Dark Adaptation as a Function of Age and Tinted Windshield Glass

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● THIS STUDY was designed to measure the relative effects of light-absorbing, clear, and tinted windshield glass on the terminal levels of dark adaptation in a large sample of subjects who varied widely in age. The penalty age imposes on dark adaptation (1, 3, 4, 19, 28) is universal, but only recently has the extensive range of individual differences in dark adaptation as a function of age been estimated (18) with reasonable confidence. If the natural physiological processes of aging reduce perceptual-motor efficiency then any conditions that artificially and unnecessarily interfere with sensory-response functions should be avoided. Previous studies have shown that tinted windshield glass is just such an artifice. Although little is known about the relative effects of tinted filters on the dark adaptation efficiency of persons in different age groups, there is reason to believe that the adverse effect increases with age.

Because there is a direct functional connection between the physiology of the dark adaptation process and night vision, and a direct statistical connection between levels of luminance on which night vision depends and the frequency of fatal and non-fatal vehicle accidents, the relevance of studying individual differences in the population is clear.

The relationship of changes in luminance to the frequency of vehicular accidents is strongly suggested by the following evidence. Studies have shown that when the probability of accident exposure was held constant that nighttime fatalities were three times greater than daytime fatalities. One study (31) conducted in Detroit showed that 75 percent of all night accidents occurred on about 100 mi of streets through which flowed nearly 15 percent of all night traffic. The illumination was raised by a factor of three, and over a two-year period the number of nighttime accidents was reduced to approximately 26 percent of the total number in the city. A similar procedure (31) in Hartford, Connecticut, involved doubling the illumination. There, the accident rate was halved. Parallel results were achieved in Atlanta (25), and in Kansas City (32). The evidence from these investigations was the same; that is, when street and highway illumination was improved, nighttime accidents were reduced.

Because several relationships within the dark adaptation process itself are important for the understanding of the problem, the restrictions on vision determined by low levels of illumination will be explored in detail.

The adaptation of vision to low levels of illumination is a complex phenomenon that takes place in two distinct though overlapping phases. Cone vision depends on relatively high levels of illumination that range between 16,000 ml, the upper limit of retinal tolerance, and 0.01 ml, the lower limit of cone efficiency. Cone vision degenerates rapidly below 0.01 ml, the cone-rod transition point, and is replaced by the much less efficient rod cell vision, the threshold of which is approximately 0.000001 ml. Both cone and rod vision are represented by successive decay curves. The first phase is relatively short and nearly reaches its asymptote in about 4 to 6 min. The second phase requires 20 min or more. Interposed between the two is the junction of the two curves where both cone and rod vision are not fully efficient, cone vision having been reduced nearly to zero sensitivity when the retina is deprived of light, while rod vision is still in the early stages of development.

The most efficient degree of visual acuity, color perception, and depth perception depends on cone vision. Rod vision, capable of mediating only gross form in certain stages of its development, is most insensitive to color, and is inferior in three-dimensional vision.

The rate at which the eye becomes adapted to low luminances is extremely important. Rate of adaptation is a function of several conditions common to daily human experience. Thus, dark adaptation and therefore, night vision, is dependent on duration, intensity, and wave length of the light band to which the individual has been exposed prior to the initiation of the process. In turn, these vary during the day, time of year, and with the geographic region. It is also known that adaptation varies adversely with anoxia (20), hypoglycemia (21), and CO concentration (22).

Adaptation to low levels of illumination requires a relatively long time, while only a fraction of a second exposure to moderately high luminance is sufficient to destroy dark adaptation. This is an unfavorable characteristic in those instances where the individual must continue to function with precision under low illumination.

It is clear that interference with the rate and degree of adaptation must reduce visual efficiency, especially when interference occurs at levels of luminance involving rod adaptation, and therefore, night vision. It has been shown (27) that much of the time night driving takes place under low luminance levels that range from 0.0028 ml to 3.176 ft lamberts. It can be seen that 0.0028 ml is less than the lower limit suggested as typical of cone vision. Thus, some driving takes place under levels of illumination that are inadequate for cone vision.

