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Bulletin 127

Night Visibility 1955

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2101 Constitution Avenue   Washington 25, D. C.

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Night Visibility 1955

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Sign Brightness and Legibility

TERRENCE M. ALLEN, Highway Research Psychologist, and
ARTHUR L. STRAUB, Highway Research Engineer
Virginia Council of Highway Investigation and Research

There is need for basic information on relationships between legibility of signs and the brightness of reflectorized materials. Four factors of primary importance to the night legibility of signs are sign brightness, the level of illumination to which the eye is adapted, characteristics of letters, and contrast direction (black letters on white or vice versa).

These factors were investigated in a field experiment and a laboratory experiment to gather information on the effects of these factors and their interrelationships on legibility. Complex relationships among factors were found, and legibility distances for different combinations of factors ranged from 22 to 92 feet per inch of letter height. Relationships are discussed with respect to the use of reflectorized materials.

The study is part of a larger study on highway signs, and future work will relate sign legibility to characteristics of reflectorized materials.

● ALTHOUGH the use of reflectorized materials has greatly increased the night legibility of signs, it has created new problems for which standard practice provides no answers. A number of reflective materials differing greatly in reflective characteristics and cost are on the market, and new ones will doubtless be developed. Highway departments faced with particular signing problems get conflicting advice from different manufacturers, and there is a general lack of objective information on the subject. There is need for a systematic investigation of the problem to begin the accumulation of a body of unbiased information which is applicable to reflectorized materials in general rather then to particular products.

This study is part of a research project on highway signs sponsored by the Virginia Department of Highways and the Bureau of Public Roads. The project consists of two main parts. The first part is a study of the reflective characteristics, durabilities, and costs of materials.[1] The second part is a study of sign legibility. This paper reports some results of initial investigation of sign legibility, and has limited practical application, but information from the two parts, when combined and integrated, will form a basis for specifications for reflective materials and for the design of effective economical reflectorized signs.

Review of Literature

Very little research on the legibility of reflectorized signs has been reported. Earlier investigations such as those of Mills (13) and Forbes and Holmes (8) were restricted to reflector buttons of a particular type and are not applicable to the range of types of materials available today. Neal (16) compared reflectorized letters to black letters on a reflectorized background for one material. The only recent study of the legibility of reflectorized signs was that of Havens and Peed (10). Unfortunately, the design of their experiment and their photometric measurements were inadequate for explaining relationships between legibility and sign brightness.

The most important problems for daytime sign legibility have received attention. Forbes and his collaborators (8, 9) have investigated the legibility of the standard letter series used on highway signs, and developed a systematic procedure for determining necessary letter size (14). Although a large number of factors have not been investigated, adequate solutions to daytime legibility problems have been reached through many years of experience.

A large number of studies on the general problem of legibility have been reported. Studies have demonstrated that letter form and spacing are important factors affecting legibility (1, 3, 5), but the relationships have not been thoroughly investigated. Con-

[1] Initial results are reported in Reference 20.

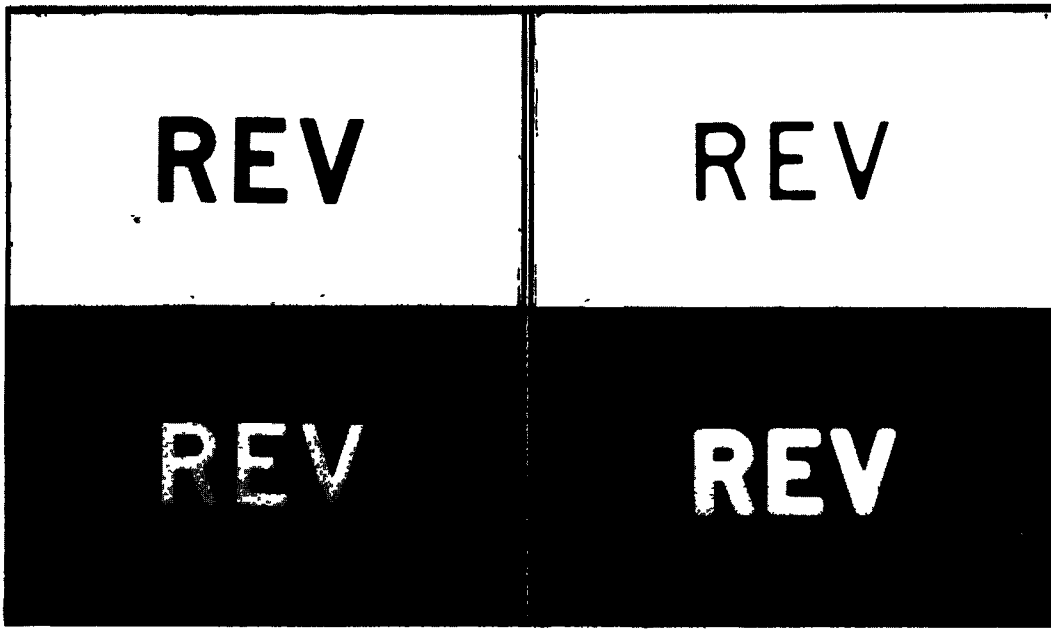

Figure 1. Appearance of signs of optimum and high brightness.

flicting results have been obtained regarding the best stroke width (width of line) for letters (3, 4, 11). Great differences were obtained depending upon the brightness used and whether black or white letters were used. Contrast direction (white letters on black or vice versa) is an important factor for reflectorized signs, since some materials can be used only for reflectorized letters while other materials are better adapted to reflectorized backgrounds. Conflicting results have been obtained on this factor (3, 12, 16) depending upon the brightness and stroke-width used.

Sign Brightness

The basic problem presented by reflectorized signs concerns the relationships between sign brightness and legibility. On the highway, sign brightness depends upon a number of factors. The amount of light reaching the sign varies with distance to the car, location of the sign, use of upper or lower beams, variation in horizontal and vertical alignment of the road, and condition and alignment of headlamps. The amount of this light which is reflected to the driver's eyes varies with the reflective characteristics of the material and the angular relationships between the car, the road, and the sign. Most of these factors vary continuously as the car approaches the sign. However, it should be possible to collect data which would permit the calculation, within reasonable limits, of the sign brightness for a given material at a specified distance and location with respect to the pavement.

Basic research on visual acuity (19) shows that when the eye is adapted to the brightness level, acuity increases with increasing brightness of the test object. At higher levels of brightness, the curve levels off, and further increases in brightness yield little increase in acuity. The brightness beyond which little increase in acuity occurs is different for different test objects.

When the eye is not adapted to the brightness of the test object, relationships become more complex (6). The point beyond which increasing brightness yields little increase in acuity depends on the level of adaptation of the eye. As brightness greatly exceeds the level to which the eye is adapted, further increases in brightness result in a decrease in acuity (21, 22). Figure 1, a reproduction of the appearance of signs of optimum and high brightness, was produced to illustrate how high brightness can reduce legibility of letters. All the messages in Figure 1 are the same size and the same letter series. Notice the change in apparent stroke width at high brightness. The black lines appear narrower and the white lines appear wider. The eye sees a spreading of the white at levels of brightness greatly exceeding the level to which the eye is adapted. This spreading of the white is called "irradiation." Figure 2 shows a higher extreme of irradiation. If brightness is increased still further, the black letters will almost disappear and the white letters will fuse into a white blur.[2]

This occurs on the highway at night when a driver whose eyes are adapted to a fairly low level encounters a sign of very high brightness. The relationship between irradiation and legibility is not a new concept, but there is need for its application to sign design. For example, for signs of very high brightness, white letters need a narrower stroke width and black letters need a wider stroke width to counteract the effect of irradiation.

Purpose of Study

The purpose of this study was to collect data on relationships between legibility and sign brightness. Such data have limited practical value until combined with data on reflective materials, sign illumination from headlights, and field validation of laboratory data. This paper then is concerned with relationships and not with the legibility of particular signs or particular reflective materials.

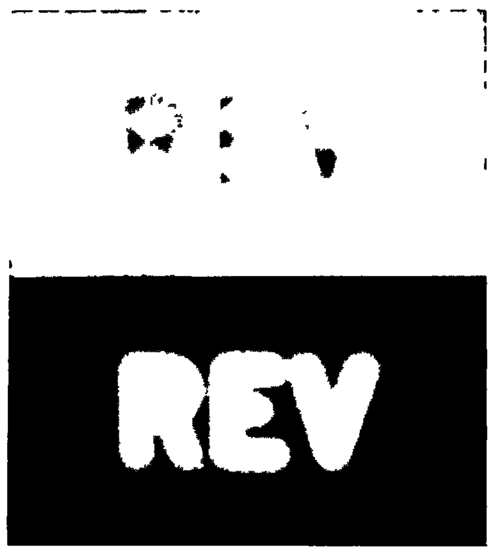

Figure 2. Irradiation.

FIELD EXPERIMENT

In order to obtain information on the magnitude of the relationships in the field and the problems involved in field experimentation, the first experiment was conducted on the highway at night. Relationships between legibility and sign reflectance for one specific type of sign were studied. Although results were not expected to yield much information regarding reflective materials in general, they would yield information valuable for further research. The factors investigated were (1) four levels of sign reflectance, (2) two conditions of background illumination, and (3) high and low headlight beams. The distances at which numerals could be read correctly for each combination of these factors was recorded for persons riding in a test car.

Four materials giving approximately equal steps in apparent brightness were chosen. The materials and their approximate reflectances (luminance factors) were as follows: white paint (.80), beads on paint (5.5), moderately reflective sheeting (32) and highly reflective sheeting (200). Four standard US route marker shields were made from each material, with different two-digit Series C numerals 7 inches high on each.

Two conditions of background illumination were used. The first condition, "Rural Intersection," consisted of a street light, lighted buildings, and a car parked with its low beams giving opposing headlight glare to the test car. (No light from these sources fell directly on the sign.) The second condition, "Open Road," included no illumination other than that from the headlights of the test car. These two illumination conditions were at opposite ends of a straight level pavement. Posts were placed at each end of the course so that the test signs could be readily mounted in a commonly-used position, 4 feet above the crown of the road and 8 feet from the edge of the pavement. Signs were mounted on the posts according to a previously arranged random sequence.

Eight subjects between 25 and 30 years of age with acuities from 20/25 to 20/15 were

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[2] Factors other than the change in apparent stroke width at high brightness are not discussed in this simplified explanation. For further discussion see References 2, 21, and 23.

used. The subject rode beside the driver as the test car approached the sign at a constant speed of 10 mph. The recorder in the back seat recorded the distance at which the subject could read the sign correctly for each combination of reflectance, illumination, and headlight beams.

Results

Statistical analysis of the results is shown in Table 1. All interactions of the factors tested were significant. (Interactions indicate complexity of the relationships — the effect of each factor depended upon the conditions of the other factors.)

TABLE 1

FIELD EXPERIMENT

ANALYSIS OF VARIANCE

Source			df		SS		MS	F
Reflectances			3		1616.906		538.969	21.93[b]
Surrounding Illumination			1		2.000		2.000	0.36
Headlight Beams			1		820.125		820.125	76.93[b]
Subjects			7		1811.219		258.746	36.57[b]
R x Illumination			3		109.938		36.646	5.18[b]
R x Beams			3		240.063		80.021	11.31[b]
R x I x B			3		81.906		27.302	3.86[a]
I x B			1		30.031		30.031	4.24[a]
R x S			21		516.094		24.576	3.47[b]
B x S			7		74.625		10.661	1.51
Error	I x S	7	77	38.500	544.813	5.50	7.075	
	R x B x S	21		200.688		9.56		
	R x I x S	21		118.063		5.62		
	B x P x S	7		25.219		3.60		
	R x P x B x S	21		162.344		7.73		

[a] Significant at 5% level.
[b] Significant at 1% level.

