Retinal Sensitivity and Night Visibility

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A previous report (HRB Bull. 56, p. 17) indicated a correlation between retinal sensitivity and visibility during night driving. A new method for estimating retinal sensitivity by determining critical flicker frequency has been completed. A large field of view is kept at a constant and high level of brightness, so that retinal adaptation is consistent throughout measurement of sensitivity. A small area within this field alternates above and below the background brightness for a measured contrast, and at levels such that the "average" of the extremes equals the background. The contrast is controlled by a unique beam-splitting device within an optical relay, at any chosen contrast from 0 to 50 percent with respect to background. The frequency of alternation of the two beams is accomplished by a synchronous motor operated by an audio-generator and amplifier, from 30 to 70 cycles per second, at will.

Random order presentation of the stimuli yields data which can be reduced to psychometric estimates of threshold by probit analysis. Subjects chosen from a large ophthalmic practice, ranging from 8 years up to 80 years of age, have been studied.

It has been found that the measure of retinal sensitivity, by means of flicker rate, indicates a superiority in young adults (21-31 yr) of five or more times above the average of the median adult population (32-50 yr). A comparable depression to one-fifth or less in the sensitivity of older adults (51-80 yr) is also demonstrable. This amounts to a superiority of 25 to 1 or better for young vs old adults. Teenagers (8-20 yr) are comparable to the young adult group, but show greater individual variance, depending in part upon immediately preceding out-of-doors activity before their testing.

It is concluded that older drivers (50 yr and more) should be cautioned, and perhaps examined. Elderly drivers should be persuaded not to drive at night, if at all avoidable. Potential protection of elderly retinas by the use of sunglasses or out-of-doors avoidance is suggested. Support of further research is greatly needed, as this degree of retinal dysfunction is a significantly potential cause of accidents due to poor night visibility.

● IN 1952 Peckham (1) reported the effect of sunlight on retinal sensitivity and indicated the night visibility dangers resulting from failure to wear sunglasses at the beach or with out-of-door sports. Those conclusions were based on measurements of a group of beach guards at Atlantic City, and a group of chauffeurs on the desert roads of Arizona (2, 3).

Since that time the observations have been continued, and herein are reported the results of calibrated measurements on a group of 100 subjects in a clinical practice of ophthalmology. These normal subjects ranged from 13 to 80 years of age. Their retinal sensitivity ranged, from the best to the poorest, by more than 500 to 1. The authors have found that "teenagers" and young adults show much greater sensitivity than the middle age group, and that elderly people, even as young as 50 years, show a serious depression of sensitivity. These data, and the methods of obtaining them, are presented because it is believed that they are related to problems of highway safety. The earlier conclusions have been justified, and represent a problem of tremendous and serious implications.

In 1951, Miziak (4) reported that the rate at which a flickering light becomes steady decreases with age. In 1834, Talbot (5) reported that the flicker rate varies with the brightness. The authors' reports (6, 7) have shown that the difference of flicker rate between individual observers can be used as an indication of the sensitivity of the retina. Careful examination of the phenomenon of flicker is required.

Flicker is a purely subjective phenomenon. It refers to the appearance of an alternating light and dark visual stimulus at certain specific rates of alternation. When the visual field, in whole or part, slowly alternates between dark and light, perception will follow the alternation; the dark phase will have the appearance of darkness, and the light phase, the appearance of lightness. As the rate increases, there will develop a tendency for the discreteness of darkness and lightness to disappear, and the perception will assume a more random character; the light appears to "flicker." As the rate of alternation continues to increase, the flickering irregularity seems to fade out until the rate is so rapid that the perception becomes one of "fusion" or smooth coherent lightness.

The appartus is shown in Figure 1. From the subject's side, a large (50 deg) field is illuminated at 300 millilamberts. In the center of this field a small aperture is illuminated from behind, with two alternating beams, one of which is slightly brighter, and the other is equally dimmer, than the background.

Alternation of the beams is accomplished with a perforated disc driven by a synchronous motor whose speed is electronically controlled. The alternation is presented from 20 to 60 cycles (or "flickers") per second in a random order. The contrast of the flicker spot can be set from 50 to 1 percent with respect to the background. The contrast of the flicker amounts to only 5 percent in the experiments reported here. Because the average of the flickering light equals the illumination on the background, the subject maintains constant retinal adaptation.