Nevertheless, the benefits that have been said to be derived from lowering illumination through the use of tinted windshield glass are (a) reduction of interior temperature of vehicles and the protection of occupants from exposure to infrared rays of solar energy, (b) relief from glare, (c) more rapid recovery from "light shock," and (d) improvement of visibility, presumably visual acuity. Evidence supporting these assertions is related only to the infrared light-absorbing effect of filters. No data have been found to support the remaining claims. The evidence against these alleged benefits follows.

The conflict between thermal discomfort and impediments to vision is more apparent than real, because engineering problems associated with filtering infrared rays and the development of vehicular air conditioning are not actually so critical. Furthermore, it is doubtful whether tinted windshield glass in vehicles can be justified on this basis partly because the dark color of many vehicles cancels out the possible temperature reduction by glass filters. Direct exposure to infrared light can be avoided in other ways, for instance, by the modification of vehicle design and through the use of appropriate clothing.

The effects of filters on light transmission, glare, "light shock," visual acuity, color rendition, and stereopsis will be considered next.

Any laminated filter reduces radiant energy that would otherwise reach the retina by (a) surface reflection, (b) limitations imposed by the transmission characteristics of the glass, and (c) the light-absorbing characteristics of colored laminating substances. Experimental data obtained by McFarland and Wolf (23) indicate that a Noviol C filter having higher transmission in red-yellow than a popular brand of bluish-green windshield influences the course of dark adaptation in almost the same way. The total transmission factor of the Noviol C filter differed by no more than 4 percent from the windshield filter. This indicates that it is luminance loss, not surface reflection, nor selective frequency absorption of the tinted laminating material which is responsible for the decrement introduced into dark adaptation.

Glare must be regarded as an entoptic phenomenon dependent on such factors as (a) the diffusion of light transmitted through media such as the iris and sclera, (b) flares, produced by multiple reflections from different refracting surfaces, (c) specular reflections from the front surface of the retina, (d) halation produced by reflections from the pigmented epithelium, choroid coat, and sclera, (e) light reflections through the vitreous humor from one part of the retina to another, (f) fluorescence of lenses, and (g) scatter by the ocular media.

Glare has three major parameters: (a) it is inversely proportional to the area of the light source, (b) increases as the ratio between source and surround increases, and (c) varies with visual angle. It is apparent that a filter interposed between the eyes of the observer and the light source and its surround decreases the total amount of light available for seeing, but it does not reduce the area of the source, visual angle nor, the ratio between source and surround. Thus, the fundamental conditions from which glare is derived remain unchanged.

Light "shock" occurs when light is presented tachistoscopically. It will be recalled that dark adaptation can be destroyed in a fraction of a second even though it requires a relatively long time to develop. Rate of recovery, then, is exceedingly important, especially where the individual must see under levels of illumination that are not constant, and where the fluctuation in intensity is great as well as rapid.

Any filter will reduce the intensity of glare and light shock. However, the same degree of absorption that reduces light intensity also reduces visibility of the background. It has been demonstrated (23) experimentally that when tinted glass is placed in front of the light source and also in front of test targets, that there is no relief from glare and no material gain in recovery time relative to the reduction of luminance. Neither is it a matter of "coming out even" because the reduction of total luminance results in an absolute degree of reduction of visual acuity or visual discrimination. Thus, there is a margin of over-all loss, depending on the transmission factor of the filter, all else being equal.

Tinted filters reduce acuity in varying amounts depending on the filters (6, 8, 10, 11, 14, 15, 24) distort color rendition (16, 17), and reduce depth perception (23). Conditions of visibility between 25 and 200 ft (8, 24) from the viewer have been found to be adversely influenced by tinted filters. However, little is known concerning the relationship of perception under conditions of lowered illumination as a function of age and tinted filters.

