Influence of Tinted Windshield Glass on Five Visual Functions

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Tinted windshields and side windows in automobiles have been introduced for two purposes: (a) to eliminate a major portion of radiant infra-red energy, and (b) to reduce excessive brightness and glare. The commonly used bluish-green tinted glass has a transmission of 65 to 70 percent, which is similar to that of sunglasses of light shade. At photopic (daylight) luminance levels the absorption of the glass is hardly noticeable. At mesopic (dusk) and scotopic (night) luminance levels a 30 percent reduction in transmission may interfere seriously with vision.

To study the effects of tinted windshield glass on vision at various luminances, tests were performed on (a) dark adaptation, (b) recovery from the shock of a blinding light flash, (c) visual acuity, (d) depth perception, and (e) the effects of glare.

Dark adaptation tests showed that when looking through a tinted windshield the thresholds for recognition of a test stimulus were higher than without an absorptive filter in the light path. The rise in threshold corresponded exactly to the brightness loss produced by the tinted glass.

When the eyes were adapted to low levels of luminance or to complete darkness and were suddenly exposed to a bright flash of light, recovery from the light shock and regaining of the previous sensitivity level was not enhanced by the presence of the tinted windshield glass. The reduction of luminance of a light flash by a tinted windshield was of no advantage, because the same absorption of the windshield also reduced the visibility of a test target.

Visual acuity was reduced slightly by tinted windshield glass. When acuity was measured with targets of small differences in size (Landolt rings) it was found that with the tinted windshield the intrinsic details could be seen only if they are 10 to 20 percent larger than when seen without an absorptive filter in the path of light.

Depth perception was also influenced by tinted windshield glass. A 25 to 35 percent loss in depth perception was observed when the test object was seen through tinted windshield glass.

When test targets were identified in the vicinity of a glare source and the ratios of glare luminance / target luminance were determined when the targets are viewed through tinted windshield glass and without the filter, it was found that the ratios remained the same whether tinted windshield glass was in the path of view, or vision was not obstructed by filters.

All tests uniformly showed that with tinted windshield glass in the line of sight the eyes appeared less sensitive by an amount that corresponded to the physical absorption of radiant flux by the filter in front of the eyes. No improvement of vision of any sort was found when tinted windshield glass was used.

● BETWEEN 1950 and 1959 millions of automobiles have been equipped with heat absorbing tinted windshield glass. By eliminating more than 50 percent of the radiant solar energy in the infrared range the comfort of occupants of automobiles is probably increased. At the same time the reduction of transmissiveness decreases visibility, thus, creating a potential safety hazard.

The tint of the windshield reduces transmission to approximately 70 percent which is the limit permitted by the American Standard Safety Code (1). While a 30 percent loss in transmittance does not affect visibility adversely at photopic (daylight) luminance levels, the reduction is more serious at mesopic (twilight) and scotopic (night) luminance levels.

The purpose of the present study was to investigate by laboratory tests effects of tinted windshield glass upon various visual functions.

In an attempt to clarify this problem the distance at which low contrast targets can be detected was determined in practical situations by Heath and Finch (2) who used targets such as road signs, posts, boxes, dirt piles, etc., of varying reflectance. Sixteen square-inch panels of low reflectance were exhibited against the glare of oncoming headlights by Roper (3). Targets used by Doane and Rassweiler (4) simulated pedestrians distributed along both sides of the road, having a reflectance of 7 percent on one side, and 3 to 3.5 percent on the other. Because a number of not easily controllable factors are involved in tests of this type, differences in results are to be expected. Six percent loss in visibility was found by Roper, 3 percent by Doane and Rassweiler, but Heath and Finch found as much as 22 percent loss in visibility distance. Despite these differences the net conclusion of the investigators was that the loss in night visibility is not serious and is compensated for by the beneficial effects of glare reduction and heat absorption during daytime driving.

Clinical tests conducted by Miles (5) have shown that all tinted filters (light yellow, pink, and greenish-blue windshield glass) reduce visual acuity at mesopic luminance levels. Also, tinted windshield glass combined with pink ophthalmic lenses is particularly disadvantageous since visual acuity was reduced to 20/60. At luminance levels involved in night driving, the resolving power of the eyes was greatly reduced. Thus, a pair of targets which appeared distinctly separate at 100 ft in unrestricted vision when seen through a clear windshield, had to be brought within 25 ft of the observer when they were viewed through a tinted windshield.

In laboratory tests Blackwell (6) found a 23 percent loss in detection distance when targets were viewed through tinted windshield glass. As distance for detection without tinted filters became smaller because of a reduction of target size or luminance level the percentage loss in detection distance increased rapidly with the tinted filter. From these findings Blackwell concluded that the loss in visual detection resulting from the use of filters at low luminance levels were so great that such filters cannot be recommended unless drivers reduce vehicular speed accordingly.

The theoretical effect of tinted windshield glass upon visibility has been calculated by Haber (7). According to his findings visibility distance is reduced 9 to 15 percent when targets are viewed through a tinted windshield at distances greater than 200 ft. If, however, the contrast between target and background is low, so that detection through a clear windshield is possible only at a short distance, the percentage loss in visibility may be as high as 35 to 45 percent with a tinted windshield.

METHODS AND PROCEDURES

Tinted windshields consist of a bluish-green plastic filter material laminated between two sheets of safety glass. The thickness of each glass pane is ⅛ in. The lower three-quarters of a windshield are uniform in density but the upper one-quarter represents a darker band increasing in density toward the top edge. Because only the homogeneous part is in the path of vision at eye level or below, studies have been made with filters taken from the midsection of the homogeneous part of the windshield.

The spectral transmission curves for two types of tinted windshield glass are shown in Figure 1. Both types transmit similar spectral ranges. The total transmission of A is greater than that of B. The transmission maximum for A is near 500 millimicrons, and for B near 480 millimicrons. Filter B has a lower transmission at both ends of the spectrum than filter A. By holding an A and a B filter side by side, the higher density and more bluish color of B can be noticed. Only filters of type A windshield glass were used in the experiments to be described. Measurements of various samples of A-glass with a Macbeth illuminometer yielded transmission values between 65 and 69 percent.

Inasmuch as tinted windshield glass cannot be regarded as a "neutral" filter it was necessary to use other filters having different spectral characteristics but having approximately the same percentage transmission. Such filters are Cruxite B which has a brownish tint and a transmission of 72 percent, and Noviol C which is deep yellow and has a percentage transmission comparable to that of the other filters, provided two sheets of filter glass are combined.

