF varies linearly with the logarithm of brightness. At the fixed brightness, B_1, a normal retina (AB) will yield the CFF at R_1. An exposed retina (CD) will yield the CFF at the depressed value R_2. This would have been shown by the normal retina at the lower brightness B_2. Hence B_1 is only as effective as B_2 for the exposed retina.

The results of the measurements in Phoenix can be expressed as shown in Figure 3 in terms of the accumulated differences between the morning and evening scores of these drivers. These data include 10 measurements each at two levels of brightness, both morning and evening, for 24 subjects for 5 successive days. That is, they represent the results of 4,800 observations. In each case, the average of 10 flicker rates each evening has been subtracted from the average of 10 flicker rates that morning for each subject. These differences are accumulated in units of flickers per second. It will be noticed from the graph, that there was, in a few cases, an actual increase in the evening, so that some subjects seemed to see better in the evening than in the morning. The examination of the figure indicates that 22 percent of the records studied, showed either no change or such an improvement. But 78 percent of the records studied show either no change or a decrease in retinal sensitivity, between evening and morning. Thus, we find that a large majority of the drivers lost some retinal sensitivity during the day. These drivers did not wear sunglasses and drove approximately 6 hours each day, covering about 250 to 300 mi. The average effect of this exposure is indicated by the position of the median point in the figure, that is, the difference of flicker which is halfway between the extremes. We find that half of the group lost a flicker frequency of 2.2 per second to the standard light. This can, in turn, be interpreted as a loss of brightness. It means than the logarithmic decrement of brightness amounts to 0.22. The antilog of this amount is 1.66; the ratio of required brightness for the same visual efficiency is therefore 10 in the morning to about 17 in the evening. The effectiveness of the light in the evening was reduced to about 60 percent of its effectiveness in the morning for half of the drivers. We see further from the figure, that smaller fractions of the population lost even more than this amount. For instance at the 75-percent level we find the remaining 25 percent lost as much as 4 flickers per second, which gives us a ratio of effectiveness of 10 to 25. The light was only 40 percent as effective in the evening as it had been in the morning for this fraction of the drivers. In other words, in one fourth of the group, over half of the light is useless due to the decrease of retinal sensitivity. We find that 10 percent of the population lost about 6 flickers per second or more. This means they require 4 times as much light in the evening as they would have required in the morning for the same visual perception. This group includes the persons most dangerously affected by the loss of retinal sensitivity due to exposure to sunlight during the day's driving. In 1,000 drivers, there are 100 persons so affected.