Results for the first condition of background illumination, "Rural Intersection," are shown in Figure 3. Increasing reflectance yielded increased legibility distance, and the curves for high and low beams are approximately parallel. For the second condition, "Open Road," the results were quite different, as is shown in Figure 4. For low headlight beams, legibility distance increased with higher levels of reflectance as before. For high beams, however, increases in reflectance beyond "beads on paint" yielded no increase in legibility distance. In fact, results showed a slight decrease, and the high-reflectance sign was read at a greater distance with low beams than with high beams.

Discussion

It was concluded that illumination conditions surrounding a sign are an important factor. Results for the "Open Road" condition seem a definite indication of irradiation, and the subjects reported that the brightest sign was "too bright." For the other illumination condition, there was no indication of irradiation. No general conclusions regarding sign reflectance can be made from these data, since results would be quite different for a different letter size, letter series, or placement of the sign. Although irradiation is not a serious problem for this sign, there is indication that it might be serious with a higher-reflectance material and smaller or narrower numerals. The complexity of the results confirmed the belief that laboratory investigation was necessary, where each of the important variables could be controlled experimentally.

LABORATORY APPARATUS

Accordingly, a test tunnel was built for investigation of each of the important factors affecting sign legibility. Figure 5 is a diagram of the test tunnel and apparatus by means of which each of the variables could be controlled experimentally to match highway conditions.

The subject, seated at the right, viewed miniature signs at a distance of 40 feet. Sign messages were produced photographically on high-contrast film, mounted in lan-

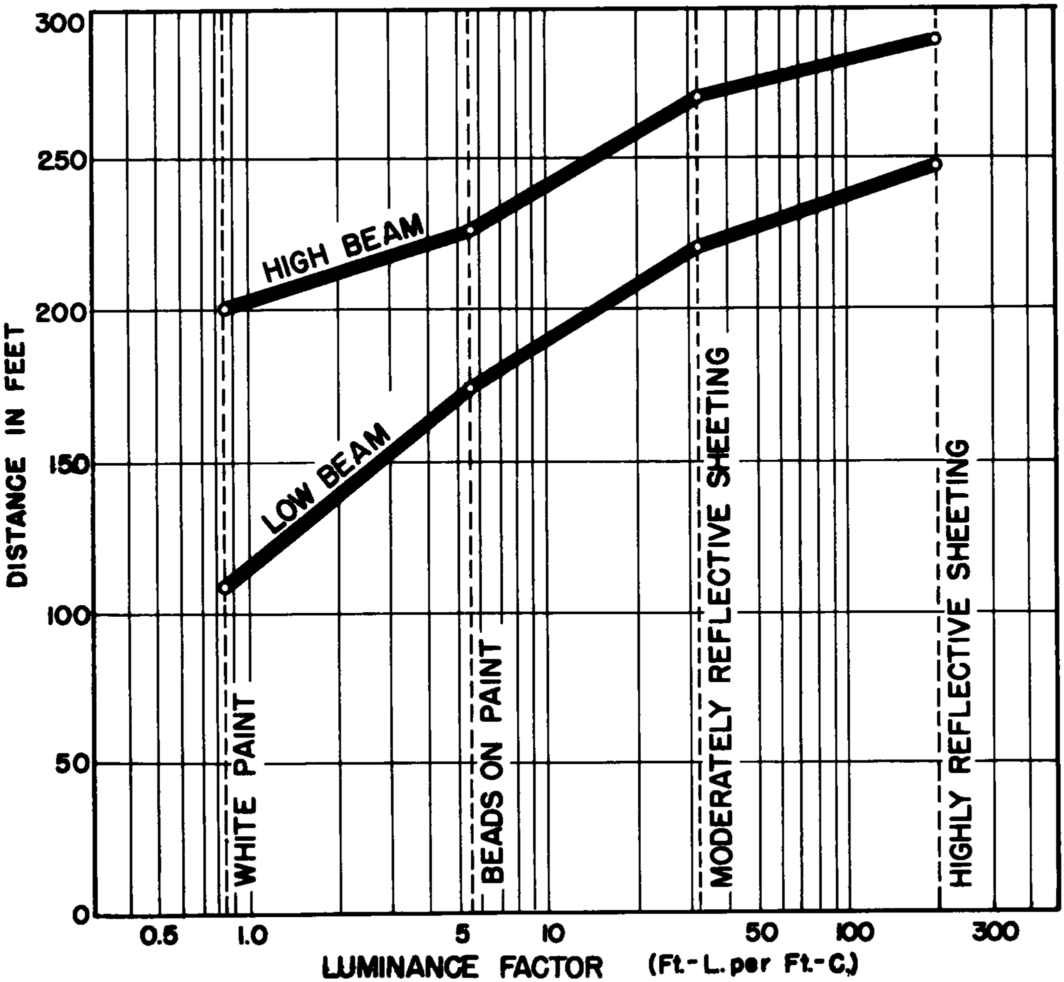

Figure 3. Field experiment results for the rural intersection.

tern slide glass, and illuminated from behind by the light source. Sign brightness was controlled by an iris diaphragm in the light source. The shield in front of the light source kept extraneous light from reaching the miniature sign.

Surrounding illumination was produced by two sources. Headlights mounted in front of the subject were designed to duplicate the intensity and distribution of light from a driver's own headlamps. Ambient lights along the sides of the tunnel were used to produce an even glareless illumination. Opposing headlight glare was duplicated by lights mounted at the far end of the tunnel.

Each of these variables could be remotely controlled by the experimenter. After field measurements were made to establish the range of each of the variables, the apparatus was calibrated at levels covering the ranges encountered in the field.

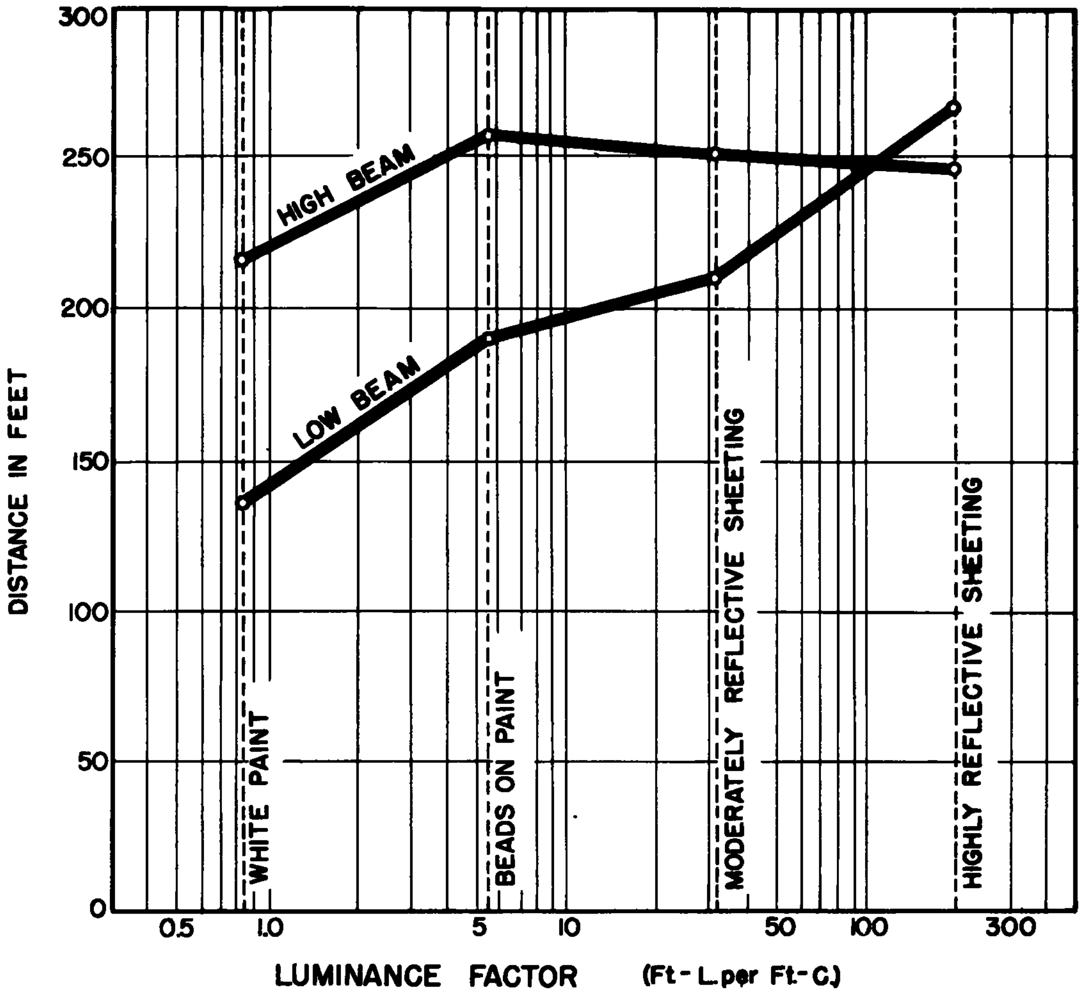

Figure 4. Field experiment results for the open road.

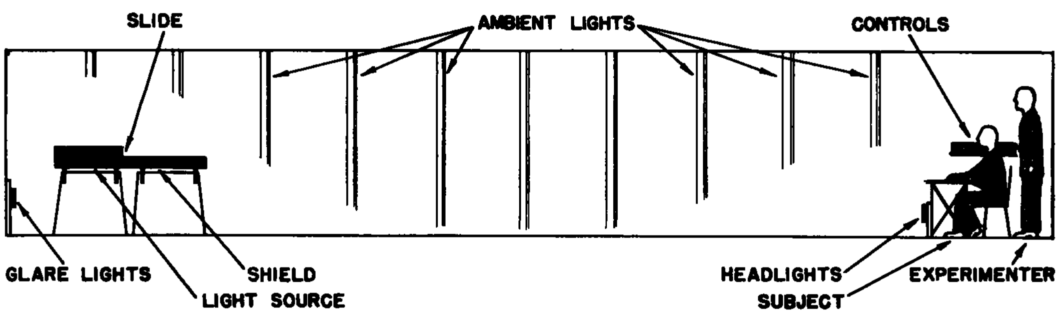

Figure 5. Diagram of laboratory test tunnel.

INITIAL LABORATORY STUDY

Factors Investigated

Four factors were selected as the most fruitful for initial investigation: sign brightness, surrounding illumination, letter series, and contrast direction.

Four levels of sign brightness were used — 0.1, 1.0, 10, and 100 foot-lamberts. Field measurements indicated that these levels covered the major part of the range of brightness at which signs are read.

Two levels of surrounding illumination were used. The low level was produced by by the headlights. Control of both intensity and distribution was considered necessary since natural pupils were used.[3] The illumination at a vertical plane in the position of the subject's eyes was 0.001 foot-candles. Field measurements indicated that this was about the lowest level to be encountered on the highway at night. The high level of illumination made use of the ambient lights as well as the headlights. The illumination at the subject's eyes was 0.1 foot-candles. Field measurements indicated that this level matched that of an area lit by street lights, and was about the maximum to be encountered in night driving without glare sources. (Higher levels are reached where street lights, building lights, etc. shine directly into the driver's eyes. However, this is treated as a separate problem to be investigated later.)

TABLE 2

LABORATORY EXPERIMENT

ANALYSIS OF VARIANCE

Source	df	SS	MS	F
Illumination	1	33.97	33 97	31
Subjects	18	31,733.86	1,762.99	16.29[b]
I x S	18	1,947.58	108.20	2.16[b]
Brightness	3	105,829.36	35,276.45	126 61[b]
B x S	54	15,045.27	278.62	5.56[b]
Letter Series	2	125,976.41	62,988.21	1,469.97[b]
L x S	36	1,542.59	42.85	.86
Contrast Direction	1	837.58	837.58	6.27[a]
C x S	18	2,401.96	133.44	2.67[b]
I x B	3	1,404.59	468.20	5.15[b]
I x B x S	54	4,907.04	90.87	1.82[b]
I x L	2	54.38	27.19	.44
I x L x S	36	2,225.95	61.83	1.235
I x C	1	3.69	3.69	.07
I x C x S	18	1,089.85	60.55	1.209
B x L	6	812.79	135.47	2.517[a]
B x L x S	108	5,812.71	53.82	1.07
B x C	3	1,905.60	635.20	9.81[b]
B x C x S	54	3,497.36	64.77	1.29
L x C	2	125.70	62.85	1.27
L x C x S	36	1,785.38	49.59	.99
I x B x L	6	236.49	39.41	.79
I x B x C	3	42.69	14.23	.28
I x L x C	2	127.02	63.52	1.27
B x L x C	6	504.80	84.13	1.68
Residual	420	21,030.38	50.07	
Total	911	330,914.98		

[a] Significant at 5% level.
[b] Significant at 1% level.