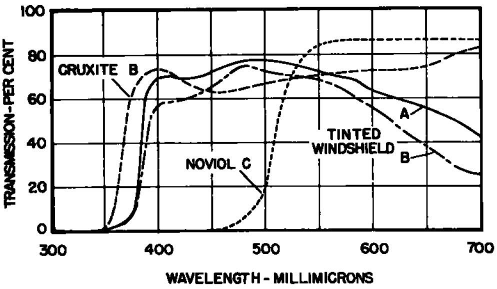

Figure 1. Spectral transmission curves for two types of tinted windshield glass, for a yellow filter (Noviol C, and for a tinted ophthalmic glass—Cruxite B).

The present investigation included studying the effects of tinted windshield glass on (a) dark adaptation, (b) recovery from light "shock," (c) visual acuity, (d) depth perception, and (e) glare.

The Effect of Tinted Windshield Glass on Dark Adaptation

In studies of dark adaptation it is customary to expose one or both eyes to a light of high luminance for a given length of time. Then on cessation of exposure to light, sensitivity thresholds are determined at intervals during the course of adaptation. The shape of the dark adaptation curve varies with pre-exposure luminance, pre-exposure time, and spectral character of pre-exposure light, as well as with the size and retinal location of the testfield, duration of the testflash, and the spectral characteristics of the testlight (8, 9, 10, 11).

Any specific changes in the pre-exposure or testing conditions will affect the course of dark adaptation. If, for instance, a dark adaptation function has been reliably established for a given testfield, retinal location, and testflash duration, the interposition of an absorptive filter such as tinted windshield glass should alter the shape of the dark adaptation curve relative to the absorptive properties of the filter, and thereby provide a direct measure of the effect of the filter on visual sensitivity.

In this study dark adaptation tests were made with the aid of a visual discriminometer (12). The testfields were squares subtending 1.3 deg on a side in the fovea and 2 deg in the parafovea. In foveal tests a red fixation point was placed at the center of the testfield. In parafoveal tests the distance between fixation point and the proximal edge of the testfield was 10 deg. The presentation time was 0.04 sec. When it was desirable to present the testfield against a surround luminance, the entire visual field of approximately 40-deg angular subtense (as limited by the dimensions of the apertures of the eyepieces) was evenly illuminated.

The observer was exposed to a luminance of 1,510 footlamberts for 10 min before the tests. The pre-exposure light was a tungsten filament lamp in front of which was mounted a lens system providing a collimated beam wide enough to illuminate evenly both eyes. The observer viewed the light source through two +20D crown lenses. These were mounted in adjustable frames which permitted correcting for interpupillary distance.

When the pre-exposure period was completed the observer shifted to the discriminometer and looked steadily at the fixation point. By means of a shutter in the path of the testlight the testfield was then presented, and the observer indicated whether he could

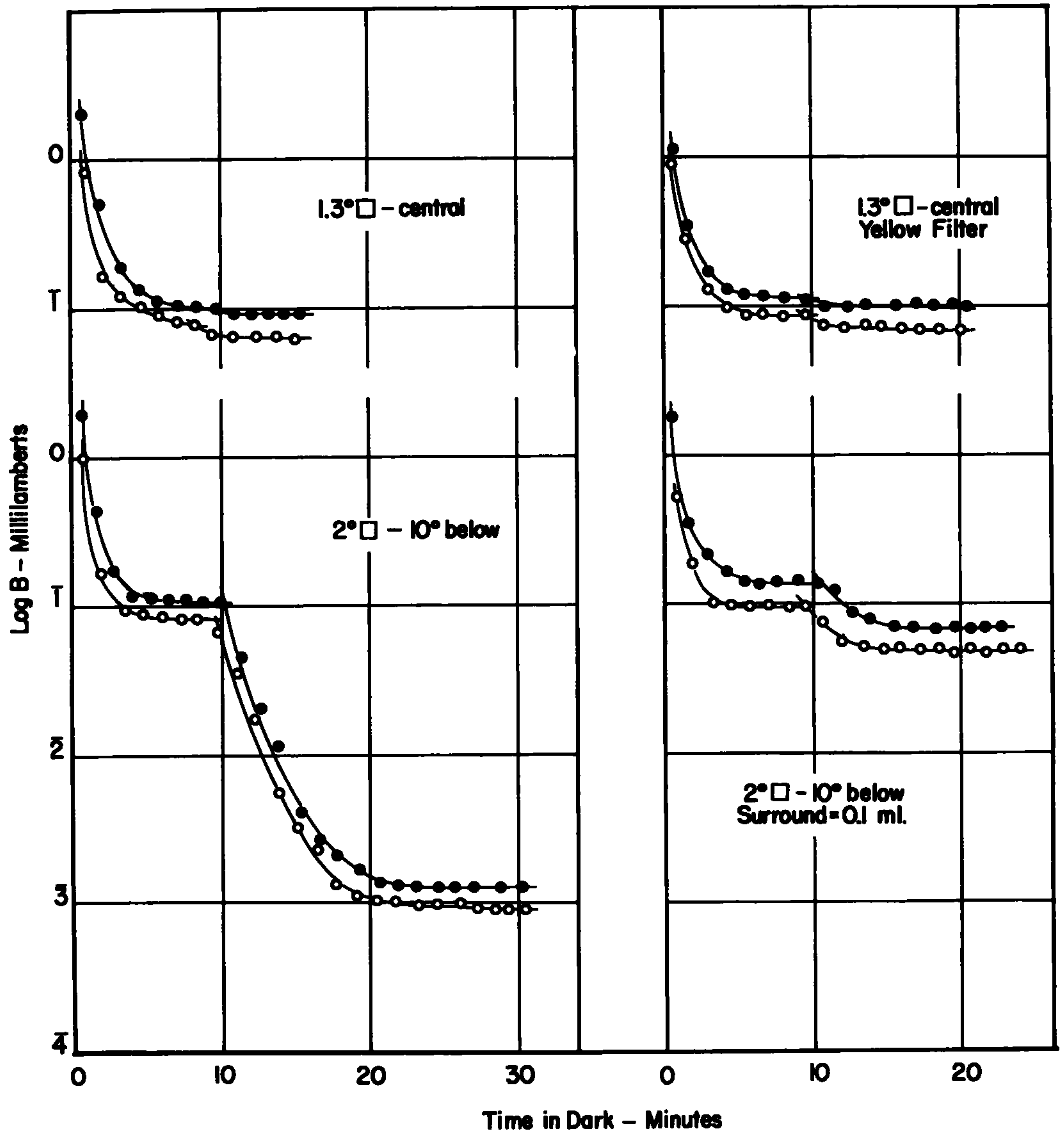

Figure 2. Dark adaptation functions obtained after 10-min pre-exposure to a luminance of 1,510 millilamberts when the testlight is not screened (open circles), and when the testlight is screened by tinted windshield glass (black circles).

see it. When just perceptible, namely, when threshold level was reached, elapsed time and threshold luminance were recorded. The tests were repeated at intervals of 1 to 1.5 min and continued until adaptation had reached a steady level.