METHOD

Subjects

There was a total of 240 male subjects drawn from YMCA youth groups, college-age students, university faculty, taxi drivers, unemployed persons obtained through a USES Agency, and men living either at home, or living in private institutions for the aged. Thirty subjects were drawn from each decade ranging from the teen-age level through the age of 89 yr. All subjects were paid for their services. After the data were obtained more than one-half the subjects in each decade were then offered and given a complete optometric examination free of charge. The optometric data will be described in a separate publication.

Apparatus

The instrument used throughout this study was a modified Hecht-Schlaer Adaptometer (12). From time to time the apparatus was housed in a dark room in each of three cities principally to accommodate aged persons for whom traveling was inconvenient.

Procedure

The subject (S) was seated in the experimental room. His left eye was covered by a patch, and his head was held steady in a standard head-chin rest. Vision was uncorrected. The lights in the dark room were turned off, and after a lapse of approximately 1 min the retina of the right eye was bleached for 3 min by exposure to a standard 1600-millilambert (ml) evenly diffused incandescent light. At the end of the pretest phase the fixation point was presented 7 deg right of the test field. The violet test light stimulus was exposed tachistoscopically. The duration of each test flash was $1/5$ sec. All the data were obtained by one technician (David Ward).

The first observation was made approximately within the first 40 sec after the termination of the pre-exposure bleaching light. Then, beginning with the second observation, one test was made every minute for the first 10 min, and every 2 min for the next 6 min, every 3 min for the following 24 min, and finally, every minute for the last 10 min. Beginning with the 41st min, a filter cut from the center of a standard clear glass windshield (CWG) was interposed between the test patch and S's eyes. On the 46th min this filter was interchanged for a second filter cut from the center of a popular brand of tinted windshield glass. Particular care was taken to obtain the sample filter from the eye level of a wide range of subjects. There were 32 observations made during 50 min of dark adaptation time, 5 of which were made with a clear windshield glass filter, filter A, and 5 of which were made with a tinted windshield glass filter, filter B.

The transmission factor of filter A was approximately 90 percent. Maximum transmission values found for samples of tinted windshield glass ranged between 65 and 69 percent. The actual value of filter B used in this study was approximately 70 percent as indicated by the Macbeth illuminometer. Figure 1 shows the percentage transmission curve of filter B.

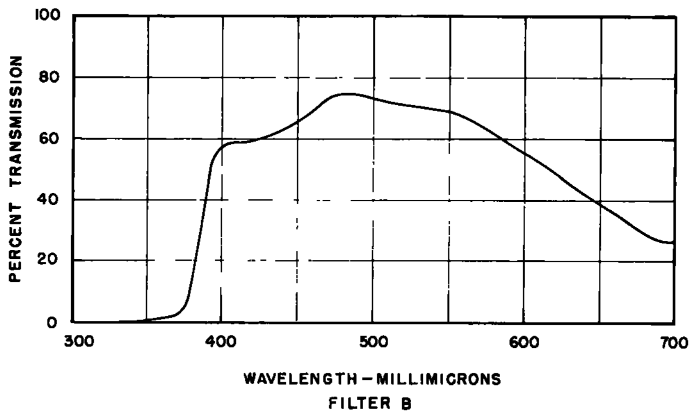

Figure 1.

RESULTS

Figure 2 shows that the family of mean dark adaptation curves rises in an orderly manner as a function of age. With the exception of the reversal of the cone curve elevations for the 16-19 and 20-29 year old groups, no other reversal is visible. This slight overlap is not sustained and it does not reverse the order of terminal points of the mean curves as a function of age.

Figure 2 demonstrates that the effects of age occur immediately since the initial mean scores are separated. It can be seen that with the passage of time the absolute differences among the mean curves increase. Therefore, the full effect of age on the course of adaptation is most clearly revealed when the curves approach their respective asymptotes.

Figure 2 shows that the first terrace-like rise in the curves begins at the 41st min, the time when filter A was interposed between the S's eye and the test light. The magnitude of the rise represents the average increase required in the intensity of the testlight before the Ss could just see the stimulus, and therefore the functional effects of the 90 percent transmission factor of filter A. The introduction of filter B at the 46th min was followed by a second rise at the ends of the curves.