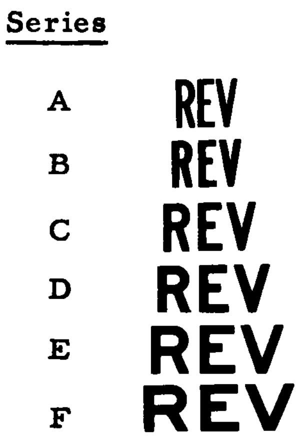

Figure 6. Examples of the six standard letter series.

The third factor investigated was letter series. Figure 6 shows an example of each of the six letter series of the Bureau of Public Roads Standard Alphabet for Highway Signs. The six series are shown in the same letter height. They vary systematically in both letter width and stroke width. In this study the Series A, C, and F were investigated. Three-letter messages (high-recognition value nonsense syllables) were photographically produced in graduated sizes. The spacing of letters used was that of Forbes (8) extrapolated for Series A and F. The fourth factor investigated was contrast direction. Duplicate sets of messages were made for white letters on a black background and for black letters on white.

Procedure

The subjects were 19 readily-available persons ranging in age from 20 to 35, with acuities from 20/25 to 20/17. After a brief period for dark adaptation and practice trials, determination of the smallest message which could be read was made for each subject, for each combination of all factors. Slides of increasing size, with messages in random order, were presented until a correct reading was obtained. An exposure time of one second was used. Order of presentation of all factors was completely randomized, except for illumination. Complete randomization would have required excessive time between observations, since a minimum of five minutes would be required

[3] Although brightness of the central field is the major determinant of foveal adaptation (15), this does not seem to be true for pupil size (17).

for foveal dark adaptation to the low level of illumination. Therefore the level of illumination was changed only once per subject.

Analysis

Selection of the proper measurement of legibility to use in the analysis was important because of assumptions of the statistical analysis and parsimony in description of

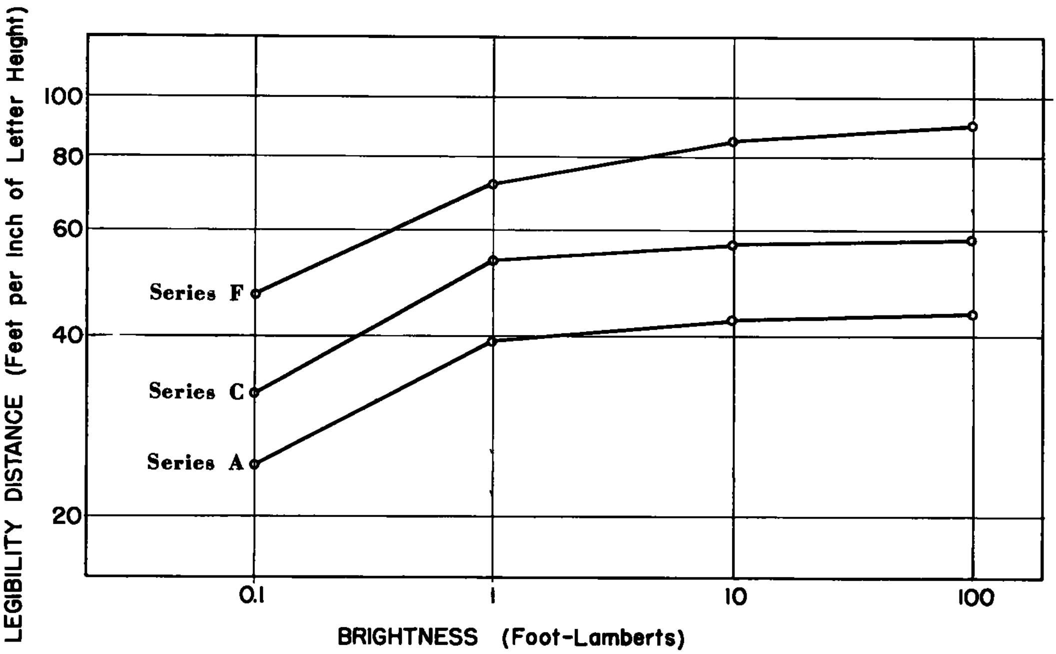

Figure 7. Results for letter series by brightness.

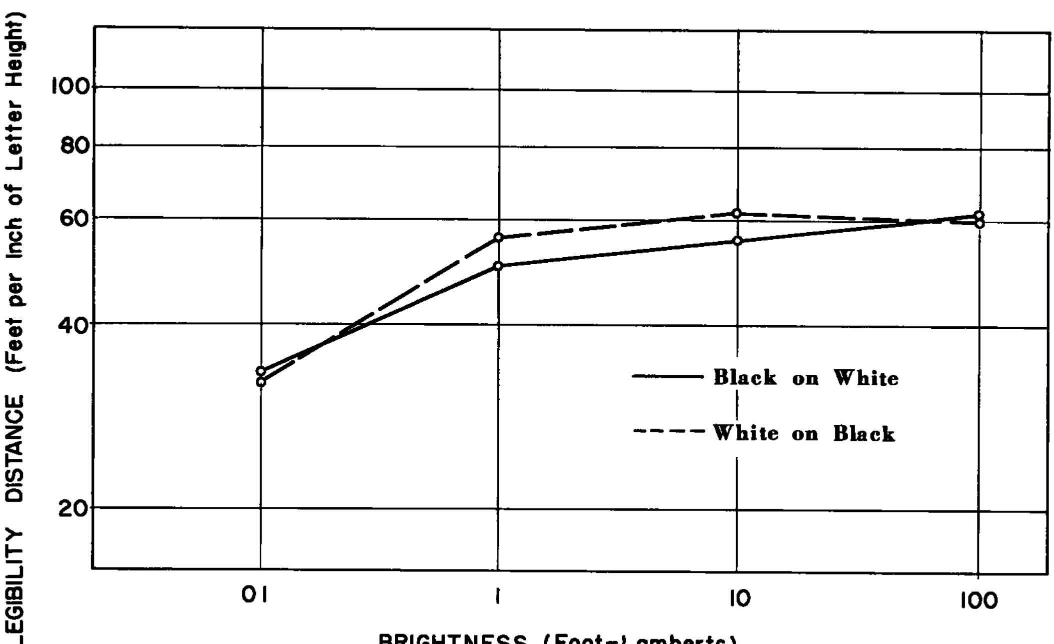

Figure 8. Results for contrast direction by brightness.

of the relationships. Log reciprocal visual angle would satisfy these considerations. However, for possible users of this research, legibility distance in feet per inch of letter height (the distance at which a letter one inch high can be read) has more mean-

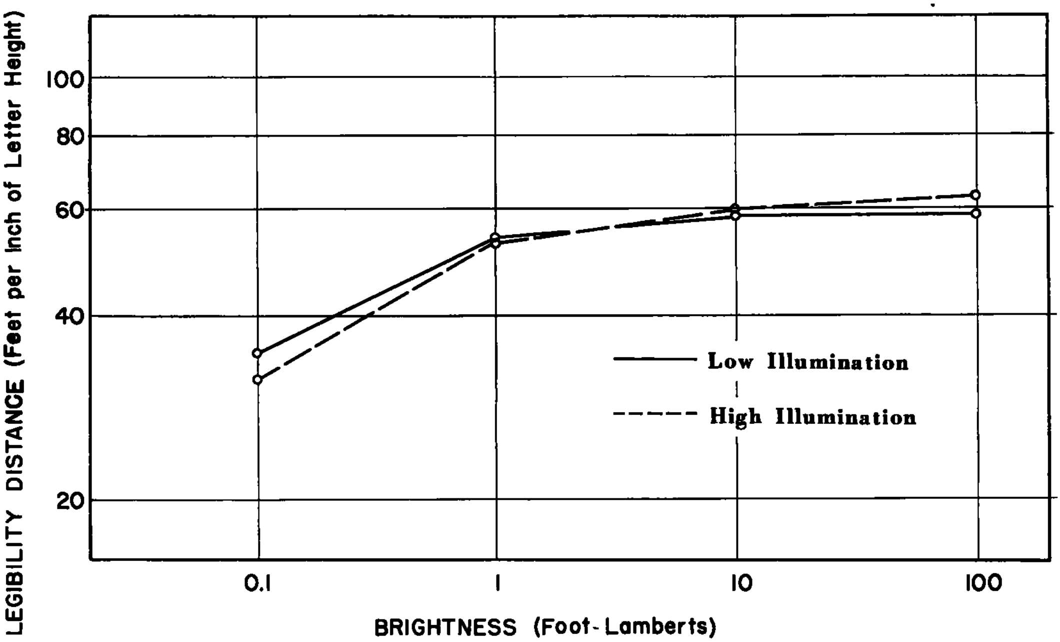

Figure 9. Results for surrounding illumination by brightness.

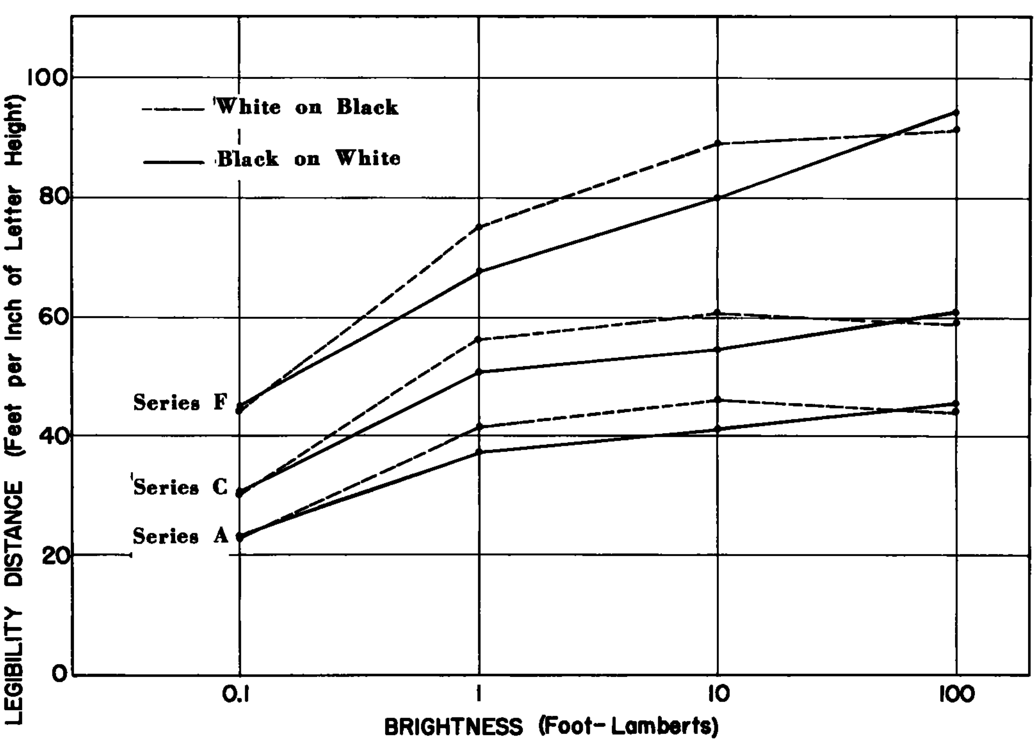

Figure 10. Overall results for high surrounding illumination.