After the dark adaptation function was established for a given retinal area, tests were repeated with a piece of windshield glass placed between the eyes of the observer and the testfield. All other conditions were kept constant. All observations were made binocularly since binocular vision is more likely to be involved than monocular observation in everyday life. The experimental results are shown in Figure 2.

Central Stimulation Without Surround Lighting.—When 1.3-deg-square testfield was shown centrally the stimulating light fell within the fovea. The resulting dark adaptation curve should have been simplex having only a cone segment. For the 1.3-deg field, however, a slight break was indicated after about 8.5 min which suggested that a small extrafoveal rod population was involved in threshold response. According to measurements on sections through the retina the rod-free fovea subtended a visual angle of 1.5 to 2 deg. It was assumed that any rod vision was due to involuntary eye tremor (13). Similar indications of rod vision with testfields of 1-deg angular subtense in the fovea have been found in studies on critical flicker frequencies in relation to luminance (14).

The final dark adapted level found with the central testfield was $\log B = \bar{2}.80$. When windshield glass was inserted in the path of the testlight, the curve obtained was shifted upward on the log luminance scale. The final level of the curve was 0.16 log units higher than when no filter was in the light path. This would indicate that 1.45 times more light was required for threshold recognition when the testfield was seen through the tinted windshield glass (Fig. 1, upper left).

Parafoveal Stimulation Without Surround Lighting.—When a 2-deg-square testfield was presented parafoveally 10 deg below center, the resulting dark adaptation curve showed the typical duplex character (Fig. 1, lower left). Initially the thresholds dropped to the cone plateau at $\log B = \bar{2}.90$. The break occurred after 9.5 min. The rod thresholds dropped rapidly over a total range of nearly 2 log units. Only a slight decline in threshold level occurred beyond 20 min. At 30 min a final threshold level of $\log B = \bar{4}.95$ was reached. When the tinted windshield glass was used the resulting dark adaptation curve again was shifted to higher luminance levels. At the cone plateau the difference between the two curves was 0.14 log unit, and at the final rod level the difference was 0.16 log unit.

Dark Adaptation with Surround Lighting.—Because the human eye is practically never required to attain its maximal sensitivity in the performance of ordinary visual tasks it was necessary to investigate the course of dark adaptation under conditions in which the testfield was presented against a surround luminance of 0.1 millilambert instead of against total darkness. The surround level was similar to that usually found during night driving. In this case dark adaptation will proceed only to the level of the surround luminance, and the perception of a testfield represents a ΔI (differential threshold) value in relation to the background luminance (15).

Results of such tests are shown at the lower right of Figure 2. The curve taken without a filter had a cone plateau at $\log B = \bar{2}.98$ which is slightly higher than without surround illumination. The break occurred at 9.5 min, and the drop of the rod thresholds was only slight, reaching a steady level at $\log B = \bar{2}.69$ after about 18 min of adaptation. When the windshield glass was in the light path, the dark adaptation curve was again shifted to higher threshold levels. At the cone plateau the difference was 0.14 log unit and 0.16 log units at the final rod level. The break was delayed about 1 min when the tinted windshield was used.

The windshield reduced the radiant energy reaching the eyes by surface reflection, the transmission characteristics of the glass, and the tinted laminated material. Therefore changes in visual thresholds, namely, increases in luminance necessary to obtain a threshold response may be due to (a) light loss as such, and/or (b) the specific spectral characteristics of the absorptive filter. To investigate these possibilities, it was necessary to perform tests in which a filter with approximately the same over-all luminance reduction but with decreased transmisssion in the blue-green, and increased transmission in the yellow and red was used in the test beam. Such a filter was found by combining a Noviol C filter 3.38 mm thick with a Noviol D filter 3.05 mm thick. The reduction in luminance produced by the tinted windshield glass and the yellow filter combination did not vary by more than 4 percent. When dark adaptation was tested at the retinal center with a 1.3-deg testfield, the curve obtained with the unobstructed testfield was almost identical to the curve shown at the upper left in Figure 2. The curve taken with the yellow filter combination in the light path was very similar to the corresponding curve taken with the tinted windshield glass in the light path. The final threshold difference was 0.16 log units shown at the upper right in Figure 2.

In all tests the threshold level was from 0.14 to 0.16 log unit higher when tinted windshield glass was used. According to transmission measurements made on the windshield glass an increase in threshold luminance of 0.15 to 0.18 log unit would have been expected. The experimental findings with tinted glass therefore agree closely with those expected to occur because of mere physical loss in luminance. A shift of the same magnitude was obtained with filters of different absorption characteristics but with approximately equal percentage of transmission. This would indicate that the luminance loss produced by the filter rather than the color is responsible for the reduction in threshold sensitivity.

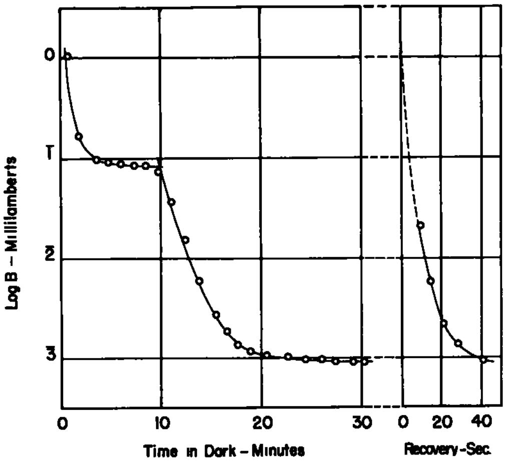

Figure 3. Dark adaptation curve obtained with a 2-deg square testfield presented 10 deg below center, after pre-exposure for 10 min to 1,510 millilamberts at 30 min a bright flash of 0.04 sec duration is presented, and the return to the previous sensitivity level followed. The time from the flash to the attainment of the final threshold level represents the recovery time from the light shock.

The Effect of Tinted Windshield Glass on Recovery from Light "Shock"

One of the reasons for using an absorptive filter as windshield glass was to reduce the effect of headlight glare during night driving. It is obvious that a filter with a transmission of only 70 percent must reduce the glare effect of oncoming headlights. However, the same absorption which decreases glare also decreases the visibility of objects on the road. It is therefore of importance to determine whether any advantage is gained by using tinted windshields.

To ascertain whether tinted windshield glass influenced recovery from light shock several laboratory tests were conducted. The time required to perceive a target in the visual field following light shock was measured when (a) the target was seen without a filter in the path of vision, and when (b) tinted windshield glass was interposed between the observer and the target.