Since there are no brightness changes in the field, artificial pupils have not been used. It was desired that the eyes be measured as naturally as possible, in order to measure the reaction of the whole visual system.

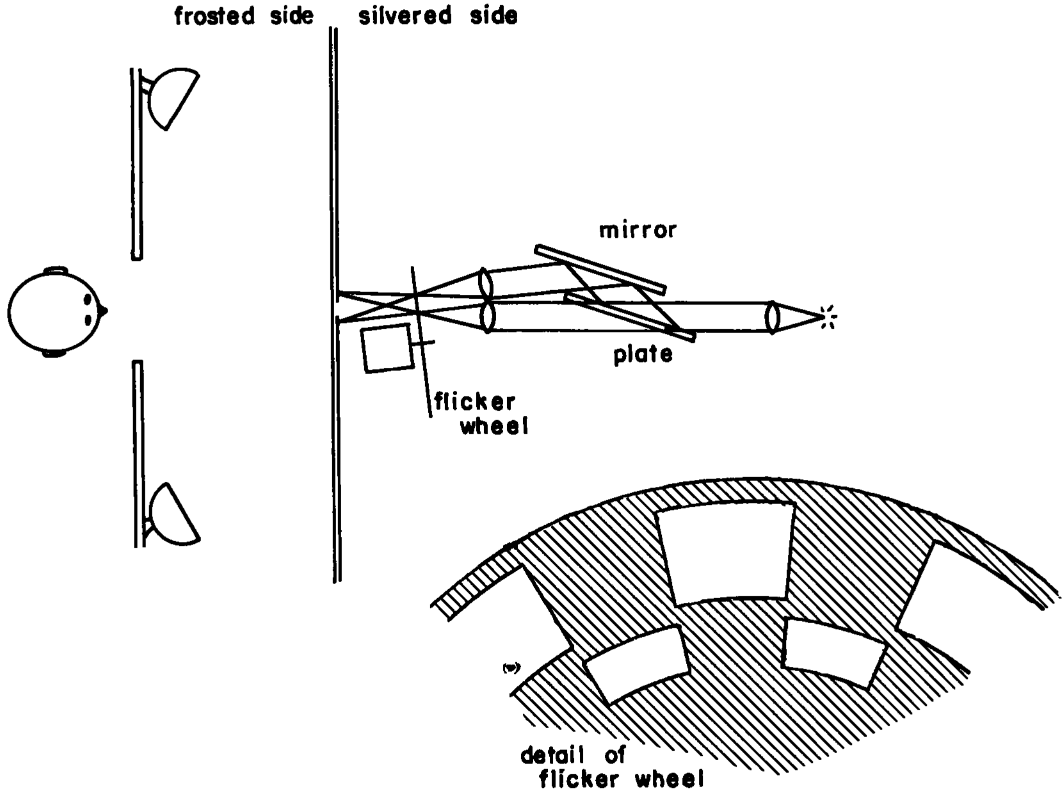

Figure 1. Flicker machine.

The subjects reported on were all normal. When they needed eye glasses to see sharply, these were provided before the tests were made. The problem is not difficult, and the test requires only about 15 min of actual work by the observing subjects. Their job is simple and easy, and it has been possible to measure children of 7 years of age as well as old folks of 80 years.

Only one eye is tested at a time. The other eye is covered with a frosted glass, which allows the light to continue, but prevents sharp vision. This maintains the state of adaptation in the unused eye. The measure of retinal sensitivity is that specific rate at which it is estimated that flicker would be reported one-half the time. This is the "threshold" measurement of the "critical flicker frequency."

The apparatus was originally devised to study certain ophthalmic dysfunctions, but a group of clinical patients whose eyes were normal has been examined to establish a base of performance. The subjects varied from 13 to 80 years of age. The flicker rates reported varied from 25 to 53 cycles per second at the 5 percent contrast and 300 millilamberts here reported.

In a second study, using trained observers only, it was established that the flicker rate could be expected to decrease with decrease in illumination, and that the rate of decrease approximates 7 flickers per second for each logarithmic unit ($\frac{1}{10}$) of the apparent brightness. This value agrees, for the 5 percent contrast conditions, with the order of that reported earlier of 10 flickers per log unit, for a 100 percent contrast neon flash flicker target (3).