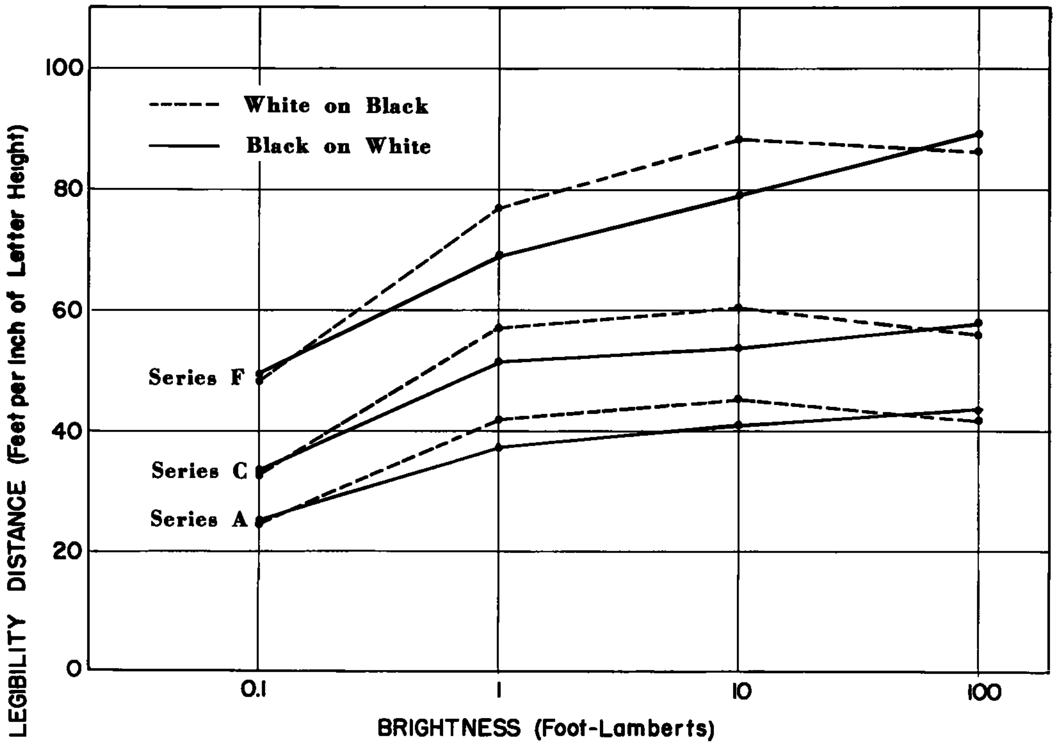

Figure 11. Overall results for low surrounding illumination.

ing. Since the relationship between reciprocal visual angle and legibility distance is almost perfectly linear within the range of visual angles used, either would yield the same results. Therefore, log legibility distance was used in the analysis of results.

Statistical analysis of the results is shown in Table 2. The particular value of analysis of variance in this case was determination of the interactions which were significant, since the interactions determine the way in which results can be properly summarized.

Significant factor interactions were as follows: (1) Brightness x Illumination, (2) Brightness x Contrast Direction, and (3) Brightness x Letter Series.

This means that results for illumination, contrast direction, or letter series were different depending upon the level of brightness.

The following subject interactions were significant: (1) Brightness x Subjects, (2) Illumination x Subjects, (3) Brightness x Illumination x Subjects, and (4) Contrast Direction x Subjects. The effect of each of the above factors, then, is different for different persons. These interactions would be larger in a population including older age groups.

Results by Factors

Guided by the analysis of variance, a series of curves was used to summarize results. Since each factor interacted significantly with brightness only, each of the factors could be summarized by plotting it as a function of brightness. Curves for each were plotted on log scales, since the relationships are shown most clearly by log scales.

Results for the three letter series are shown in Figure 7. For Series A and C, there is little increase in legibility beyond a brightness of one foot-lambert. In general, Series F letters are legible at about twice the distance at which Series A is legible. These curves illustrate the Brightness x Letter Series interaction. If there were no interaction the three curves would be parallel.

Figure 8 shows results for contrast direction by brightness. White letters on black were definitely superior in the middle range of brightness, but not at the extremes. Further work will be needed to determine the effects on this relationship of extending the range of brightness and using different stroke-widths.

The relationship between illumination and brightness is shown in Figure 9. Results are as would be expected, with the eye which is adapted to low illumination seeing low-brightness signs better, and vice versa.

Overall Results

Overall results for any combination of illumination, brightness, letter series, and contrast direction are shown in Figures 10 and 11. The curves are plotted on a linear scale of legibility rather than a log scale, so that curves may be compared in reference to the zero point. Curves were plotted from a statistical regression analysis, taking account of significant factor interactions.

The relationships shown by these curves indicate that each of the factors tested is an important factor affecting the night legibility of signs. Legibility distances for different combinations of factors ranged from 22 to 92 feet per inch of letter height. Points on these curves were connected by straight lines since only the four levels of brightness were investigated. Further work is needed at both ends of the range to determine more accurately the shape of these curves.

For the high level of surrounding illumination, increases in brightness within the range tested resulted in greater increases in legibility than for the low level of illumination. At low illumination, increases in brightness beyond one foot-lambert yielded little increase in legibility for Series A and C, while the increase for Series F was greater. White letters on black were more legible at 10 foot-lamberts than at 100, which indicated excessive irradiation at 100 foot-lamberts. For black letters on white, 100 foot-lamberts did not cause enough irradiation to decrease legibility.

DISCUSSION

In interpreting the results of this study, it is necessary to take account of differences between legibility in the laboratory and sign legibility on the highway. The subjects used in this study had an average acuity of 20/18. Correcting these results to "normal" vision would yield a 10 percent reduction in legibility distances. If the acuity required for an operator's license were used as the "design" acuity, a further reduction of as much as 50 percent would be necessary. However, relationships between night vision and age are of more importance, since they would affect the relationships investigated in this study. It is well-known that night vision deteriorates with age (7, 18), and the significant subject interactions found in the analysis indicate that caution is necessary in generalizing to the population of drivers on the highway.

Account must also be taken of differences between reading slides in the laboratory and reading signs on the highway. Precise comparison of laboratory data with results of the field experiment was not possible with data at hand, but a rough comparison indicated two differences. First, legibility distances were less in the field experiment by about one-third. Part of this difference was probably due to reaction time and differences in message familiarity. Secondly, there seems to be less reduction in legibility due to irradiation in the laboratory than in the field. This may be due to the fact that after-images are possible in the laboratory which may facilitate the legibility of short messages of high brightness. Further investigation of these relationships is needed, and the differences point out the need for field validation of laboratory results.

Another factor of importance is the presence of glare sources of light in the field of vision, such as street lights, or the headlights of approaching cars. Some preliminary investigation was done with an intensity of one foot-candle from the glare lights in the laboratory. As would be expected, there was a marked reduction in the legibility of low-brightness signs. However, at high brightness where irradiation was serious, this intense glare increased the legibility distance. The glare caused a reduction in pupil size and a reduction in irradiation, and resulted in facilitation of legibility. The practical implication of this is that where glare sources are in the field of vision, brighter signs are needed for legibility and brighter signs can be used without excessive irradiation.

Practical Application

The results of this study have not yet been validated in the field or related to reflective materials. However, from the relationships observed in this study, the following practical conclusions are made for what they may be worth:

1. Surrounding illumination is an important factor to be considered in relation to reflective materials. In a brightly-lit area, higher sign brightness is needed for legibility, and higher brightness is permissible without excessive irradiation. High-reflectance signs on a dark open road may have poor legibility because of irradiation.
2. Letter size is a very important factor, since it determines effective sign brightness. Large letters can be read at distances where illumination from headlights is low, if sign reflectance is high. Small letters, however, must be read at distances where illumination from headlights is high. In this case, high sign reflectance may produce excessive irradiation.
3. Results for the different letter series indicate that the wider letters with their wider stroke width are less severely affected by irradiation. However, these differences intrinsic in the letter series are small compared to the differences in legibility distance. Series A letters must have about twice the letter height as Series F to have the same legibility distance and the same illumination from headlights.
4. In this study, white letters on black gave superior legibility in the middle range of brightness, but results indicate that irradiation is more serious for white letters of the standard series. White on black signs may be very effective, but care should be used to achieve a well-designed sign.

Further Research Needed

Further investigation of relationships between brightness and legibility is needed. Extension of the range of brightness to lower levels is needed in order to determine more accurately the shape of the curves in the region of rapid change of legibility with changes in brightness. Investigation of higher levels of brightness is needed, since field measurements indicate that brightnesses as high as 1000 foot-lamberts may be found in certain cases, and more irradiation is to be expected at higher brightness levels. Relationships between irradiation in the laboratory and on the highway should be checked on.

Effects of glare sources of light and the role of pupil size on the relationships requires further study. The stroke width of letters should be varied, and its effects on the legibility of both white and black letters studied.

In addition, there are a large number of other factors for which no immediate plans for investigation have been made. For example, research is needed on such factors as sign color, letter design and spacing, target value, the legibility of symbols, and sign layout.

After field validation of laboratory data and correlation with data on reflective materials and illumination from headlights, results can be applied to field legibility of reflectorized signs. For any given sign there is a substantial increase in legibility for increases from low sign brightness, followed by a range of brightness where differences in legibility are small, followed finally by a reduction in legibility at very high sign brightness. A sign of a material with the lowest long-range cost yielding a brightness in this middle range would be the best choice. Of course, the different conditions under which the sign must be read must be taken into account, and it would not be possible to design signs individually. However, signs may be classified on important factors such as message and type of sign, required legibility distance, conditions of illumination, and location with respect to the pavement. With such a classification, it should be possible to design for each class an economical combination of letter series, letter size, and reflective material.

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Candle Power of Rear Lights on Trucks

EDMUND R. RICKER, Traffic Engineer
New Jersey Turnpike Authority

● LATE in 1953, the Inter-Turnpike Safety Committee was formed with representatives from the Pennsylvania Turnpike Commission, the Ohio Turnpike Commission, the New York Thruway Authority and the New Jersey Turnpike Authority. This committee was organized for the purpose of comparing operating experience, preparation of uniform traffic regulations and study of additional safety measures. The first job assigned to this committee was the evaluation of the rear lighting of vehicles as it pertains to expressway operation, to determine the adequacy of existing lighting requirements and the preparation of recommendations for additional requirements if necessary. This committee has met on several occasions, studied the requirements of the various states and the Interstate Commerce Commission and collected certain data as to the candle power and condition of existing rear lighting on trucks. This paper is concerned with the latter phase of this study.

Present legal requirements for the intensity of rear lighting are stated either in terms of visibility distance (generally 500 ft.) during night operating conditions or by bench measurements of candle power measured at certain angles to the lamp axis. Neither of these methods appears satisfactory for field checks or for enforcement purposes. A visibility distance is subject to many variations, such as presence of other lights and dark adaptation of the observer, with the result that a glowing cigar butt can meet the minimum requirements under certain conditions. The bench measurements, while definitive, do not take into account the many variables encountered in practical truck operations, such as deterioration of equipment, loss of voltage, dirty lenses and reflectors, displacement from normal position, or connection to batteries and generator systems with low voltage or improper voltage. Police detachment representatives asked the committee to seek some means for direct measurement of the intensity of rear lamps with a corresponding regulation which would provide that a certain minimum output must be present regardless of design, maintenance, or condition of the lighting system.