The visual discriminometer served as the test instrument. A square testfield subtending a visual angle of 2 deg on a side was presented in the center or 10 deg below center. Observations were made binocularly. The exposure time was 0.04 sec. After 30 min of dark adaptation the threshold level for perception of the light stimulus was determined and was found to be similar to the final levels shown in Figures 2 and 3. The observer then was exposed to a luminance of 370 millilamberts for 0.04 sec reflected into his eyes from a white screen embracing a large visual field. Immediately after light shock the fixation point was located in the discriminometer. At intervals of 2 sec the operator exhibited the testfield until the observer indicated that he was able to see the testlight. The time from cessation of exposure to the light shock to first recognition of the stimulus was the measure of recovery time.

Figure 2 shows the course of dark adaptation for a 2-deg square testfield presented 10 deg below center. After 30 min in the dark a steady final level of adaptation had been reached. Then the intense light flash was presented. The initial thresholds following shock were about 2 log units higher than the final level. The recovery curve descended rapidly, and after about 40 sec the final threshold level was regained (16).

In the case illustrated, the testfield luminance was set at five predetermined levels in rapid succession, and for each predetermined level perception time was determined. Such tests were strenuous and required long rest periods between trials since cumulative effects of light exposure contributed to a higher final threshold level. The experimental procedure was therefore modified. A value was chosen for the threshold luminance which was 0.3 log unit above the level recorded at 30 min. This luminance level corresponded to twice the final level, or one-half the completion of recovery. This may be compared in meaning to the chronaxie of Lapicque (17, 18).

The shock source consisted of a projector mounted in a light tight housing about 4 ft behind the observer. In front of the objective was a compur shutter which could be released by the experimenter by means of a cable. The projector illuminated a white surface of high reflectance located above the discriminometer head. The white area subtended a visual angle about 50 deg in width and 30 deg in height at the position of the observer's eyes. About 6 deg to the right of the center of the bright field was the fixation point at which the observer looked during exposure to the shocklight.

With headlight glare no large retinal area is suddenly flooded by light. Instead, two distinct sources of high luminance are seen by the motorist. To simulate this condition a second arrangement for reflecting the shocklight into the eyes was used. Thus, the light from the projector was reflected by two small concave mirrors placed side by side. They were separated by a distance corresponding to the distance between headlights seen at 100 ft. In this experimental situation the observer again fixated a point on the same level but 6 deg to the right of the right mirror. The luminance reflected by one mirror was 28,400 footlamberts. Because of extremely bright and vivid after images which go through a rapid series of color changes there was great difficulty in finding the fixation point in the discriminometer; both types of shock exposure were extremely annoying.

To reduce the luminance of the light shock instead of exposing the observer to the full shock luminance, a tinted windshield filter could be placed in fromt of the projector. Although the manipulation of the filter at the projector occurred behind the observer, he was not ignorant of the change. The absence or presence of a filter was known to him also in terms of a change in color of the shocklight. However, subjects did not know that velocity of recovery from light shock was being measured.

Tests were performed with a 2-deg-square testfield presented centrally and 10 deg below center (a) when the testfield was exhibited against a black background, and (b) when the testfield appeared against a surround luminance of 0.1 and 0.01 millilamberts.

For each testfield location and surround luminance there were 4 experimental conditions where, (1) both the shocklight and the testlight were unfiltered, (2) the shocklight was unfiltered while tinted windshield glass was in the path of the testlight, (3) the shocklight passed through tinted windshield glass while the testlight was not filtered, and (4) both shocklight and testlight passed through tinted windshield glass.

Condition (1) in a practical situation corresponded to shock by headlight glare and recovery when no tinted windshield was present. Condition (4) corresponded to a situation in which a tinted windshield was used. Conditions (2) and (3) are not found in a practical situation. Condition (2) required that headlight glare influenced vision without passing through a tinted windshield while targets must be recognized through the tinted windshield glass, and condition (3) required that the headlights of oncoming cars be dimmed by the tinted windshield while the vision of the driver was not impeded by the tinted glass.

The mean recovery times were calculated for the various filter conditions, retinal location of testfield, and surround luminances. Usually 40 exposures were made during an experimental session, 10 exposures for each filter condition. A typical example for measurements of recovery time is given in Table 1.

It may be seen that the recovery times in the four groups overlapped to a certain extent. When the shock source was not shielded the recovery time of 26.7 sec found without a filter in the path of the testlight increased to 31.1 sec when tinted windshield glass was placed in front of the testfield. The presence of the tinted glass increased the recovery time by 4.4 sec, or by a factor of 1.2. When the testfield was shown against an illuminated surround this value rose to 1.4. When the luminance of the shock light was reduced 30 percent by interposition of tinted windshield glass recovery time was shortened from 26.7 sec to 23.8 sec. Recovery was accelerated by a factor of 1.2.

The Effect of Tinted Windshield Glass on Visual Acuity

Acuity may be influenced (a) by loss in luminance occasioned by the absorption of a filter, (b) by its spectral transmission, and (c) by prismatic effects introduced by the curvature of a filter and other differences in refraction of the two laminated sheets of glass. For an evaluation of tinted windshield glass it was necessary to study visual acuity at various luminance levels with and without tinted windshield glass in the path of vision.

TABLE 1

No Filter in Front of Shock Source.				Tinted Windshield in Front of Shock Source.			
No Filter in Testbeam		Tinted Glass in Testbeam		No Filter in Testbeam		Tinted Glass in Testbeam	
28	+1.3	29	-2.1	25	+1.2	27	-0.3
27	+0.3	30	-1.1	23	-0.8	24	-3.3
29	+2.3	32	+0.9	22	-1.8	28	+0.7
27	+0.3	31	-0.1	23	-0.8	24	-3.3
24	-2.7	34	+2.9	22	-1.8	31	+3.7
25	-1.7	31	-0.1	26	+2.2	25	-2.3
24	-2.7	34	+2.9	23	-0.8	28	+0.7
30	+3.3	33	+1.9	23	-0.8	30	+2.7
29	+2.3	30	-1.1	24	+0.2	28	+0.7
24	-2.7	27	-4.1	27	+3.2	28	+0.7
26.7		31.1		23.8		27.3	
	19.6		17.4		13.6		18.0

Visual acuity is usually tested by Snellen charts composed of letters of various sizes and types. In the conventional Snellen chart the changes from one size letter to the next are coarse and therefore are inadequate for measuring of visual acuity limited by a filter such as tinted windshield glass.