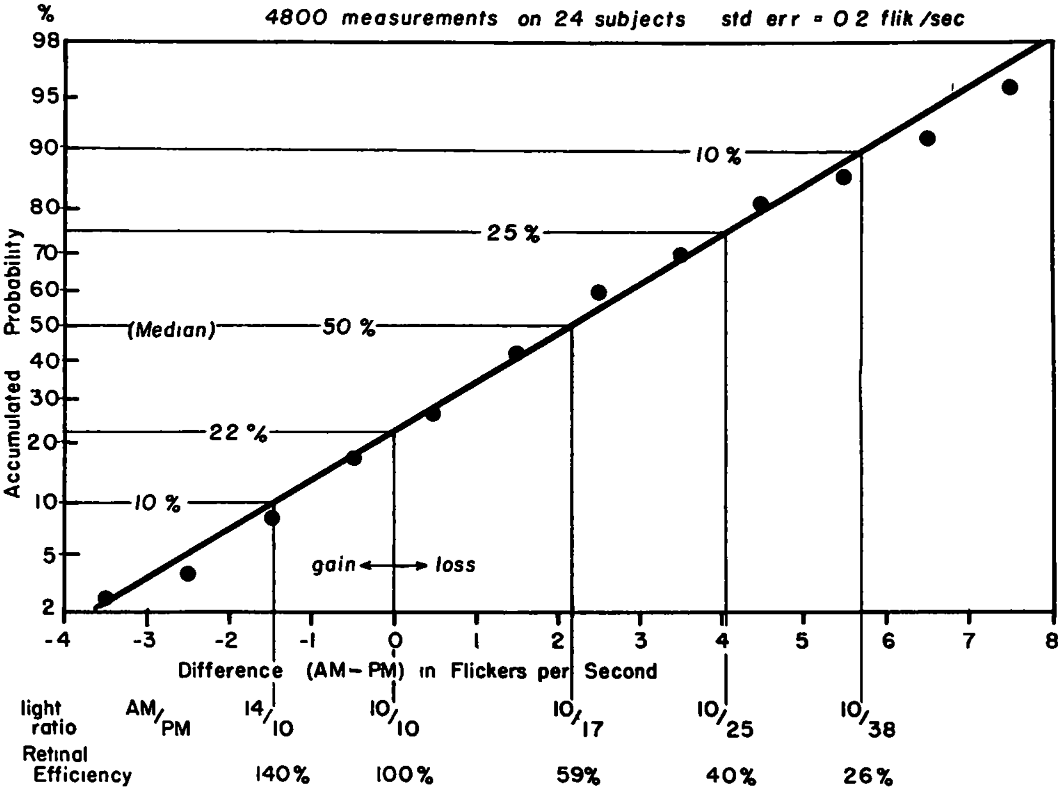

Figure 3. Diurnal loss of retinal sensitivity from exposure during driving: The difference between the averages of each set of ten morning and evening flicker readings at two brightnesses for 5 days on 24 subjects is presented as an accumulated distribution curve on a probability scale. Each change of 10 flickers per sec. represents a change of one $\log_{10}$ unit of effective brightness, hence the ratios of effective illumination between morning and evening can be expressed for any change in critical flicker frequency, as shown.

On the other hand, among those who gained, very little gain is found. At the 22-percent point we find a ratio of no gain or loss. At the 10 percent point the gain was 1.5 flickers per second, amounting to a ratio of 14 to 10, or a gain of 40 percent. Thus, the most gainful 10 percent gained very little compared to the most damaged 10 percent. We can summarize these results as indicating a very significant loss of retinal sensitivity as the result of a moderate day's driving in relatively moderate sunshine. This loss might be attributed to fatigue, or to some function of fatigue, if we had not previously shown that similar loss could be directly correlated with sunlight and could be prevented by the use of sunglasses.

The effect of this change in retinal sensitivity between morning and evening, after driving during the day without sunglasses, can be used to predict safe driving conditions (Fig. 4). Retinal sensitivity can be expressed as retinal efficiency in percent. The division of the group, for various degrees of loss, can be shown at various levels of probability. As a measure of safe driving, we can use the estimates of stopping distances, including reaction time and braking time, for various speeds. In driving at night, obstacles become visible when the illumination from the headlamps reaches a sufficient intensity to make them so. With two upper sealed beams, of 25,000 beam candle power each, the illumination reaches this critical level at a predeterminable distance, depending upon the size, reflectance, and contrast of the obstacle. We can suppose, therefore, that the level is reached at the stopping distance, for a "normal," or unexposed retina, as shown in the diagram. With decreased retinal efficiency, more illumination will be required, depending upon the degree of loss. For each stopping distance this has been computed. For example, at 60 mph. the stopping distance on a dry, level, concrete road is about 260 ft., at which distance the illumination will be 0.7 foot-candles. An obstacle just visible at this distance and brightness can be avoided, under these conditions, with normal retinal sensitivity. But the average reduction of retinal efficiency will require more light for the "normal" response to 0.7 f.c. Such a retina is only 59 percent efficient. Hence, the car must have proceeded to within 200 ft. to provide this illumination. To similarly avoid this obstacle, the driver could not exceed much over 50 mph. The poorest 10 percent, which would include 100 in any group of 1,000 exposed drivers, could not see such an object until the car was within about 140 ft., and could not stop unless the car were travelling below 40 mph. Thus, under identical road conditions, the same degree of safety for one driver at 60 mph. is unsafe for another at 40 mph.

It is not the habit of drivers to accommodate their speed to their retinal efficiency. Rather, a group of cars all travel at about the same speed. This inevitably forces the exposed driver to overdrive his headlamps to keep up with accompanying cars.

At any speed, we can thus predict the effect of retinal efficiency upon safe driving, or upon the probability of an accident. This prediction cannot be considered complete; it is only suggestive. But enough information has been accumulated to show that within the framework of visual sensitivity, a significant cause of accidents can be predicted. It is of great importance that this avenue of approach to accident prevention be fully explored. In the meantime, it is fairly safe to predict that the use of sunglasses during the day is really worthwhile.

As a result of these various researches, the following facts have been determined: (1) the effect of exposure to sunlight is to reduce visual performance during the evening; (2) this reduction can be expressed as a fraction of the measured illuminations provided by artificial light, that is, headlamps; and (3) the effect can be prevented by the use of adequate sunglasses.