The committee asked the Nela Park Laboratory of the General Electric Company to construct an experimental photometer to make direct measurements of the output of vehicle tail and stop lights. This device is shown in Figure 1. It consists of a baffled photometric tube, lens, barrier-layer cell, microammeter and appropriate switches and circuitry. It is balanced about a carrying handle and the total weight is less than three pounds. The major dimensions of the device are taken up by the hollow tube which is 8 inches in diameter and 4 feet long, for the purpose of providing a constant photometric distance of 4 feet as used in other tail light requirements. The end to be placed against the tail lamp is padded with 1½ inches of sponge rubber with a tapered hole which accepts the tail lamp and allows a 4-inch diameter or smaller source to be measured. At the opposite end of this tube is a plastic fresnel lens which focuses the light from a 10 degree cone onto the face of the barrier-layer cell. Two microammeters with scaled ranges of 0 to 0.8 and 0 to 20 candle power are used to measure the cell current. Two buttons positioned under the fingers of the operator's left hand select the appropriate scale range. A special calibration device was also provided consisting of a red sealed-beam type lamp having a suitable beam distribution and two filaments to simulate tail and stop lamp ranges and distribution. It is operated from a separate six volt DC source.

It must be understood that this device is experimental in nature and does not represent a direct measurement of any existing legal requirements for lamp output. The design is such that the candle power reading is obtained by the integration of light over a 10 degree cone, and all readings reported in later paragraphs are stated in these terms, rather than in light output at specific points. As a very rough relationship to the requirements of the Society of Automotive Engineers, the equivalent integrated candle power is approximately one-half the "on-axis" requirement, which, according to current standards, is 1.5 candle power for tail lamps, 15 candle power for stop lamps,

Figure 1.

and 100 candle power for turn signals.

The above described photometer was used over a period of several months to make measurements on vehicles traveling over the Pennsylvania and New Jersey Turnpikes. During the collection of this data, all trucks wishing to enter the turnpike at a given interchange were stopped on the shoulder and measurements made of the tail lamp and stop lamp intensity. Due to the fact that this operation was performed under the direction of state police personnel and was accompanied by a check of other safety equipment, it is probable that most of the truck drivers tried to present their lighting equipment in the best condition possible. This was indicated by the fact that some of them kept the motor turning at a faster-than-idling speed, that many of the lenses were freshly cleaned, that some trucks avoided the checking point by using other routes and that some had actually performed re-wiring operations as indicated by the fact that stop lamps were wired as tail lamps. The drivers were not requested to keep the motor turning at faster-than-idling speeds, but were permitted to do so. On several nights, the weather was rainy. Thus it is felt that the measurements taken are generally better than the average of existing conditions. The results of some 660 observations on the New Jersey Trunpike are shown in Table 1. The personnel making the tests attempted to make a rough comparison between the better lamps as measured, and their usefulness as observed while the truck was pulling away. It was the general concensus that the group having 1.5 or greater integrated candle power in tail lamps and 15 or greater integrated candle power in stop lamps was the minimum which could be considered adequate for safe operation on expressways. It may be noted from the table that 88.5 percent of the tail lamps and 97.4 percent of the stop lamps were thus adjudged inadequate. Some reference measurements were made of the tail lamps on the current model passenger cars and these were found to give readings on the photometer in the range of 3 to 7 candle power for tail lights and the stop lights were generally off-scale on the meter.

Additional data were collected during the tail and stop lamp intensity survey. Concerning the height above ground and the distance from edge of body to the centers of

TABLE 1

SUMMARY OF TRUCK TAIL AND STOP LAMP SURVEYS CONDUCTED ON THE NEW JERSEY TURNPIKE BETWEEN JULY 27 AND SEPTEMBER 20, 1954

Integrated Candle Power	Tail Lights	Cumulative Percentage	Stop Lights	Cumulative Percentage
None	55	8.8	119	18.0
Less than 0.10	112	26.7	24	21.7
0.10 - 0.24	140	49.1	37	27.3
0.25 - 1.4	252 (6)[a]	88.5	191	56.2
1.5 - 4.9	84 (22)[a]	98.4	179	83.3
5	5 (1)[a]	Vehicles with stop lights wired as tail lights and no stop lights in operation were subtracted from the total for calculation of these percentages.	26	87.3
6	2		26	91.2
7	3 (2)[a]		10	92.7
8	1 (1)[a]		4	93.3
9	1		8	94.5
10	1		6	95.5
11	2 (1)[a]		7	96.5
12	1 (1)[a]			
13			3	97.0
14			3	97.4
15			1	97.6
17			2	
18	1 (1)[a]	100.0	3	
19			3	
20			3	
Greater than 20			5	100.0
	660		660	

[a] These vehicles had stop lights wired as tail lights and did not have stop lights in operation.

TABLE 2

MOUNTING HEIGHTS – TAIL LAMPS

	TRACTOR TRAILERS					STRAIGHT TRUCKS						
Mounting Height	Box	Flat Bed	Car Transport	Low Bed	Van	Tanker	Box	Rack	Panel	Open Body	Tractors	Total
Less than 18"					1							1
18 - 23 in.	6	1	3		15		1	3				29
24 - 29 in.	18	2	9		11		24	9	1	7	2	83
30 - 35 in.	77	29	7	2	5		27	16		10	2	175
36 - 48 in.	299	31	1			17	8	2	1	4	1	364
Greater than 48"	3					5						8
Total	403	63	20	2	32	22	60	30	2	21	5	660

MOUNTING HEIGHT – STOP LAMPS

Mounting Height	Box	Flat Bed	Car Transport	Low Bed	Van	Tanker	Box	Rack	Panel	Open Body	Tractors	Total
Less than 18"					2							2
18 - 23 in.	7	1	3		15		1	2				29
24 - 29 in.	26	4	4		10		24	10	1	10	2	91
30 - 35 in.	86	38	12	2	5		28	16		9	1	197
36 - 48 in.	281	20	1			17	7	2	1	2	2	333
Greater than 48"	3					5						8
Total	403	63	20	2	32	22	60	30	2	21	5	660

TABLE 3

DISTANCE FROM EDGE OF BODY —TAIL LAMPS

	TRACTOR TRAILERS						STRAIGHT TRUCKS					
Edge Distance	Box	Flat Bed	Car Transport	Low Bed	Van	Tanker	Box	Rack	Panel	Open Body	Tractors	Total
Less than 12"	3	1	4			1	1					10
12 - 18 in	8	1	3		3	5	4	2				26
19 - 24 in	22	3	1		4	1	7	5		1		44
25 - 36 in.	24	9	1		3	2	3	2				44
37 - 48 in	82	13			2	1					1	99
Total	139	27	9		12	10	15	9		1	1	223
DISTANCE FROM EDGE OF BODY – STOP LAMPS												
Less than 12"	4	1	3			3	1					12
12 - 18 in	10	1	4		5	4	3	2				29
19 - 24 in.	20	3	1		2	1	7	5		1		40
25 - 36 in.	21	8	1		4	2	3	2				41
37 - 48 in	84	14			1		1				1	101
Total	139	27	9		12	10	15	9		1	1	223

both tail and stop lights. These data are summarized in Tables 2 and 3. Examination of the mounting height summary indicates that 94 percent of the tail lights and stop lights lie within the 24 inch to 48 inch height range. This would probably be an acceptable placement range in the vertical plane. The location of lights with respect to the edges of the body is not standardized. It would appear most desirable to have these lights reasonably close to the edges of the body, as they would also serve the function of clearance lamps and provide better delineation of the extreme sides of the vehicle. However, present practice seems to be to place these lights close to the center of the body even when two lights are displayed.

SUMMARY

The Inter-Turnpike Safety Committee is continuing its study with a view to proposing to its parent bodies definite requirements as to the intensity placement and use of tail and stop lamps for vehicles traveling on the various turnpikes. It is recognized that the setting of these standards and the methods of measurement are matters of widened interest in the traffic field. Comments are earnestly solicited as to the significance of the reported measurements and suggestions for the proper standards to be used.

Specifications and Performance of New Sealed-Beam Headlamp

W. F. SHERMAN, Manager, Engineering and Technical Department
Automobile Manufacturers Association

● THIS paper reports on the final outcome of a cooperative engineering and development program aimed at improving the sealed-beam headlamp for automobiles. Participants in the activity have been the chief automotive lighting engineers from each major lamp manufacturing concern, the lighting engineers from each of the American vehicle companies, and representatives of the states' motor vehicle administrators. Necessarily, the author must acknowledge in advance the contributions of a great many people, and does so with gratitude.

Origin of Program

The reasons why the program was initiated are worth mentioning, first of all.

In the last two decades, particularly since the end of World War II, the volume of traffic on America's streets and highways has grown at a surprising rate. In 1955, the number of cars, trucks and buses registered in the United States is near the 60-million mark, just about double the 1945 total. This tremendous increase in registrations, and a comparable increase in usage, has a special effect on night-driving conditions. A result is that the average driver is meeting other traffic more frequently, and in consequence has fewer opportunities to use the upper beam of his headlamps than he normally would in open country driving. More and more of his night driving now must be done on the lower beam, designed for traffic use and for meeting other vehicles on the highway. The significant factor, of course, is that, since the highway system is really no more extensive than it was before the war, the concentration of vehicles on the road at night is obviously much greater.

This change in night-driving conditions prompted public officials and the manufacturers of headlamps and motor vehicles to see the need for an improvement in the lower beam pattern which would satisfy headlighting requirements through a wider range of driving situations. There also was a desire to improve headlamp features for adverse weather conditions.

Fortunately, an important pattern for work of this sort had been established in the mid-thirties when a handful of people, looking down the road toward the future, with some idea then of the nature and prospective volume of highway transportation, had established the original cooperative headlamp program.

Because that sealed-beam program and the present one are not widely understood, it is perhaps worthwhile to examine the magnitude of the task which the group attempted cooperatively. First of all, it required the establishment of a basis for understanding and joint action between at least a score of competitive motor vehicle manufacturers, about six competitive producers of lamps and bulbs and the responsible motor vehicle authorities in some 59 jurisdictions in the United States and Canada. All of these interested groups and individuals undertook to reach agreement on at least seven basic technical factors involving the characteristics of lens, reflector, bulb, voltage, wattage, aim and focus. When the program was undertaken originally, there were at least fifteen different designs of lens in current use. Moreover, there were six different types of aiming instructions offered motorists and service men to maintain the headlighting systems then in use.

Understandably, the original sealed-beam program achieved results that made the more recent program an easier one from every viewpoint except that it did represent the somewhat difficult task of extracting another measure of performance out of a unit which already met fairly exacting requirements.

The Night Lighting Problem

The prime purpose of motor vehicle headlamps is to provide seeing distances in excess of the distance required to stop the moving vehicle. This varies, depending upon driving speeds and road conditions, but enough light is required at least several hundred feet ahead to disclose the road itself adequately, as well as any obstacles that may be on it.

With the upper beam for driving on the open road this is not, of course, a difficult problem. But the lower beam, to distribute adequate light without interferring seriously with the vision of the oncoming driver, must be very carefully designed. The best available talents in the related realms of optics, illumination and electrical engineering have been devoted to this purpose.

Enough light does not mean daylight intensities; in fact, the lighting engineers considered that one-ten-thousandth of sunshine intensity is satisfactory if the headlamps provide this much light 350 feet ahead. Such light must be modified for glare relief when vehicles approach closely. Hence, the solution of the problem generally used has been to provide two different distributions of light from the headlamps; one is an upper beam for clear road driving and the other is a lower beam providing a compromise between the requirements of enough light for adequate seeing, and glare relief.

Essentially the problem faced in designing the new sealed-beam headlamp was a very careful modification of this compromise distribution to provide a considerable increase in light intensity directed at the right hand side of the vehicle path during times that the vehicle is operated with the lamps on the lower beam. This was the design target established when the Engineering Committee of the American Association of Motor Vehicle Administrators asked that an attempt be made to provide for better seeing distances on the lower beam, having in mind particularly that many of the important hazards at night arise when a pedestrian or some obstacle is in, or about to enter, the path of the vehicle. They also requested that steps be taken to reduce the "stray" light above the horizontal to cut down the reflections from particles such as water, dust and snow in adverse weather.

Changes in Lamp Design

In summary, the technical story about the new lamps is that they represent a series of engineered refinements of lens, reflectors and filaments. An attempt will be made in this paper to outline briefly what was done in these respects and what was accomplished.