Reading charts were therefore prepared of Landolt rings of 10 different sizes varying from 4.0 mm to 1.2 mm in diameter. The gaps were ⅕ of the diameter of each ring. The rings were arranged in blocks of 25 symbols, the gaps appearing in random positions (Fig. 4). The blocks of rings were mounted on a strip of white cardboard. This moved in a frame behind a white screen 4 ft wide and 3 ft high in the center of which only the 25 rings of a particular block were visible through a square opening. The screen was mounted vertically on the wall of a darkroom and could be evenly illuminated over a wide range of luminances. In the present tests only a luminance level of 55.25 footlamberts in the photopic range, and a luminance level of 0.089 footlamberts in the mesopic range were employed. The task was to identify the random position of the

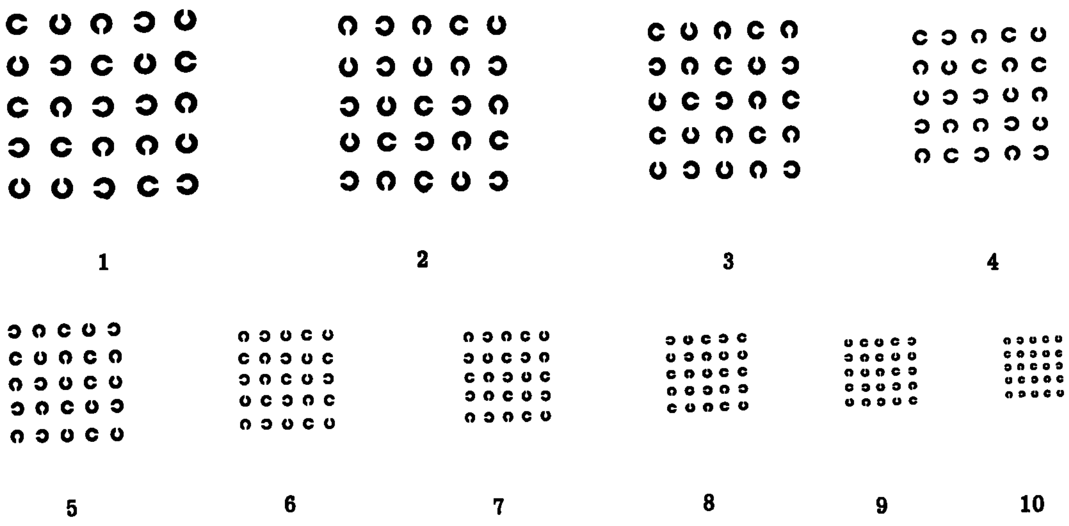

Figure 4. Sample blocks of 25-Landolt rings used for visual acuity tests.

gaps. The observer was seated 187 cm (6 ft) from the screen with his chin on a rest so that his eyes are at the same level as the test targets. At this distance the gaps in the largest ring size were easily recognizable. The visual acuity ratings of the intrinsic criterion, namely, the size of the gaps in the Landolt rings are given in Table 2.

The visual acuity values for the 10 rings indicate that only one-half of maximal acuity were needed for seeing the gaps in the smallest rings under optimal luminance conditions. At a luminance of 55 footlamberts size 7 and 8 should be identified accurately, provided visual acuity were normal. When illumination would be reduced to 0.089 footlamberts the critical ring size should be larger. The experimental results indicate a close correspondence to the findings of earlier investigators (19, 20, 21).

TABLE 2

Ring Size	Visual Acuity Value
1	0.068
2	0.076
3	0.085
4	0.096
5	0.114
6	0.230
7	0.303
8	0.342
9	0.390
10	0.455

In the tests an observer had to identify the position of the gaps in the rings of each block reading the lines in conventional manner as long as he was able to recognize the gaps. The time for completing the reading of each block and any errors were recorded. In order to study the effect of tinted windshield glass on visual acuity, a windshield was placed at a distance of 18 in. from the observer's eyes, and the results obtained were compared with those obtained when no windshield or other filters were in the path of vision.

Twenty-one observers participated in the tests, each serving 3 to 5 times as subject. If corrective lenses were customarily worn, they were used during the tests. Most observers were able to identify the gap positions correctly up to ring size 7 or 8; sizes 9 and 10 were clearly seen only by a few. The numbers of correct identifications in each block of 25 symbols obtained (a) without the windshield, and (b) with the windshield in a typical test series are given in Table 3.

TABLE 3

Ring size	1	2	3	4	5	6	7	8	9	10
No filter	25	25	25	25	25	25	25	12	0	0
Tinted windshield	25	25	25	25	25	25	16	4	0	0

These results clearly indicated that visual acuity was reduced by tinted windshield glass.

In these tests comparisons were made between visual acuity determinations obtained under unequal luminance conditions. Because the tinted windshield glass has an absorption of about 30 percent, the better visual acuity recorded without a filter could be attributed to the loss of light when the tinted glass was in the path of vision. For this reason it was necessary to study visual acuity with the tinted windshield and to compare the results with those obtained when the screen brightness was reduced by 30 percent. This reduction could have been achieved in either of two ways: (1) by placing absorptive filters of the proper density in front of the light source illuminating the screen, or (2) by placing filters of proper density in front of the eyes of the observer. For such purposes neutral filters were used. However, they have the disadvantage of not being large enough to be used as a shield at 18 or more inches from the eyes. They are also flat and therefore are not suitable for use as eyeglasses. To overcome these difficulties plano ophthalmic lenses with a 6-base curvature of AO Cruxite B type glass were used (Fig. 1).

Twenty observers were tested with Cruxite B and with tinted windshield glass. With both types of filters the tests were continued until the subjects were unable to specify the position of the gaps in the rings. The results of the best and the worst observer are given in Table 4.

TABLE 4

Best Observer										
Ring size	1	2	3	4	5	6	7	8	9	10
Cruxite B	25	25	25	25	25	25	25	25	22	0
Tinted windshield	25	25	25	25	25	25	25	24	6	0
Worst Observer										
Cruxite B	25	25	25	25	25	25	14	0	0	0
Tinted windshield	25	25	25	25	25	12	2	0	0	0

These two cases typify the general outcome of the tests. In approaching the limit of acuity, each observer was capable of indicating the positions of the gaps in the rings easier without a filter, or with Cruxite B, than when the tinted windshield glass is in the path of vision. In comparing the tests without a filter with those obtained with the tinted windshield the difference in visual acuity could be regarded as the result of difference in luminance. But the comparative results obtained with the tinted windshield glass and Cruxite B (two filters of approximately the same density), showed that the difference in acuity was due either to the bluish-green color of the glass or to prismatic effects produced by the heavy laminated shield. Comparisons of results obtained with a clear windshield and with a tinted windshield showed that visual acuity was better with a clear windshield.

When the tests are performed at a luminance level of 0.089 footlamberts, the limiting ring size at which the gaps could just be recognized was 3 to 4 sizes larger than when the luminance was 55.25 footlamberts. The scores of two observers are presented in Table 5.