In Table 1 columns B, C, and D give the log values at the 40th min, 41st min after the introduction of the clear glass filter, and after the introduction of the tinted filter at the 46th min. Columns E, F and G give the anti-log values of columns

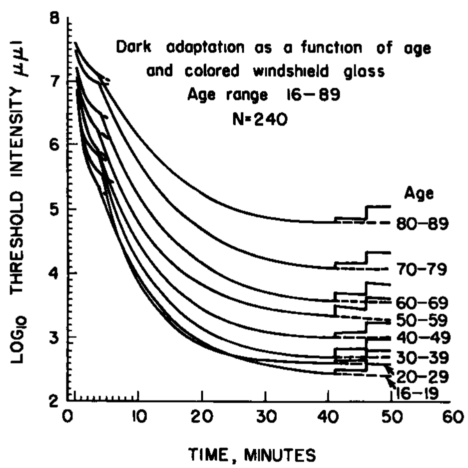

Figure 2.

TABLE 1

DARK ADAPTATION AS A FUNCTION OF AGE, TIME AND WINDSHIELD GLASS

Age	Luminance									
	Log10			uul					% Luminance Increase	
A	B 40thMin No Glass	C 41st Min Clear Glass	D 46th Min Tinted Glass	E 40th Min No Glass	F-E Diff CG-NG	F 41st Min Clear Glass	G-F Diff TG-CG	G 46th Min Tinted Glass	H No Glass to Clear Glass	I Clear Glass to Tinted Glass
16-19	2.427	2.446	2.571	267.3	12	279.3	93.1	372.4	4.48	33.33
20-29	2.602	2.632	2.777	399.9	28.6	428.5	169.9	598.4	7.15	39.64
30-39	2.694	2.789	2.952	494.3	120.9	615.2	280.2	895.4	24.45	45.54
40-49	3.016	3.043	3.204	1037.5	66.6	1104.1	495.4	1599.5	6.41	44.86
50-59	3.346	3.408	3.600	2218.2	340.4	2558.6	1422.5	3981.1	15.34	55.59
60-69	3.642	3.653	3.813	4385.3	112.5	4497.8	2003.5	6501.3	2.56	44.54
70-79	4.104	4.142	4.306	12705.7	1161.8	13867.5	6362.5	20230.0	9.14	45.88
80-89	4.806	4.847	5.030	63973.3	6333.2	70306.5	36846.0	107052.5	9.89	52.40

B, C, and D. It can be seen in the difference columns F-E and G-F that both the clear glass filter and the tinted glass filter lead to an increase in the demand for light for all age groups. However, as age increased the relative demand for light increased at a geometric rate. Thus, the light decrement for elderly persons was far greater than the light decrement for younger persons. Columns H and I give relative percent change in the demand for light as a function of filter A and B, and age.

The range of mean increase in demand for light associated with filter A was 12 μμl for age 16-19 to 6333.2μμl for age 80-89. Tinted windshield glass was associated with a similar mean increase in demand for light of the order of 93.1 μμl for age 16-19 to 36846.0 μμl for age 80-89.

An elaborate statistical analysis of the results was not considered appropriate because the effect of both filter A and filter B on the degree of dark adaptation of Ss within the various age groups was so obvious. When filter A was introduced during the time interval 41-45 min, 6 Ss indicated a decrease in demand for light, 7 Ss failed to change their demand, and 227 subjects demanded an increase in the brightness of the test patch. When filter B was introduced in the interval 46-50 min, one subject decreased his demand for light, and 239 Ss demanded an increase in the brightness of the patch.

The complete data are given in Table 2.