Eleven different lamp designs, representing a planned effort at modifying lamp characteristics, were developed and submitted by the various lamp manufacturers, starting early in 1951. These were laboratory tested and road tested first by the individual lamp companies and the engineers of the vehicle companies. As experience was gained with the various sample lamps, cooperative road test programs at the General Motors Proving Ground were undertaken, using test techniques that employ fleets of vehicles operating under controlled conditions on proving ground roads.

This work demonstrated that it should be feasible to raise the top level of the lower beam on the right hand side about one-half degree and at the same time elevate the position of the zone of maximum intensity on the right hand side approximately one degree. With necessary modifications in photometry to provide an otherwise satisfactory gradation and distribution of light, this was the modification to provide the better light along the right side of the driving path. At the same time, design efforts produced a good spread of the light sideways in the area which is necessary to permit adequate seeing of obstacles close to the vehicle, for example, at times when it is being turned into a driveway.

Filament Cap Introduced

A filament cap was developed for mounting above the lower beam filament to reduce the stray light projected upward from the filament. This produced outstanding benefits for the driver in adverse weather situations. It also reduces the apparent brightness of the lamp when viewed close up. Under conditions of heavy traffic it also reduces the "flash" which drivers receive in their eyes at the time of meeting an oncoming vehicle.

Both the photometric specifications and the aiming specifications for the new lamps were written in such form as to outline the technical requirements for accomplishing these results. These specifications finally were evolved to a point where they were submitted just one year ago to the Society of Automotive Engineers with the approval of both the AAMVA and the AMA. They have since been published as an SAE Standard. There is no point in reviewing here in any detail the numerical values of candle power at the various test points except to reiterate that they represent mainly a shifting of the area of maximum intensity of the lower beam on the right hand side as described above.

Wattage Increased for Each Filament

In the course of the program it was determined that the new distribution of light called for availability of more light at the source, even though the maximum beam intensity was not being increased beyond the previous established values of 75,000 cp. per pair of lamps. The increase of light at the source was accomplished by raising the wattage of each filament by five watts. The new values are 50 and 40 watts, respectively, for the upper and lower beam.

Increase in Performance

Evaluation of the lamps finally selected by the cooperating group and approved by the administrators was the result of the observations in general driving and tests under controlled conditions with observer-drivers utilizing techniques that have been described on a number of occasions to this Committee on Night Visibility of the Highway Research Board.

Under clear-road seeing conditions, i.e., on dry roads in good weather and without approaching vehicles, these tests show up to 80 feet more seeing distance along the right edge of the roadway when operating on the new lower beam. This is approximately a 23 percent increase. Members of this committee appreciate the qualification of both the figures (the seeing distance and the percentage) because of the many variables involved, but can regard the figure as representative. Similarly, and with the other variables involved when the driver is meeting an approaching vehicle, the tests show an increase ranging from 20 to 60 feet, or from 10 percent to 19 percent.

Because it is even more difficult to obtain quantitative data under adverse conditions, the cooperating group has not attempted to provide any figures to indicate the advantages which the new lamp offers in inclement weather. However, observations under a great variety of adverse weather situations indicate that the improvement in seeing distance is much greater than the gains measured on dry roads in clear weather.

In addition, the greater amount of light available at the source to the lamp designer, and the opportunity to devote such intensive effort over a considerable period of time, has resulted in a smoothness of light distribution which drivers will certainly be inclined to regard with great favor. Personal experience indicates that it offers considerable reduction in fatigue because of the better and more adequate light distribution.

Interchangeability

Dimensionally, and in all other respects, the new lamp is completely interchangeable with headlamp units installed at present in all automobiles now using the sealed-beam system. In fact, at present the replacement market channels are being supplied with the new units in states and jurisdictions where they have been approved for sale. The automobile industry is, however, faced with a situation in which the laws of some 22 states contain some detailed specifications of their own, over and above performance requirements, which make it necessary to have the laws modified or clarified to permit the industry to install such lamps 100 percent on vehicles on assembly lines for sale throughout the country. The Uniform Vehicle Code has been appropriately modified and the legislatures which are currently meeting are expected to take the matter up in these jurisdictions. It is anticipated that the lamps will be installed on all new vehicles some time before the middle of 1955.

Aiming Specification

Part of the modification of the lamp specification is accomplished by a change in the aim specification so the geometric center of the zone of highest intensity of the upper beam falls 0.4 degree below the photometer axis, as contrasted with the previous requirement of 0.6 degree. This is, of course, a laboratory requirement to be complied with in the determination of photometric values at various test points.

Inherent in the design of the lamps is the intention that the loaded vehicle, operating on the highway under conditions where the upper beam can and should be utilized, should have those upper beams directed approximately horizontal. In the past this desired aim has been achieved in practice by specifying that the upper beams should be aimed 3 inches below horizontal, at a distance of 25 feet from an appropriate aiming screen, the 3 inches obviously representing necessary load allowance and tolerance. The practical value established for the new lamp calls for aiming 2 inches below horizontal at a distance of 25 feet.

It is the ambition of the motor vehicle administrators, the headlamp manufacturers and the vehicle manufacturers to acquaint the public with the value of having headlamps aimed properly, both from the viewpoint of getting better seeing distance at night and from the viewpoint of affording other drivers necessary glare relief. This ambition is being furthered by educational efforts directed at the public and maintenance people from all three of the cooperating groups.

Discussion

OSCAR W. RICHARDS, American Optical Company, Research Center, Southbridge, Massachusetts — What change is there in color temperature with the new lamps using a higher wattage?

W. F. SHERMAN, Closure —The color temperature of the new sealed-beam headlamp is essentially the same as for the former headlamp. This is approximately 3,000 degrees K.

Cooperative Road Tests of Night Visibility Through Heat-Absorbing Glass

HARRY C. DOANE, Buick Motor Division, and
GERALD M. RASSWEILER, Research Staff
General Motors Corporation

Seventeen thousand individual observations of "seeing distance" have been made in road tests carried out cooperatively by the Automobile Manufacturers Association, General Electric, and General Motors. The purpose of the tests was to determine, under actual night driving conditions, the effect of heat-absorbing glass on nighttime visibility. Observations were made of the distance at which obstacles could first be seen from cars traveling 40 mph. against approaching headlights. The tests were similar to those previously described by Roper[1] except that the seeing task of the observer was made much more difficult in some of these more recent tests by using blacker obstacles, by using a black-top road instead of concrete, and by reducing illumination from the headlights. The average difference in nighttime seeing distance through heat-absorbing glass compared to ordinary windshield glass in these experiments was around 3 percent. This agrees with the earlier observations described by Roper taken under less difficult seeing conditions.

● THE principal advantage of "tinted" or heat-absorbing glass is that it absorbs more than half the sun's radiant energy in the infrared. Thus it increases the comfort of the occupants of the automobile by protecting them from the hot rays of the sun when it shines through the windshield and windows. It also reduces daytime glare and is advantageous even in winter when the ground is white with snow.

Automotive use of heat absorbing glass is relatively new. It was first introduced on one make of car in 1950 and it was not until 1952 that it became available on all makes. It is optional equipment for which the customer pays extra — from $25 to $45. Nevertheless, the total number of cars ordered with heat absorbing glass now exceeds five million according to a recent check with automobile manufacturers. This demonstrates the popularity and importance of this new glazing material in the automotive field.

In achieving high absorption in the infrared region, the glass manufacturers have found it necessary also to reduce luminous transmittance to about 73 percent, as compared to about 87 percent with conventional safety-glass windshields. Although this 73 percent is well within the A. S. A. standards for windshield material, it nevertheless represents a reduction in luminous transmittance as compared with conventional windshields. Thus it is apparent that an object viewed through heat-absorbing glass will appear somewhat less bright than when viewed through a conventional windshield. It might at first seem that this reduction in brightness would result in an equal loss in our ability to see the object. A moment's consideration, however, shows that this is not necessarily the case. The eye is very adaptable to changes within the daytime range of brightness and thus it sees objects equally as well through the heat-absorbing glass as through conventional glass during the daytime. At night when light levels are reduced, the eye is less effective in compensating for loss of brightness. Thus, the question occasionally has been raised as to whether the use of heat-absorbing glass reduces nighttime visibility.

Extensive tests have already been run to determine whether there is an appreciable loss in the distance at which objects can be detected when driving at night with heat-absorbing glass. The last important group of cooperative road tests of this nature was made in February 1952, reported to this board by Val Roper in 1953, and published in Highway Research Bulletin 68. Cooperating in these tests were representatives from the State of Massachusetts, the Automobile Manufacturers Association, General Electric, and major motor car manufacturers. The tests were run at Orlando, Florida and

[1] Highway Research Board, Bulletin 68, 1953.

the 2,880 observations showed an average reduction of seeing distance with heat-absorbing windshields of 3 percent as compared with conventional windshields.

These Orlando tests generally have been accepted as correct for the conditions maintained during the tests. However, the question has since been raised as to whether the conditions were sufficiently severe to show the maximum difference in nighttime seeing distance which a driver might find under extremely adverse circumstances. Since the eye is less and less adaptable as brightness levels are reduced, it might appear possible that substitution of heat absorbing for conventional windshield glass might show a difference greater than 3 percent in seeing distance under adverse conditions such as, for example, a black object on a black-top road.

The tests to be reported here were designed to investigate this possibility, and were especially planned to make the seeing task very difficult compared to normal conditions.

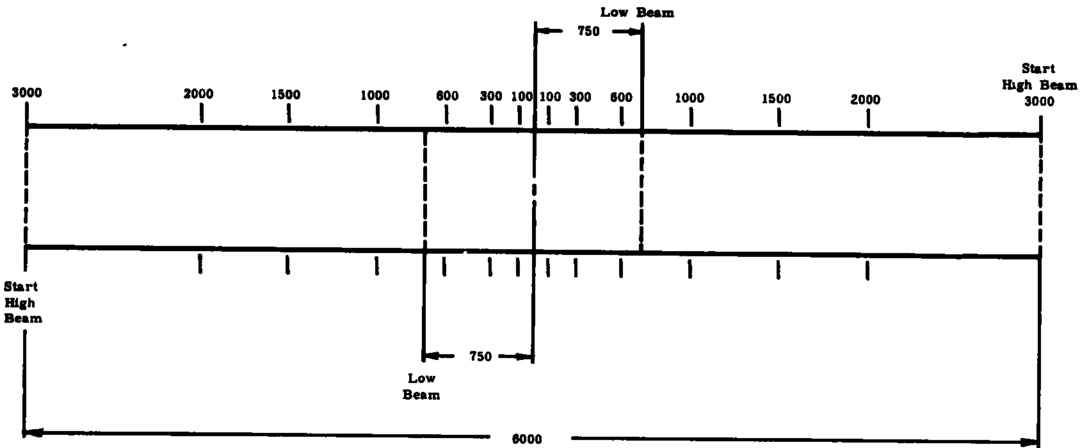

Figure 1.

They were carried on in the fall of 1953 at the General Motors Military Proving Grounds. Cooperating in the tests were the Automobile Manufacturers Association, General Electric and General Motors. We were fortunate in having Val Roper and George Meese from General Electric as consultants to assist in this extensive series of tests. Most of the test work was carried on by the proving grounds staff under the direction of Paul Skeels. Cars and windshields were furnished by Henry Boylan of the Buick Motor Division who also supervised the major part of processing the data. The authors are very grateful to Howard Gandelot of the General Motors Engineering Staff and W. F. Sherman of A. M. A. for valuable consultation and assistance. Thus it is clear that the authors are acting only as reporters for the group as a whole.