The results of this preliminary survey are given in Figure 2, which shows the distribution of measured threshold flicker rates on 181 normal eyes, of patients between 13 and 80 years, as a whole group.

In a sense, it is as if the same light, comfortable to the normal group, dazzles the highest group, whereas the lowest group can hardly see at all. This is not the actual case, because all of the subjects are always adapted to this same light, but the persons

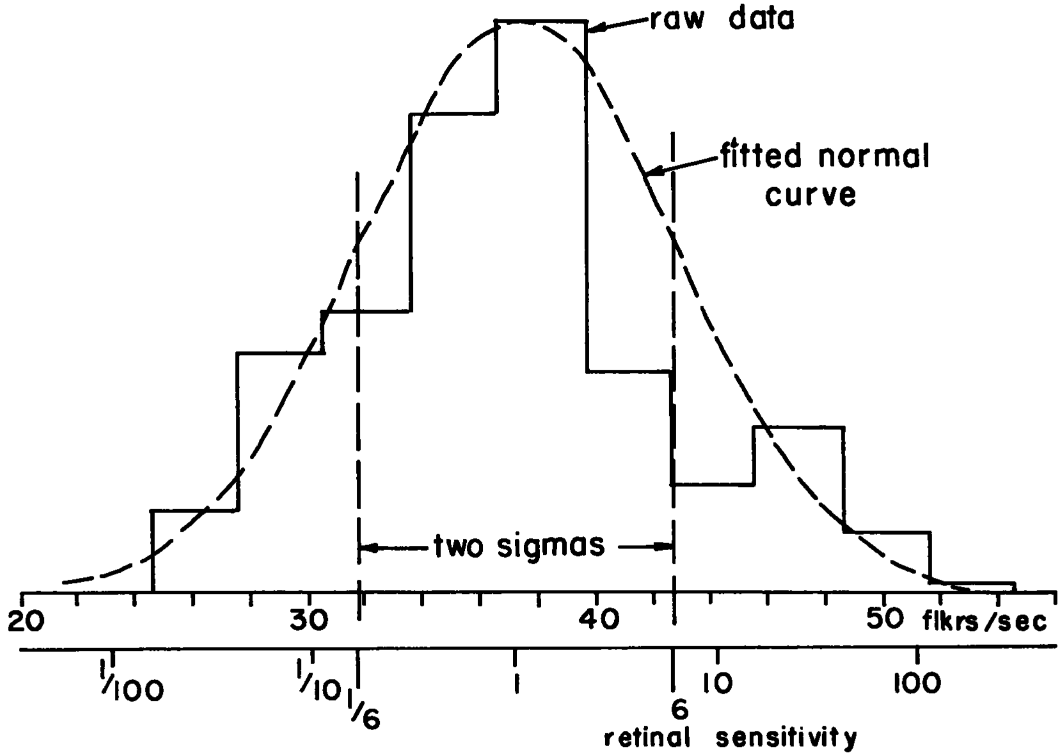

Figure 2. One hundred and eighty-one measurements of retinal sensitivity.

in the highest grade can use it better, and what is sufficient light for the average grade is inadequate for the lowest grade. The extreme grades are the uppermost 15 percent, whose retinal reaction was six times or more as efficient as that of the normal group, and the poorest 15 percent, who behaved as if the light were onle one-sixth as bright as it was.

The data of this Figure 2 include all the subjects reported; that is, all ages. Next, only the extreme data for each age-group are examined separately. These are given in Table 1, in the two youngest age groups, 13 to 19 years, and 20 to 31 years, there were no cases in the poorest grade. There were, however, about one-third in both the younger age groups whose retinal sensitivity was in the highest grade.

Between the ages 32 and 50, both extremes are found—lowest and highest. But in the oldest age group, from 51 to 80 years, more than one-half the cases are found in the very poorest grade.

These data are illustrated graphically in Figure 3. The teenagers have remarkably strong response to low contrast flicker stimuli, as do the young adults. In the middle age group a more normal situation is found, with examples of each extreme. In the older age group, however, retinal sensitivity has tremendously diminished.