TABLE 2

CHANGE IN DARK ADAPTATION LEVEL FOLLOWING THE INTRODUCTION OF CLEAR WINDSHIELD GLASS AND FOLLOWING TINTED WINDSHIELD GLASS

	Number of Ss Changing Demand for Light After Introduction of Filter A			Number of Persons Changing Demand for Light After Introduction of Filter B		
Age	Decrease	Unchanged	Increase	Decrease	Unchanged	Increase
16-19	1	1	28	1	0	29
20-29	1	0	29	0	0	30
30-39	3	1	26	0	0	30
40-49	0	0	30	0	0	30
50-59	0	2	28	0	0	30
60-69	0	2	28	0	0	30
70-79	1	0	29	0	0	30
80-89	0	1	29	0	0	30
Sum	6	7	227	1	0	239

Because the probability of a change in the demand for light would be one-third in favor of decreasing illumination, one-third in favor of increasing illumination, and one-third favoring no change, the hypothesis of chance may be tested as shown in Table 3. X^2, 405.205, and .P, 0.001 show that the chance hypotheses could not be maintained. Therefore the increase in the demand for light in the presence of filter A cannot be considered a chance effect.

Since 239 subjects of the total sample of 240 Ss demanded an increase in light following the introduction of tinted windshield, the influence of tinted windshield glass appears to be unequivocal.

TABLE 3

NO GLASS VERSUS CLEAR GLASS

Chi Square Test for Chance			
	Decrease	No Change	Increase
Frequency of observed changes in demand for light	6	7	227
Frequency of expected changes in demand for light	80	80	80
Chi square	405.2050		
df	2		
P	Exceeds 0.001 level of confidence		

DISCUSSION

The present data show that dark adaptation efficiency drops sharply as age increases. As a matter of fact, at the 40th min of adaptation subjects in the oldest group required 239 times more light to just notice the test stimulus than persons in the youngest group. Tinted filters decreased the efficiency for both groups.

The statistical treatment and Figure 2 show clearly that when the viewer was presented with the tinted windshield filter that the amount of light necessary to just see the test patch increased. Functionally this was equal to a regression in time to some former, less adequate, level of adaptation. For the youngest and most efficient Ss, the filter, in effect, reinstated the lower degree of efficiency present at the 30th min of adaptation. Because maximum dark adaptation is nearly reached after ½ hr the youngest subjects were not seriously penalized. However, the older subjects, who were many times less sensitive than the youngest persons, regressed still further on the time continuum to a level characteristic of the 23 min of adaptation. This was equivalent to the threshold manifested by the youngest group after only 5 min of adaptation. Comparatively, then, the oldest subjects were not only penalized by age, but were further penalized by the tinted filter to a relatively greater extent than were the youngest subjects. Stated in another way: the eldest subjects who viewed the test patch through the tinted filter required 50 min to achieve a degree of dark adaptation achieved by the youngest subjects without any filter after only 5 min. Or stated in still another way: after 5 min of dark adaptation the night vision of the younger subjects on the average was equivalent to the maximum threshold expected of subjects 80-89 years of age who viewed the test patch through tinted windshield glass.

The evidence from this study and other research clearly indicates that filters of all types including sections of tinted windshields interfere with every major visual function. There is no evidence to support the assertion that tinted windshields aid vehicle drivers in any way. Nevertheless, between 1950 and the present time millions of land vehicles have been equipped with different types of windshield glass that reduce illumination coming to the eye of the operator from 30 (23) to 28 percent (6). Coincidently, a 30 percent reduction in transmission is the lower limit permitted by the American Standards Safety Code (2), a criterion difficult to justify because it fails to take into consideration individual differences or the variation in individual tasks performed by persons at reduced levels of illumination.

A 30 percent reduction in luminance may not present difficulties as long as there is enough illumination to maintain cone vision if there is no serious distortion of images, interference with depth perception, or false rendering of color. But tinted windshields are permanent installations, and therefore do not allow vehicle operators a choice of filter with maximum transmission when the level of illumination in the driving environment falls below the amount necessary to maintain cone vision. As indicated previously, road illumination is often less than enough to sustain cone cell sensitivity.