TABLE 5

Best Observer										
Ring size	1	2	3	4	5	6	7	8	9	10
Cruxite B	25	25	25	25	25	0	0	0	0	0
Tinted windshield	25	25	25	25	8	0	0	0	0	0
Worst Observer										
Cruxite B	25	25	25	24	20	0	0	0	0	0
Tinted windshield	25	25	25	20	13	0	0	0	0	0

At photopic and mesopic luminance levels tinted windshield glass reduced visual acuity more than a neutral filter of equal percentage transmission of better optical quality.

The Effect of Tinted Windshield Glass on Depth Perception

Depth perception was studied with the aid of a Verhoeff stereoptor (22, 23). The experimental arrangement is shown in Figure 5. The ½- by 2-in. opening of the stereoptor containing the three vertical bars of different width and at different depth was illuminated by a 50-watt tungsten filament lamp L_1 concealed in a housing. The luminance of L_1 was varied by means of filters and a diaphragm. The stereoptor was attached to a disc which could be turned 180 deg so as to provide the eight-bar positions incorporated in the test. The disc was behind a white screen 20 in. high and 18 in. wide, in the center of which the stereoptor was seen through an opening. In front of the screen and on each side were 2 lamps enclosed in cylindrical housings which provide a uniform illumination of the screen. The luminance was varied by placing matched neutral filters in front of L_2 and L_3. In order that the stereoptor could be placed at various distances from the observer the components of the depth gauge were assembled on a carriage which ran on metal tracks on a heavy wooden plank. Mounted behind the white screen the black front surface of the Verhoeff stereoptor was completely covered so that the three bars were seen against a homogeneous white surround. By these means the transilluminating light from L_1 and the frontal illumination from L_2 and L_3 could be made equal in luminance and color.

To study the effect of tinted windshield glass on depth perception an observer was seated at the end of the optical track on which the stereoptor was mounted, his head being stabilized on a chin rest. The stereoptor was placed at 100 cm and the eight positions shown. If correctly identified, the distance was increased until the spatial relationships of the three bars was just perceptible. If stereopsis was poor and the distance of 100 cm too great for correct identification of bar positions the stereoptor was brought nearer until the distance was found at which depth could be perceived correctly.

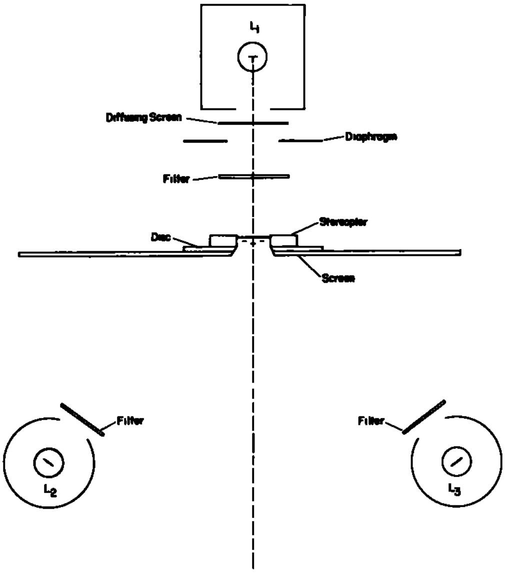

Figure 5. Diagram of arrangement of Verhoeff Stereoptor for depth perception tests.

Twenty observers were tested. The majority had no difficulties in perceiving depth at 100 cm, some recognized depth at 150 cm, and one giving a correct score at 200 cm. For observers for whom the distance of 100 cm was too great, the distance was decreased to 75 or to 50 cm. After the critical distance had been found for each individual without a filter, the determinations were repeated with the tinted windshield glass in the path of vision.

The results of these tests showed consistently that stereopsis was reduced from 12.5 to 37.5 percent when the depth target was viewed through the tinted glass. To specify the relative positions of the bars in all eight presentations correctly the stereoptor had to be moved closer.

Inasmuch as the tinted windshield absorbs 30 percent of light while the luminance of transillumination of the stereoptor and of the surrounding screen were equally reduced and rendered bluish-green, it was necessary to test stereopsis when the luminance was reduced by filters placed in front of the light source. Reduction of luminance with tinted windshield glass, neutral filters, or Cruxite B had the same effect as when tinted windshield glass was placed into the path of view. Subjective observations do not indicate a preference for one or the other type of filter. Some observers stated that the bars appeared sharper with the neutral filters, others preferred the bluish-green tint of the windshield glass.

When the over-all luminance of the depth target and the screen was reduced from 50 to 5 and 0.5 footlamberts, depth acuity for some observers decreased. In others the change in luminance had no effect. For some subjects the stereoptor needed to be brought 10 to 15 cm closer before the bar positions were identified correctly. When the stereoptor was viewed under reduced illumination through clear windshield glass, tinted windshield glass, or neutral filters placed in front of the light sources, depth acuity was reduced by amounts corresponding to those found at the high luminance level.