NATURE OF THE TESTS

Figure 1 shows the course used for these tests which were run with the same general procedure previously described by Roper. It was 1.2 miles long. There were twelve targets or obstacles, made to simulate pedestrians, distributed along each side of the road. These were placed on the pavement just outside the traffic lanes. The object of the test was to determine the distance at which each of these obstacles could first be detected when driving on the test course. Two cars were started simultaneously from opposite ends of the course and approached each other at a speed of 40 mph. The drivers used upper beam headlighting for road illumination until the two cars were 1500 feet apart. They then depressed to the lower beams, passed each other at the center of the course, and continued with lower beams. Thus the seeing condition immediately after passing was more critical than under normal operation when the headlamps are switched to the upper beams immediately after passing. The driver and each of the two passengers in the front seat of each car acted as observers. The point at which each target was first seen by each observer was electrically recorded on paper

TABLE 1

TEST CONDITIONS

Condition Number	Figure No.	Target Reflectance percent	Headlamps	Filament Voltage (Ave. Reading) Upper	Lower	Headlamp Aim	Date
1	2		New				
	6 to 11	7	facing same	6. 25	6. 30	Standard	Oct. 6, 1953
2	3		Used				
	12 to 17	3	facing same	6. 28	6. 29	Standard	Oct. 7, 1953
3	4		Used	6. 12	6. 20	2° low	Nov. 5-6, 1953
	18 to 23	3	facing new	6. 53	6. 63	3° high	
4	5		New	6. 53	6. 63	3° high	Nov. 5-6, 1953
	24 to 29	3	facing used	6. 12	6. 20	2° low	

tapes driven by a flexible shaft from an adaptor on the speedometer drive essentially as described in the earlier paper on the Orlando tests.

The procedure was to make six runs with a conventional windshield, six with a heat-absorbing windshield, and so on until 60 runs had been made by each car. Thus for a particular set of conditions, 30 observations through each of the two windshield types, by six observers, of twelve targets were made. This is 4,320 observations for each set of experimental conditions. It took most of a night to make a complete set of observations. Four different conditions were used on different nights making a total of more than 17,000 individual observations of seeing distance. This large number of observations was necessary because the seeing distance differences are so small that, as shown by many previous tests, it is difficult to differentiate consistently between the two types of windshields with a small number of observations. The random differences between observations will be discussed later.

TEST CONDITIONS

All the tests covered by the present paper have the following conditions in common: (1) Black top road was used. (2) Tests were run on clear, moonless nights. (3) The shoulders alongside the road were dirt with grass and weeds; reflection was very low. (4) The observation targets were made of plywood cut to the size and shape of pedestrians and carefully painted. (5) Cars were equipped with readily changeable windshields so that the conventional and heat absorbing glass could be exchanged frequently and expediently. (6) All windshields were kept free of dirt and fingerprints. (7) Luminous transmittance for all the windshields used in these tests were measured by the Libbey-Owens-Ford Glass Company as follows: Three conventional laminated plate glass: 87. 5, 87. 0, 87. 0 percent (average of 27 measurements over the whole area). Three heat-absorbing glass: 73. 3, 72. 0, 74. 3 percent (average of 27 measurements over the lower "road viewing" portions of the area). Measurements were made normal to the surface with Illuminant A.

Table 1 shows the test conditions which were varied from one set of tests to another.

1. The target reflectance was varied. Each target was painted on one side with a dark gray paint which had a reflectance of about 7 percent.[2] The other side of the target was painted with a black paint with a reflectance range between 3 and 3. 5 percent. This was the blackest paint we could find which would not readily change its gloss with handling. Table 1 shows which side of the target faced the observers in each set of tests.

2. In the first set of tests new headlamps were used. In a second set of tests,

[2] The reflectance was measured on a goniophotometer. The sample was viewed normal to the surface with the light striking the sample at 45 degrees.

TABLE 2

OBSERVERS

Observer Number	Position in Car	Vision Left	Vision Right	Glasses	Reaction Time
1	Driver	20/20	20/20	No	0.56 sec.
2	Right hand	20/20	20/20	Yes	0.47
3	Center	20/60	20/60	Yes	0.53
4	Driver	20/20	20/20	No	0.46
5	Right hand	20/20	20/20	Yes	0.59
6	Center	20/40	20/50	No	0.64

headlamps were used having previous service equal to about one-half of their normal life expectancy. This actually had a negligible effect on the illumination but the change was made in order to avoid the possible criticism that only new headlamps were employed. In fact, one of these lamps burned out during a test, showing that it was really "used." It was replaced with a previously photometered and similar half-service-life lamp. Headlamp aim and filament voltage were the same for the first two conditions (Table 1).

3. In the last two sets of tests the used headlamps were aimed two degrees below horizontal, and the new lamps two degrees above horizontal to further accentuate the differences. The voltage regulator in the car with the used lamps was adjusted to give lower voltages; in the car with the new lamps higher voltages were used as shown in Table 1.

In Table 2 is some information on the personnel who made the seeing distance observations. A variation in observers purposely was introduced into these tests in order that they would represent a wide range such as might be found among car drivers. It will be noted that two of these observers had normal vision uncorrected, two had vision corrected to normal by glasses, and two had vision below normal. Reaction times on these observers are also shown in the table. The average change in reaction

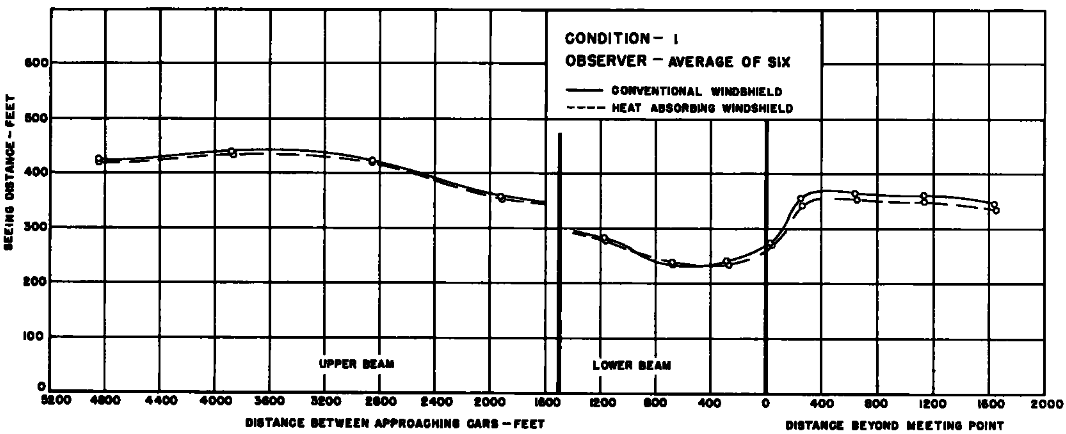

Figure 2.

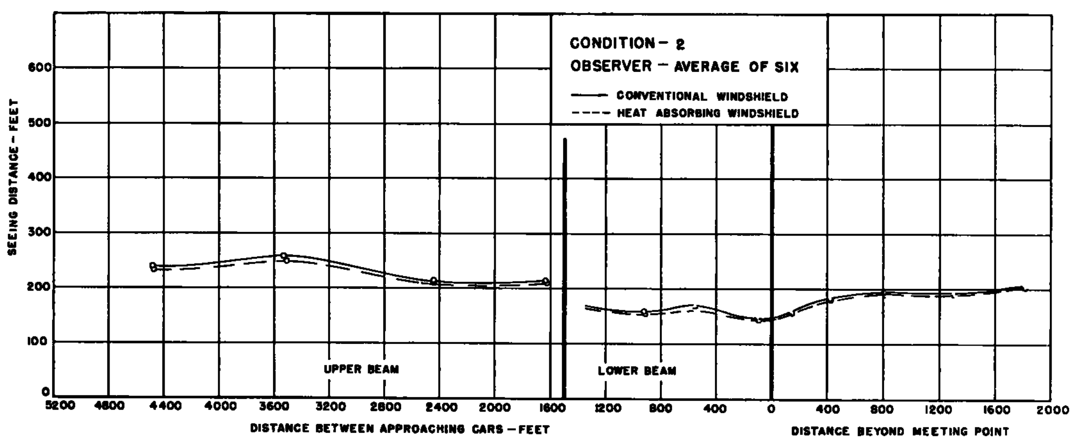

Figure 3.

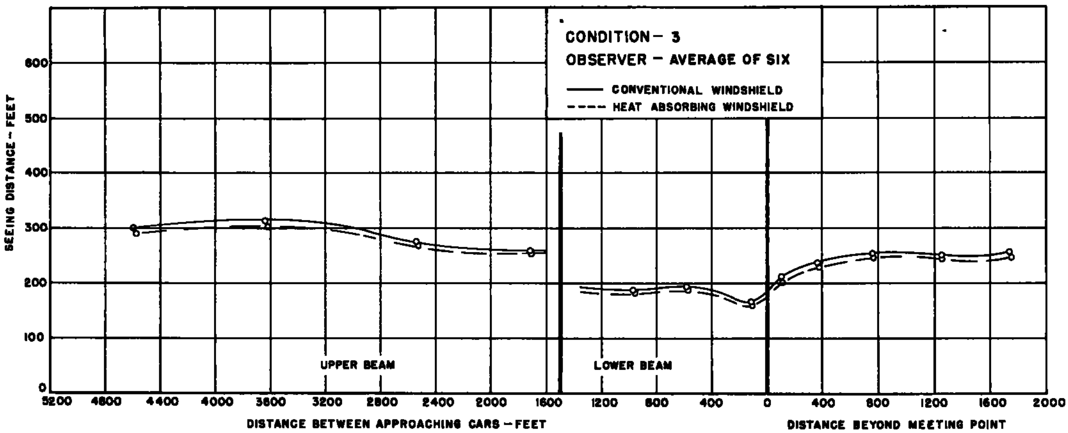

Figure 4.

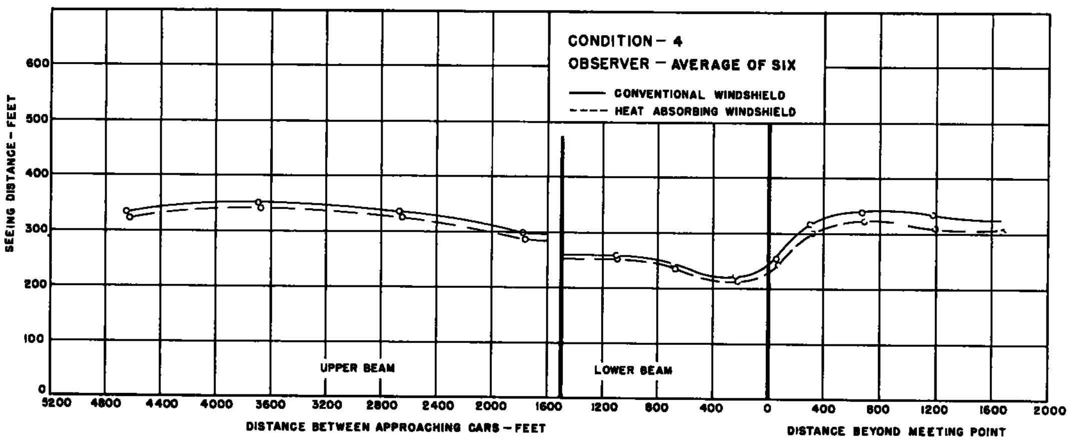

Figure 5.

time during the course of a test was less than 1 percent and changes in individual observers varied in a random manner.

The tests were started as soon as the sky turned dark and continued until about 4 AM with only one "coffee break." This meant that the observers experienced a great deal of fatigue by the end of the tests. This was done purposely in order to introduce this added difficulty into the seeing task of the observers.

SUMMARY OF RESULTS

Summaries of the test results are shown in Figures 2, 3, 4, and 5 and in Table 3. In these curves the seeing distance in feet is plotted against: (1) distance between approaching cars before they pass (left of zero on the curves) and (2) distance beyond meeting point after they pass (right of zero on curves). Each point on these curves represents the average data taken by six observers in 30 runs, that is, the average of 180 individual observations of seeing distance. The solid line represents observations through conventional windshields, the dotted line, through heat-absorbing windshields.