What then is the relationship of these findings to the problems of vehicle control? It has already been shown that the frequency of accidents is proportionally greater at night than during the day. In addition it has been demonstrated in four different cities that there was a statistical correlation between reduction of fatal and non-fatal accidents and increases in road and street illumination. No data seem to be available showing that when road, street, and highway illumination is increased that accidents also increase. The data favor the hypothesis that the correlation between accident reduction and increasing illumination is not accidental.

It can be seen that there is a relationship between variation in rate of adaptation not only among persons of the same age but as a function of age as well. For instance, illumination in the night driving is not constant. It fluctuates in intensity from relatively high levels, 3.1716 ft lamberts, to relatively low levels, 0.0028 millilamberts. But it does so intermittently, and in an unpredictable manner at a rate that cannot be matched by the dark adaptation process of even the most efficient visual apparatus. The low levels of illumination are often not high enough to sustain cone vision. This is indicated by the 0.0028 ml shown above. Thus, the vehicle operator must depend part of the time on rod cell vision, usually of the incompletely dark adapted eye, or otherwise on the relative levels of partial dark adaptation characteristic of the intersection between cone and rod vision. It is clear that age brings deterioration of the initial capacity, and that filters artifically deprive the viewer of a considerable degree of his remaining sensitivity. Vehicle operators are forced to depend on something less than the full sensory command over their driving environment.

Vehicle operators must function under the dynamic conditions of traffic movement which at varying rates demand accurate perception of movement and velocity. This perceptual capacity varies among individuals to a marked degree. Individual differences as high as 40 percent (7, 34, 35) have been found. And because the perception of movement and velocity varies as a function of cone vision and rod vision, it is directly related to age and to degrees of illumination which determine cone and rod sensitivity. This means that the rate of movement of a vehicle will not appear to be the same under high and low luminance levels. Unnecessary reduction of available light will not assist the operator to function more adequately. For instance, it would be expected that if tinted windshield glass merely changed the appearance of the stimulus world of the driver that he would adapt to novelty quickly. But this is not the main effect: at certain distances stimuli that would ordinarily be seen through clear glass cannot be seen at all through tinted windshield glass.

The perception of distance, movement, and velocity is growing in importance with every increment of increased speed added to the flow of modern traffic. For instance, when the limitations imposed on vision by tinted windshield glass are integrated with the data on mean braking distance it has been demonstrated (8) that operators who use tinted windshield glass should reduce their general speed by a factor of about 30 percent. But it has been found that in the last 19 yr, average traffic speed has increased by about 5 mph, and that the passing time of the more powerful vehicles has decreased by approximately 5 percent. Evidence does not show that tinted windshield glass has resulted in lower speed on the highway.

More interesting was the discovery that even on highways where the passing sight distances ranged from 1,800 to 3,300 ft some vehicles completed their pass when an oncoming vehicle was less than 200 ft away. When it is realized that two vehicles approaching one another at the rate of 50 mph will meet in slightly less than 200 ft in 1.4 sec, it will also be recognized that margins of safety on highways become slight indeed. Reducing illumination by 30 percent in this situation at night could not be expected to improve visual perception on which safety depends.

Still more arresting was the finding that though vehicle speed has increased slightly, and passing time (26) reduced by a small percentage, the left lane road distance required to pass another car has increased by about 19 percent. This was found to be true on roadways where the geometry of the seeing and passing distance of the track had not changed in 20 yr.

It has been shown that tinted windshield glass results in the reduction of visual efficiency even at distances less than 200 ft. Therefore, not only does tinted glass interfere with vision, it does so in a man-machine-environmental situation complicated by conditions of marginal safety.

Visual efficiency is fundamental to the precise and reliable control of vehicles under these circumstances. In demonstrable instances these margins are being reduced by such factors as increasing traffic congestion, and increasing demand for more passing space in fixed sight distance regions. Thus, when the limitations imposed on vision by tinted windshield are integrated with the data on mean braking distance it has been demonstrated (8) that operators using filters should reduce their general speed by about 30 percent. But vehicle speed has not been reduced on the average. It has been increased by at least an average of 5 mph. The relevance of the perception of movement and velocity to highway traffic problems of many types is clear.