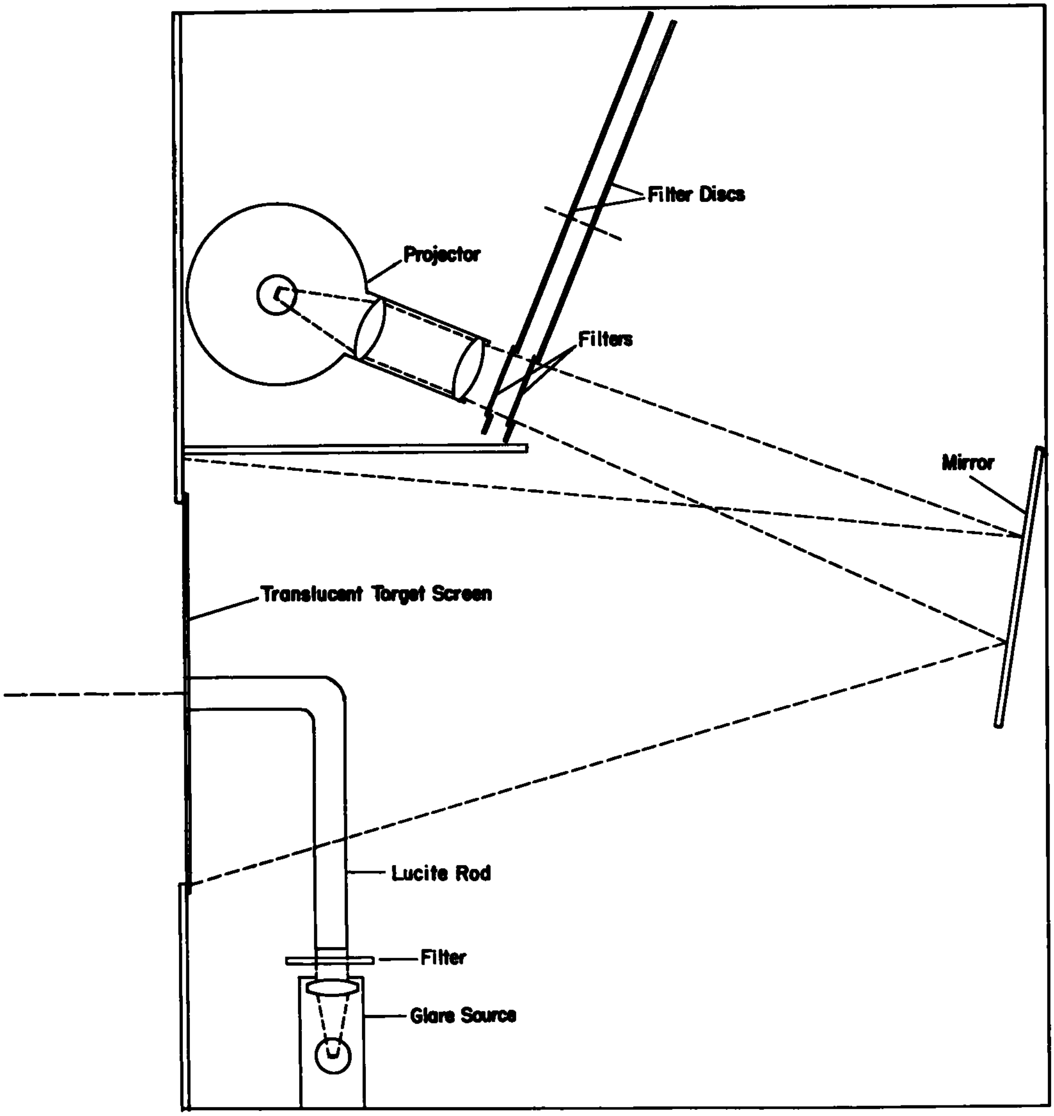

Figure 6. Diagram of instrument for measuring the effect of glare on visibility in the vicinity of a glare source.

In some observers depth perception was tested also with yellow filters of the Noviol C type. This filter reduced luminance about 12 percent. The results obtained with Noviol were compared with those obtained when no filter, when tinted windshield glass were used, and when luminance was reduced by neutral or tinted windshield glass filters placed in front of the light sources. Yellow filters worn in the form of aviation-type goggles had no noticeable influence on depth perception.

The Effects of Tinted Windshield Glass on Perception as a Function of Glare

Claims have been made that colored filters provide relief from glare. Because tinted windshields are one variety of color, filter tests were made to determine their effect on perception as a function of glare. To conduct this study a glare meter was constructed and is shown in Figure 6. This instrument provided a glare source of high luminance, and presented targets in the form of Landolt rings at various distances and directions from the source.

The glare source consisted of a Spencer microscope lamp, the light was collimated and passed through a clear plastic rod of 1-in. diameter. The plastic rod was bent 90 deg so that its front end appeared in the 1-in. center hole of a translucent screen on which the Landolt rings were displayed. The full luminance of the glare source as measured from the eye position of the observer was 3240 millilamberts. To control glare, absorptive filters could be interposed between the glare source and the plastic rod. The plastic rod was encased in cardboard tubing to prevent stray light from falling on the target screen.

The target screen was illuminated by a small, well-shielded projector located behind the front wall of the instrument. The light from the projector passed through openings cut near the edge of two discs in front of which were mounted neutral density filters. One series of filters provided transmissions of 10,20, 30, 40, 50, 60, 70, 80, and 90 percent. The other series provided transmissions of $^1/_{10}$, $^1/_{100}$, $^1/_{1,000}$, and $^1/_{10,000}$. By combining 2 filters the luminance of the target screen could be varied in 10 percent steps over a wide range.

The light passing through the filter discs was reflected by a mirror in order to illuminate the target screen evenly. Because the encased plastic rod was in the light path, a shadow was cast on the screen downward from the center. Hence, no Landolt rings were visible on the vertical radius below the glare source. However, targets were visible along the radii at 0, 45, 90, 135, 180, 225, and 315 deg. On each radius were 3 Landolt rings at different distances from the center, forming 3 circles of symbols around the glare source.

The screen was viewed from a fixed distance of 230 cm, while the head of the observer was so adjusted on a chin rest that the eyes were at the same level as the glare source. As seen from this position the angular separation was 1.25 deg between glare source and the inner circle of rings, between glare source and the middle circle of rings it was 2.25 deg, and between glare source and the outer circle of rings it was 3.25 deg.

The tests were performed in a darkroom. When the glare source was turned on and the target screen only barely illuminated, the targets were invisible. By changing the filters in front of the projector to lesser densities, a luminance level was found at which the Landolt rings of the outer circle and the gaps became just perceptible. As the screen luminance was further increased the threshold for seeing the gaps in the rings of the middle circle was found; finally, a further increase in luminance revealed the thresholds for seeing the gaps in the Landolt rings of the inner circle. By these means luminance values for seeing targets of fixed size at fixed angular distances from a glare source were determined. The values obtained for the differentials in luminance were indicative of an observer's perceptual capability in the presence of glare. For instance, if the luminance of the glare source, or that of the target screen was altered by placing absorptive filters in front of the glare source, or in front of the eyes, it was possible to determine whether such a change reduced the differential between glare and target screen luminance, and thus, reduce the disturbing effect of glare.

Thirty-one observers, all college students, participated in the glare tests. The threshold luminance of the target screen at which the gaps in the Landolt rings of the outer, the middle and the inner circle were visible was determined successively (a) when there was no filter in front of the glare source nor in front of the observer's eye, (b) when the eyes of the observer were not shielded and the luminance of the glare source was reduced by tinted windshield glass, (c) when a tinted windshield was in front of the observer and no filter was in front of the glare source, and (d) when the tinted windshield was in front of the observer and the glare source was shielded by tinted windshield glass.

Condition (a) corresponded to a night driving situation in which no tinted windshield was used, and condition (c) to the situation in which a tinted windshield was used. Under condition (b) the driver's vision would not be handicapped by a tinted filter, but the glare from headlights would be reduced by a filter in front of the source. Under condition (d) a tinted windshield would be in front of the driver's eyes while glare would not be reduced. Results of these tests are given in Table 6.