TABLE 1

ANALYSIS OF AGE GROUPS, EXTREME CASES
(Values in parentheses represent expected frequencies by chance)

Age (yr)	Lowest Grade, 1 σ Below Average	Highest Grade, 1 σ Above Average	Total Eyes
13-19	0 (5.7)	12 (5.7)	38
20-31	0 (3.6)	7 (3.6)	24
32-50	12 (12.8)	9 (12.8)	85
51-80	19 (5.6)	2 (5.6)	34
All			181

$X^2 = 55.08$
$p = 0.000001$

These data tell a story parallel to that previously reported about the effect of sunlight. The earlier studies included only men in the young adult group. Differences in sensitivity as great as here reported were found in these young men between evening and morning, as a result of sunshine exposure, and their losses were found to be preventable by the use of dark sunglasses (2).

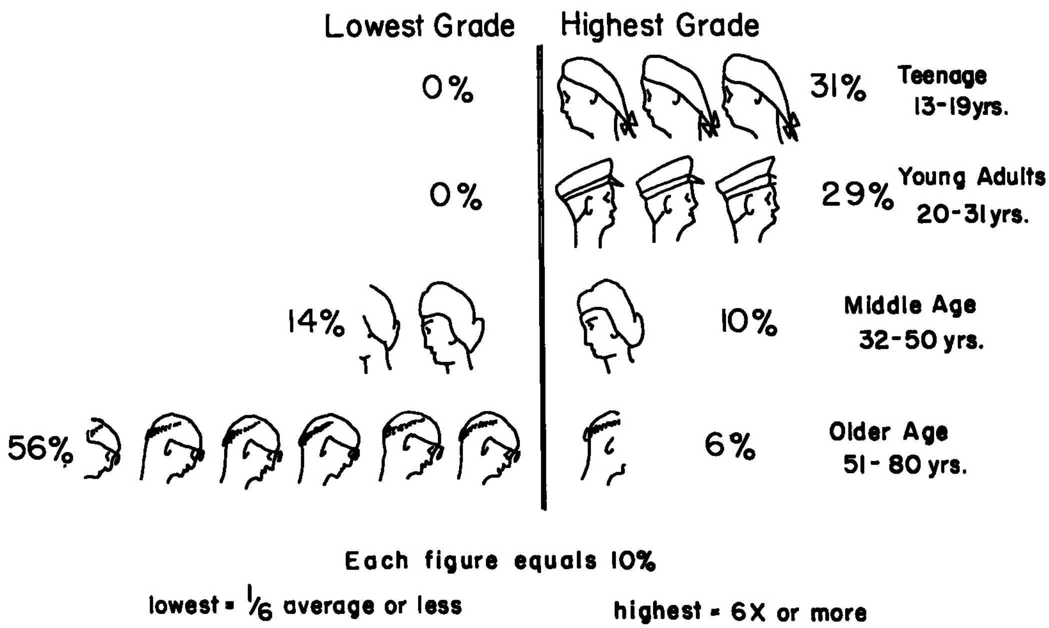

Figure 3. Younger persons show highest retinal sensitivity to low contrast flicker, older persons show retinal depression.

INTERPRETATION OF DATA

It is well known that the eye is a very poor instrument for estimating absolute brightness, although it is an excellent instrument for matching equal brightnesses. Thus, although two observers will agree within a few percent (usually within 2 percent) of the match between a standard and unknown brightness, it has been impossible to ascertain how bright the standard is to either observer.

It is the authors' thesis that the effective brightness of an illuminated field is represented by the ability of the adapted retina and its associated mechanisms to respond to flicker at the brightness in question. When the retinal system is superior, the flicker rate is increased; when the retina is depressed, the flicker rate is depressed. In these experiments, the background is maintained at a level higher than that of the room, and two or three minutes are allowed for adaptation to this higher level (probably a few seconds would suffice). Differences between the determined flicker rates are therefore interpreted as retinal sensitivity; that is, as estimates of the effective brightness of the field.

On the basis that 7 flickers per second represent a brightness difference of one log unit, or ten times, the difference of 5.5 flickers, or standard deviation, represents 0.78 log units. This corresponds to a brightness difference in the effectiveness of illumination of 6 times. Hence, the data in Figure 3 present an interesting picture. Effectively, the illumination of a headlamp beam is 6 times or more as effective for one-third of the teenagers and the young adults, as it is for the median group. And, conversely, the headlamp is one-sixth or less as effective for more than one-half of the eldest group. Between the youngest and oldest extremes there is a range of effective brightness exceeding 36 to 1 for any given level of illumination.