Inasmuch as it has been demonstrated that tinted windshield glass does not aid, but distinctly hinders visual efficiency at low levels of illumination, then the advocates (5, 6, 9) of increasing highway illumination and the advocates of tinted windshield glass are diametrically opposed. Actually the introduction of TWG has cancelled out much of the effort of agencies working to increase illumination. To compensate for the limiting effects of tinted windshield glass, illumination of streets, roads, and highways should be increased by the same amount, preferably more. To do this, artificial illumination would have to be further raised by 30 percent or more merely to maintain the advances made by highway illumination engineers in the last few years.

CONCLUSIONS

1. Both clear and tinted windshield glass reduce the amount of light that reaches the retina of the vehicle driver's eye.
2. Tinted windshield glass transmits less light than clear windshield glass, where the transmission factor of clear windshield glass is about 90 percent, and the transmission factor of tinted windshield glass ranges from 55 to 70 percent.
3. Some areas of tinted windshield transmit less light than is permitted by the American Standard Safety Code. The lower limit allowed by this code is 70 percent transmission.
4. Dark adaptation is a function of age.
5. Clear windshield glass interposed between the testlight and the eye of the subject at terminal levels of dark adaptation is followed by a greater demand for light to just see the test stimulus, and therefore a rise in the dark adaptation curve.
6. Tinted windshield glass interposed between the testlight and the eye of the subject at terminal levels of dark adaptation is followed by a demand for light to just see the test stimulus that exceeds in magnitude the demand caused by clear windshield glass.
7. Both clear and tinted windshield glass are impediments to vision under low levels of illumination for persons ranging in age from 16 through 89 yr.

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REFERENCES

1. "Age and the Ability to See at Night." Res. Rept. No. 43, Traffic Eng. and Safety Dept, Amer. Auto. Assn. (1953).
2. "American Standard Safety Code, Z.26.1-1950." Amer. Standards Assn. (1950).
3. Birren, J.E., Bick, M.W., and Fox, G., "Age Changes in the Light Threshold of the Dark Adapted Eye." Jour. Gerontol., 3:267-271 (1948).
4. Birren, J.E., and Shock, N.W., "Age Changes in Rate and Level of Visual Dark Adaptation." Jour. Appl. Physiol., 2:407-411 (1950).
5. Bouma, P.J., "Perception of Roads When Visibility is Low." Philips Tech. Rev., 9:5, 149-157 (1947).
6. Doane, H., and Rassweiler, G.M., "Cooperative Road Tests of Night Visibility Through Heat Absorbing Glass." General Motors Corp. (1955).
7. Gordon, D.A., "The Relation Between the Thresholds of Form, Motion and Displacement in Parafoveal and Peripheral Vision at a Scotopic Level of Illumination." Am. Jour. Psychol. 60:202-225 (1947).
8. Haber, H., "The Safety Hazard of Tinted Automobile Windshields at Night." Jour. Opt. Soc. Am., 45:6, 413-419 (1955).
9. Harris, A.J., "Some Problems in Road Safety Connected with the Lighting of Streets." Presented at Assoc. of Public Lighting Eng. Conf. Bournemouth, England (Sept. 21, 1950).
10. Heath, W.M., and Finch, D.M., "Determinants of Windshield Levels Requisite for Driving Visibility." HRB Bul. 56, 1-16 (1952).
11. Heath, W.M., and Finch, D.M., "Effects of Tinted Windshield Glass on Night Time Visibility Distances." HRB Bul. 68, 1-15 (1953).
12. Hecht, S., and Schlaer, S., "An Adaptometer for Measuring Human Dark Adaptation." Jour. Opt. Soc. Am., 28: 269 (1938).
13. "Tinted Optical Media." Joint Committee on Industrial Ophthalmology of A.A.O.O. and A.M.A., Trans. Am. Acad. Ophthalmology and Otolaryngology (Mar.-Apr. 1952).
14. Lauer, A.R., Fletcher, I.D., Winston, P., and Takohashi, E.S., "Effects of Night Glasses and Colored Windshields." Optometric Weekly, 41:25, 951-955 (1950).
15. Lauer, A.R., et al., "Effects of So-Called Night Driving Glasses on Visual Acuity: A Preliminary Study." Proc., Iowa Acad. Sc., 56:263-270 (1949).
16. Mathews, J.L., "Physiological Effects of Reflective Colored, and Polarized Ophthalamic Filters." Project 21-02-040, Rept. 1, U.S.A.F. School of Aviation Medicine, Randolph Field, Tex. (Aug. 1949).
17. Mathews, J.L., et al., "Tinted Optical Media." Indust. Med. and Surg., 21:3, 129-131 (1952).
18. McFarland, R.A., Domey, R.G., Warren, A.B., and Ward, D.C., "Dark Adaptation as a Function of Age. I. A Statistical Analysis." Jour. Gerontol., 15:2, 149-154 (1960).
19. McFarland, R.A., and Fisher, E., "Alterations in Dark Adaptation as a Function of Age." Jour. Gerontol., 10:4, 10 (1955).
20. McFarland, R.A., Halperin M.H., and Niven, J. I., "Visual Thresholds as an Index of the Modification of the Effects of Anoxia by Glucose." Am. Jour. Physiol., 144:3, 379-388 (1945).
21. McFarland, R.A., Halperin, M.H., and Niven, J.I., "Visual Thresholds as an Index of Physiological Imbalance During Insulin Hypoglycemia." Am. Jour. Physiol., 145:3, 299-313 (1946).
22. McFarland, R.A., et al., "The Effects of Carbon Monoxide and Altitude on Visual Thresholds." Jour. Aviat. Med., 15:6, 381-394 (1944).
23. Wolf, E., McFarland, R.A., and Zigler, M., "The Influence of Tinted Windshield Glass on Five Visual Functions." HRB Bul. 255, p. 30 (1960).
24. Miles, P.W., "Visual Effects of Pink Glasses, Green Windshields, and Glare Under Night Driving Conditions." Arch. Ophthalm., 51:15 (1954).
25. Murrah, J.H., "Atlanta Lighting Cuts Crime 50 Percent, Averts 1700 Traffic Accidents: It's First Big City to Be Lighted by Illumination Engineering Society Standards." Am. City, 67:9, 157 (1952).