When the luminance values of the target screen for detection of the gaps in the Lan-

TABLE 6

	No Filter in Front of Eyes		Tinted Windshield in Front of Eyes	
Test Condition	Threshold Luminances (millilamberts)			
	(a) No Filter in Front of Glare	(b) Filter in Front of Glare	(c) No Filter in Front of Glare	(d) Filter in Front of Glare
Outer circle	0.082	0.050	0.082	0.050
Middle circle	0.094	0.082	0.094	0.082
Inner circle	0.181	0.095	0.162	0.121

dolt rings of the three circles under condition (a) was the standard, it was seen that when the luminance of the glare source was reduced by a tinted windshield glass that the critical thresholds were lower in accordance with the luminance reduction of the glare, (b). When a tinted windshield was in front of the observer the luminance of the glare source and of the target screen were both reduced, (c). Except in close proximity to the glare source the over-all reduction of luminance did not change the threshold values found under condition, (a). Finally, when the target screen was viewed through a tinted windshield when a filter of the same type was in front of the glare source, (d), the threshold luminances were smaller than in (a), but not essentially different from those found under condition (b).

There is little variation in the results among the 31 observers tested so that the example presented in Table 6 may be regarded as typical for the group. Only in subjects of advanced age (70 years and over) an increase in target screen luminance in excess of 1 log unit is needed for recognition of the targets under the various conditions (Table 7).

TABLE 7

Test Condition	Threshold Luminances (millilamberts)			
	(a)	(b)	(c)	(d)
Outer circle	0.586	0.181	0.586	0.586
Middle circle	1.011	0.311	0.011	1.011
Inner circle	1.116	1.011	1.481	1.481

If the reduction of glare by a tinted windshield was helpful in rendering targets more visible in the vicinity of a glare source, then a significant difference in threshold luminance should be obtained between conditions (a) and (c), and in no case was a significant change indicated. The effect of a tinted windshield in front of the glare source alone was always easily recognized. Smaller target screen luminances were required when a tinted windshield was in the path of vision and the glare source itself was dimmed by means of a tinted filter. This suggests that the glare-reducing effect of a tinted windshield was lost by the absorption of light from the targets. An advantage was gained only when the glare luminance was reduced in the absence of a tinted windshield.

The recognition of targets in the vicinity of a glare source required the same ratio of glare luminance/target luminance, both when the eyes were not shielded by an absorptive filter and when they were shielded by tinted windshield glass. The beneficial effects claimed for tinted windshields in coping with headlight glare were not substantiated by tests under controlled conditions.

When the tinted windshield glass was replaced by ophthalmic Cruxite B in the glare tests, the results were essentially identical with those obtained with the tinted windshield. The observer's subjective impression is that the Lamdolt rings and gaps appear sharper at threshold with Cruxite B filter than with the tinted windshield glass, but in no case is there a reduction in threshold luminance.

DISCUSSION

In studies on the effect of tinted windshield glass on dark adaptation, recovery from light shock, visual acuity, depth perception, and visibility in the presence of glare, it was shown that a reduction of visual efficiency occurred with a tinted windshield in proportion to the absorption of radiant energy.

When filters of approximately the same density but with different transmission characteristics were used, the reduction in visual function was the same as with tinted windshield glass. This indicated that it was the loss of luminance rather than spectral selectivity which was responsible for reduction in visual function.

Glare must be regarded as an entoptic phenomenon into which enter such factors as diffuse transmission of light through the iris and sclera; flares, produced by multiple reflections at the different refracting surfaces; specular reflection from the front surface of the retina; halation produced by reflection at the pigment epithelium, choroid, and sclera; light reflection through the vitreous from one part of the retina to another; fluorescence of the lens; and scatter by the ocular media (24, 25, 26). Effects of glare may be somewhat mitigated by the exclusion of short-wave radiation from the glare source. This suggests a reason for claims that yellow or amber filters are advantageous in coping with glare.

When a glare source is viewed while the ambient illumination is sufficiently high, the ill effects of glare are not experienced in their full extent. The glare effect increases as the contrast between glare source and surround becomes greater. Also the glare effect is lessened with large glare sources since glare is inversely proportional to the area of the source. For this reason it has been suggested that the size of headlights ought to be increased (5).

Another factor contributing to the annoyance of glare in automobile driving consists in the dispersion of light within the windshield. With an absolutely clear and homogeneous medium between the eyes and a glare source, the image of the glare source is sharp, and flares and halations are reduced. The surface film of small particles on the windshield undoubtedly adds to the unpleasant effects of glare. It would therefore be desirable to develop and apply adequate techniques for the elimination of surface film and fogging of windshields.

Because the purpose of tinted windshields is twofold, namely (1) the screening of radiant heat, and (2) glare reduction, the essential question is whether a tinted windshield is the proper and only possible solution of this complex problem. Whether heat absorption by tinted glass is of any real value is questionable since the dark colors of automobile bodies will absorb far more heat than that which is excluded by the heat-absorbing glass. It also should be realized that the heat absorbing characteristic of glass does not depend on dark tints.

The reduction of daytime glare by 30 percent through the windshield does not necessarily eliminate the need for sunglasses. To be effective sunglasses should have at least 80 percent absorption as well as a spectral transmission which will allow good color rendition (27). The percentage absorption of tinted windshield glass is far too small to remove the need of sunglasses under daylight conditions. The combination of sunglasses of various colors and densities with tinted windshields may yield very undesirable filter combinations for visual comfort (5). Not to be overlooked is the fact that high density sunglasses can easily be removed at dusk, and a clear windshield would interfere considerably less with visual perception in mesopic and scotopic vision at dusk and at night.

SUMMARY

Dark adaptation, recovery from light shock, visual acuity, depth perception and visibility under glare conditions were studied when the targets were seen through tinted

windshield glass. The results were compared with those obtained when no filters or filters of different absorptive properties were used.

The tinted windshield glass used in these tests was an absorptive filter of light bluish-green tint with a maximum transmission near 500 millimicrons. The transmission of this type of glass is approximately 70 percent.

Thresholds were about 0.15 log units higher in dark adaptation tests when tinted windshield glass was used in front of the testlight compared with the data obtained when no filter was used. The higher threshold corresponded to the reduction in test-field luminance caused by the filter.

Recovery time after light shock was 1.2 to 1.4 times longer when the test target was obscured by tinted windshield glass than when no filter was placed in front of the test target. The increase in recovery time was proportional to the loss in luminance.

When Landolt rings of small size differences were used as targets, visual acuity was less when a tinted windshield was interposed between the observer and the target than when no filter was used. Besides, the lower luminance prismatic effects produced by two curved heavy laminated sheets of glass were responsible for reduced visual acuity.

Tests with a Verhoeff stereoptor showed a 25 percent reduction in depth perception when a tinted windshield was placed in the path of vision than when no filter was involved.

When thresholds are determined at which targets at fixed angular distances from a glare source become visible, it was found that the ratios of glare-luminance/target-luminance were the same whether or not the glare source and target screen were shielded by tinted windshield glass or by an absorptive filter.

The results of these tests in no way indicated any advantage in the use of tinted windshields.

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