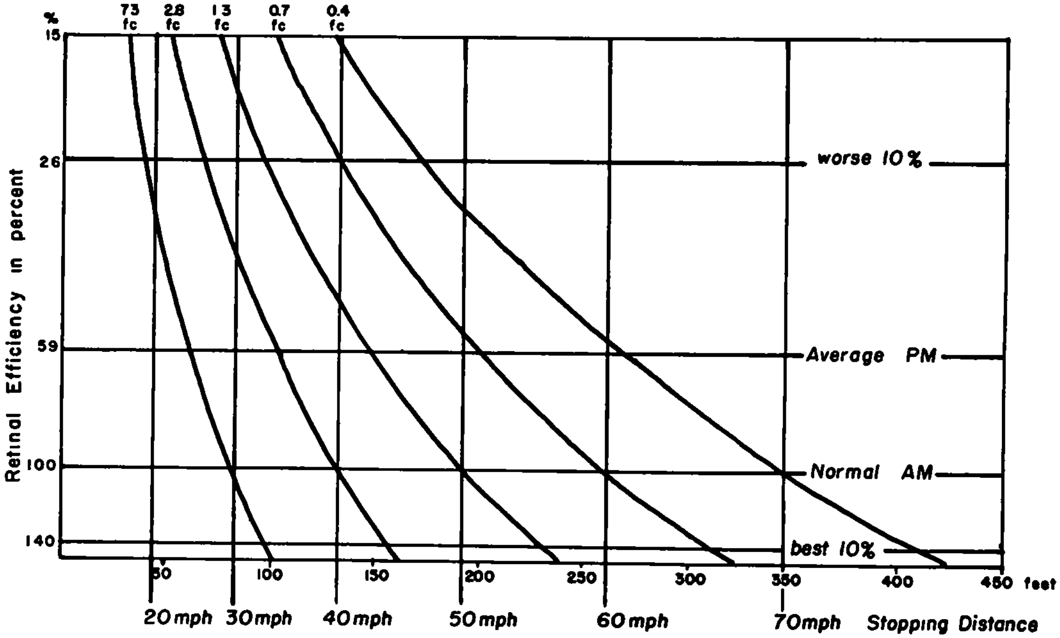

Figure 4. Effect of retinal efficiency on road illumination and stopping distances: Depressed retinal efficiency requires a closer approach of the car to provide equivalent visual response, thus demanding a reduction of safe driving speed. Computed for two upper sealed-beam lamps at 25,000 beam candle power. (Data from General Electric Company and Ford Motor Company).

From our research, we can clearly specify what sunglasses are needed. They should transmit approximately 10 percent, or should transmit from, say, 8 to 18 percent. It may appear that such sunglasses would be abnormally dark and might reduce daytime vision. An examination of the effect of reducing illumination 10 times from 1,000 to 100 foot-candles, or from 100 to 10 f.c., upon visual acuity, shows that the resulting loss of visual performance is so minute as to be practically negligible. Such sunglasses cannot be considered too dark. Certain other research indicates that the color of the glass used is immaterial (10). Finally, the quality of even the least expensive types of sunglasses is not deleterious to vision (11).

Sunglasses of any type, at any price, of any color, will be helpful to automobile drivers if they are worn during the day and thus protect the retina and prepare it for the difficulties of seeing at night with the automobile headlights. Many of the sunglasses on the market, while dark enough to provide comfort, are not dark enough to provide retinal protection. However, if automobile drivers will take the simple precaution of buying the darkest sunglasses they can find, and substituting even darker glasses for those they have already purchased, they can expect a very considerable degree of assistance to their retinal efficiency.

Visual perception is itself an erratic phenomena and the prevention of an accident will require not only visual perception of the situation, but also the psychological and experiential recognition of the danger involved. Visual reduction may be a significant contributory cause to accidents, the primary cause of which may most logically lie in violation of safety rules or bad traffic engineering. Nevertheless, we can logically rationalize that in any accident there is included a visual requirement which might have prevented the accident, and which could have been assisted to a considerable degree by the use of sunglasses. Since driving an automobile is essentially best described as a continual series of avoided accidents, any program of highway safety should recognize this visual factor. It is hoped that this report will assist in disseminating the knowledge of the great usefulness of sunglasses in accident prevention.

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