At high daylight illuminations, with high-contrast targets, these differences are not particularly discriminating between the two groups, because visual acuity, as so measured, does not greatly change from about 8 to 300 foot-candles. In the conditions of night driving, however, these retinal differences can easily become disastrous. One need only consider the reduction in effectiveness of one's own headlamps, to one-thirtieth of their present value, to comprehend the effect of the decreased retinal sensitivity for the older as compared to the younger group. Vision of both would be comparable within the small area of maximum illumination, down the road, but the tremendous effect of loss of perimacular vision, to either side of the headlamp beam, is at once evident.

It is not impossible that some remedial cognizance might be taken of these preliminary findings. In the first place, after the not really old age of 50 years drivers should be made aware of the need for extra caution. Older drivers should be persuaded to avoid all night driving, as a matter of survival. Extraordinary visual deficiency, resulting from loss of retinal sensitivity, might be made a basis for a suitable screening test for all drivers above 50 years of age, for example. Also, the estimates of visual benefits from improved lighting conditions and visual aids should not be based on the superior perception of younger observers.

There is adequate information to show that occasionally among younger persons, and not infrequently among the middle age group, temporary retinal depression is quite probable. In fact, the extremes for all groups tend to overlap. This fact is interpreted as evidence that certain conditions of protection, enhancement, and other factors of depression and exposure are effective, and must be discovered, defined, and applied, especially with regard to traffic safety programs. Exposure to sunlight, the longer effects of even mild alcoholic imbibition, potential "tobacco amblyopia", and even systemic dysfunction due to illness, may play a causative role in this condition. The great effect of sunlight exposure was reported in 1952 (2, 3). Middle aged and elderly persons should be taught to use sunglasses for protection during daylight driving, if they anticipate continuing after sunset.

With this discussion in mind, certain specific cases among those here reported can profitably be examined. Two persons of the oldest group, whose ages are 60 and 80 years, show retinal sensitivity within the superior range of the young adults. One of these is a Catholic Mother Superior; the other, a retired Protestant Minister. Both persons live regular and sheltered lives of good regimen, and avoid excess out-of-doors exposure. Among the teenagers a few have been found with greatly depressed retinal sensitivity, for their age, and in particular the poorest performance was found in a boy who was examined within a few minutes after a 2-hr football practice session in bright sunlight.

Certain seasonal changes greatly affect retinal sensitivity and, thereby, traffic safety. In this geographical area, near Washington, D. C., the sun in October was still shining strongly at 5:00 P. M., during the evening rush hour. When civil time was changed from Daylight to Standard, the peak evening traffic changed abruptly from one-half hour before sunset to one-half hour after sunset. Not only do driving habits need to be adjusted for these different conditions, but the fact that the previous days were clear and bright found the retinal sensitivities of the drivers at their poorest. A specific caution was issued at this time through the local newspapers (7) by John W. Childress of the District Division of the American Automobile Association. He pointed out that 75 percent of traffic deaths occur during these evening peak hours, between 4 and 8 P. M. His observation correlates closely with the conclusions herein concerning retinal sensitivity.

Because this paper is a preliminary report of a condition that may be of very serious import to traffic safety as dependent upon night visibility, it is presented with the obvious plea for support of further and more definitive research in this suggestive field.

REFERENCES

1. Peckham, R. H., "Effect of Exposure to Sunlight on Night Driving Visibility." HRB Bull. 56, p. 17-24 (1952).
2. Peckham, R. H., and Harley, R. D., "The Effect of Sunglasses in Protecting Retinal Sensitivity." Am. Jour. Ophth., 34:1499-1507 (1951).
3. Peckham, R. H., and Arner, W. J., "Visual Acuity, Contrast, and Flicker, As Measures of Retinal Sensitivity." Jour. Optic. Soc. Amer., 42:621-625 (1952).
4. Misiak, H., "The Decrease of Critical Flicker Frequency with Age." Science, 113:551-552 (1951).
5. Talbot, H. F., "Experiments on Light." Phil. Mag. (S. 3), 5:321-334 (1834).
6. Peckham, R. H., and Hart, W. M., "Critical Flicker Frequency, Photochemical Mechanisms, and Perceptual Responses." A. M. A. Archives of Ophth., 60: 461-471 (1958).
7. "Drivers Warned of Early Darkness." The Evening Star, Washington, D. C. (Oct. 29, 1958).