26. Normann, O.K., "Research to Improve Tomorrow's Traffic." Presented at Annual Meeting Inst. for Traffic Eng., Detroit, Mich. (Sept. 23, 1957).
27. Richards, O., "Vision at Levels of Night Road Illumination." HRB Bul. 56, pp. 36-65 (1952).
28. Robertson, G.W., and Yudkin, J., "Effects of Age upon Dark Adaptation." Jour. Physiol., 103: 1-8 (1944).
29. Roper V.J., "Nighttime Seeing Through Heat-Absorbing Windshields. The Effects of Tinted Windshields and Vehicle Headlights on Night Visibility." HRB Bul. 68, pp. 16-30 (1953).
30. Rulon, P.J., and Beaton, A.E. "The Individual Dark Adaptation Curve. I. Procedure for Fitting." (In Prep.)
31. Schrenk, L.J., "Effects of Light Changes on Traffic Accidents Shown in Detroit Lighting Report." Illum. Engin., 46:9, 890-892 (1947).
32. Seburn, T.J., "Street Lighting—Traffic Accidents—Crime." Illum. Engin., 42:9, 482-483 (1951).
33. "The Field of Highway Safety Research." Comm. on Highway Safety Research, NAS-NRC, Washington, D.C. (Aug. 1952).
34. Warden, C.J., and Brown, H.C., "A Preliminary Investigation of Form and Motion Acuity at Low Levels of Illumination." Jour. Exp. Psychol., 32: 437-449 (1944).
35. Warden, C.J., Brown, H.C., and Ross, S., "A Study of Individual Differences in Motion Study at Scotopic Levels of Illumination." Jour. Exp. Psychol., 35: 57-70 (1945).