TABLE 3

SUMMARY

Condition	Seeing Distance ft. Conventional	Seeing Distance ft. Heat Absorbing	Difference ft.	Difference %
	Average of All Observers and Targets			
1	346	340	6	2
2	195	191	4	2
3	242	235	7	3
4	303	290	13	4
				Average 3%

Inspection of Figure 2 shows that the

first points at the left represent a seeing distance of approximately 430 feet. The two cars then were almost a mile apart and thus the effect of opposing headlights was negligible. As the two cars approached, and the glare from opposing headlights increased, seeing distance began to drop off. There was a sudden change in seeing distance when the two cars were 1500 feet apart. This was due to depressing the headlight beams at a greater than normal distance and thus suddenly decreasing the illumination on the targets. The effect of opposing headlights caused seeing distance to decrease as the cars approached each other, reaching a minimum of about 230 feet just before they passed. It then rose to about 360 feet and the curves leveled off.

The important thing to observe in Figure 2 is the very small difference between seeing distance through conventional and heat-absorbing windshields. The seeing distance averaged over all targets and observers on this test course changed from 346 to 340 feet — a change of only 6 feet in 346 or 2 percent. It is interesting to note that where the seeing distance is the least the two curves are very close together. The maximum spread between the two curves is at the right hand end where the difference is about 4 percent.

These results in Figure 2 are in very close agreement with the earlier tests performed at Orlando which showed 3 percent difference in seeing distance with targets having the same reflectance. There is certainly no indication that the change in contrast, brought about in the present tests by using a black-top road instead of white concrete, appreciably affected the difference in seeing distance through the two types of windshields.

Figure 3 shows the average curves for the second set of conditions in which blacker targets were used. It will be noted that decreasing the reflectance of the targets from 7 to 3 percent reduced the seeing distance through both windshields very considerably from Figure 2. The first target was first seen at about 240 feet instead of 420. Although the curves in Figure 3 are flatter than in Figure 2, there was a definite decrease in seeing distance as the cars approached each other. Minimum seeing distance was about 150 feet. It is most important to observe, however, that the curves for conventional and heat-absorbing windshields still lie very close together. The average difference between the two windshields under Condition 2 was 4 feet in about 200 or 2 percent as shown in the Summary Table 3. This result is especially significant because the seeing task imposed upon the observers while taking the data in Figure 3 was far worse than would be experienced in ordinary night driving. The targets were very dark and the contrast so small that without benefit of headlights on these dark nights a target could not be seen by an observer walking down the road until he was within a few feet of it.

The comparison of Figures 2 and 3 shows principally the effects of reducing the contrast between target and background. The change in headlamps between these sets of runs had little effect on the illumination. Table 4 shows that at 200 feet the illumination changed from 1. 55 to 1. 3 ft. candles or 16 percent. The average change was probably less. This and other details of Table 4 will be discussed under the heading Photometric Measurements. Although headlight illumination underwent little change, the brightness of the targets themselves was markedly reduced by substituting 3 percent for 7 percent reflectance paint. Thus it was principally the contrast between target and background that was reduced.

Conditions 3 and 4, listed in Table 1 were designed to determine the effect of reducing illumination from the observer's headlights and increasing glare from opposing headlights, while holding the contrast essentially constant at the same low value maintained for Condition 2. It was decided to make this change in headlight illumination realistic by holding it within a range that might be expected with modern headlights. Changes in voltage and aim are considered as large as could reasonably be expected in service.

It is clear from Table 1 that a difference in glare between Conditions 3 and 4 was achieved by establishing different headlight conditions for the two approaching cars. Observers in both cars took data, in one car under Condition 3, and in the other under Condition 4. On the next night the observers and conditions were interchanged and the remainder of the data taken.

Figure 4 shows the results obtained under Condition 3 of Table 1. It was anticipated

TABLE 4

PHOTOMETRIC MEASUREMENTS

(Made through windshields from driver's eye position at 200 feet from target)

Condition	Target Reflectance percent	Beam	Brightness (ft. - lamberts) Target	Background Left	Background Right	Pavement	Shoulder	Illumination (ft candles)
(New Headlamps)								
Heat-absorbing	7	High	.103	.006	.020	078	013	1 55
Conventional	7	High	.073	.009	.016			
Average			.090	.008	.018			
				C = 10	C = 4	C = 0.1	C = 6	
(Used Headlamps)								
Heat-absorbing	3	High	032	.017	.028			1.3
Conventional	3	High	.038	.024	.038			
Average			.035	.021	.033			
				C = 0 7	C = 03			
(New Headlamps)								
Heat-absorbing	7	Low	.014					
Conventional	7	Low	.010		.007			
Average			.012		.007			
					C = 0.7			

$$C = \text{contrast} = \frac{\text{target brightness} - \text{background brightness}}{\text{background brightness}}$$

that the shortest seeing distance would be obtained under this condition. Actually the seeing distance was greater than under Condition 2 as shown in Table 3. The reason is not known but it should be pointed out that the tests under Conditions 3 and 4 were made a month later than those under 1 and 2. This lapse of time was required to obtain similar moonless nights. In any case, the comparison of the first two conditions with the second two is not important. It is intended rather to compare data taken under Conditions 3 and 4, summarized respectively in Figures 4 and 5.

Figure 4 shows the average results of observations made in the car with reduced headlamp voltage and with lamps aimed low. The average difference between the two curves is 7 feet in 242 or about 3 percent.

The data in Figure 5 were taken from the car having somewhat greater headlight illumination. Average seeing distance was about 60 feet, or 25 percent greater in this car than in the opposing car represented by Figure 4. The important fact is that the reduction in seeing distance with heat absorbing, as compared with conventional windshields is comparable under Conditions 3 and 4 as shown in Table 3.

It should be pointed out that it is unnecessary to run seeing distance tests with further reductions in illumination such as might be obtained with poor or obsolete headlamps. This is because all cars which manufacturers equipped with windshields of heat-absorbing glass also were equipped with sealed-beam headlamps which provide good highway illumination and little change in beam candle power output during their service life.

EXAMINATION OF DATA FROM DIFFERENT OBSERVERS

The curves in Figures 2 to 5 represent the data for four conditions averaged over six observers and thus summarize the results. The examination of the corresponding curves for each observer is also of interest. These curves are shown in Figures 6 to 29 assembled at the end of this paper. A comparison of data from different observers operating under one condition may be made with curves on a single page. Comparison of results from a given observer under different conditions may be made by comparing curves opposing each other on facing pages.

Visual comparisons by the authors have led to the following observations:

1. The seeing distance under a given set of conditions varies with the vision of the driver: drivers 1 and 4 with 20/20 vision uncorrected see the targets at the greatest distances; observers 2 and 5 with corrected vision, at lower distances; observers 3 and 6 with poorer vision, at slightly lower distances than observers 2 and 5 in some cases, and nearly the same in others. It should be pointed out that another variable besides vision enters this comparison, namely, observer position in the car. The data

do not allow separation of effects of vision and position because observers occupied the same positions throughout the tests.

2. Reducing target-to-background contrast (Condition 1 to 2) reduces the seeing distance by comparable amounts for all observers.

3. The changes in going from Conditions 3 to 4 which increased illumination from the observers headlights and decreased glare from the opposing headlights results in some increase in seeing distance for all observers, but the increase appears to be greater with observers 1 to 3 than with observers 4 to 6.

4. The difference in seeing distance between conventional and heat-absorbing windshields does not appear, from visual inspection, to be markedly or consistently affected either in direction or magnitude by changes in conditions or observers.

A. The seeing distance with heat-absorbing windshields is slightly less than with conventional in all Figures 6 to 29 with the single exception of Figure 9 where the seeing distance with heat-absorbing windshields is slightly greater over most of the test course. Occasional crossovers in other curves are probably a result of random variations which appear in the mean values even though each point in these figures represents the mean of 30 observations. (See the later discussion of Table 5.)

B. The magnitude of the difference varies from one pair of curves to another but not in a manner which appears from visual inspection to be related consistently to experimental conditions or observers.

TABLE 5

SAMPLE OF ORIGINAL DATA

Target 1, Condition 1, Observer 1

Observed Seeing Distance (ft.)		Ave. in sets of 6 (ft.)		
Conventional Windshield	Heat Absorbing Windshield	Con	H A.	Difference
454	544			
530	495			
540	535			
502	500			
530	495			
525	520	514	515	-1
562	450			
557	480			
479	480			
509	478			
517	480			
524	508	525	479	+46
450	541			
510	542			
472	447			
426	422			
562	394			
496	480	486	471	+15
513	516			
434	537			
458	450			
501	486			
409	521			
512	497	471	501	-30
501	523			
423	490			
535	516			
535	544			
478	460			
565	515	506	508	-2
Average 500	495			
Std. dev. 44 ft.	37 ft.			
Difference 5 ± 11 ft.				

EXAMPLE

Std. dev of individual readings =

$$\sqrt{\frac{\Sigma(454-500)^2 + (530-500)^2 + \text{-------} + (565-500)^2}{(30-1)}}$$

$$\text{Std}^{a} \text{ error of mean difference} = \sqrt{\frac{44^2}{30} + \frac{37^2}{30}} = 11 \text{ ft.}$$

[a] See for example "Applied Mathematics in Chemical Engineering" Sherwood and Reed.

5. It is very difficult by visual examination to draw definite conclusions about the effect of glare on the difference between seeing distance with the two windshields. In some cases the curves are closest together near the minimum points where glare is greatest but visual inspection does not establish this as a general effect.

STATISTICAL EXAMINATION OF THE DATA

It is well to point out again that each of the plotted points in Figures 2, 3, 4 and 5 represents an average of 180 individual observations of seeing distance. Each of these figures then represents the result of 4,320 observations. It is only by making a very large number of observations that curves can be obtained showing so little scattering of points. The importance of having a large number of observations and the statistical significance of these data will now be discussed briefly.

Individual observations of seeing distance made by one observer, under one set of conditions, on one target, show large random variations from one run to another. In some cases this variation may be as great as 2 to 1. In order to examine the nature of these variations more closely, Table 5 presents two columns of 30 readings each, taken by observer 1, on target 1, under Condition 1. The first column presents 30

TABLE 6

AVERAGE SEEING DISTANCE DATA FROM ALL TESTS

D = Average of 30 observations of seeing distance through conventional windshield.
Δ = Difference of average seeing distance (conventional - heat abosrbing).
[a] Difference is minus.
Where no value is entered difference is zero.
σ = Average standard deviation of individual readings (60°).

		Observer																	
		1			2			3			4			5			6		
Target	Condition	D	Δ	σ	D	Δ	σ	D	Δ	σ	D	Δ	σ	D	Δ	σ	D	Δ	σ
1	1	500	5	41	374	8	55	343	16	40	494	16[a]	43	450	9[a]	38	405	10	40
1	2	299	1	44	211	4[a]	43	221	4	34	263	11	31	217	10	38	222	6	48
1	3	342	19	42	262	19	34	273	13	28	348	11	41	289	16	44	289	5[a]	36
1	4	413	8	47	301	31	38	313	18	36	359	14	38	314	14	30	314	3	28
2	1	507	7	24	395	16	42	355	4	42	506	8[a]	43	463	1[a]	28	420	6	30
2	2	301	5[a]	39	244	11	38	235	6	30	267	3	46	255	15	42	245	12	43
2	3	342	17	35	281	25	36	267	7	32	356	6[a]	44	312	3	25	319	1	33
2	4	430	4[a]	29	323	21	46	334	9	33	362	30	33	321	15	28	331	1[a]	26
3	1	499		21	398	11	55	326	2[a]	27	484	3[a]	32	434	13	40	399	6[a]	44
3	2	260	4	36	196	13	37	198	6[a]	41	215	2	30	194	2	30	207	1	30
3	3	305	7	44	268	21	50	255	16	39	312	3	25	255	5[a]	39	272	5	31
3	4	428	8	49	318	17	58	301	10	28	343	10	34	313	10	36	310	11	35
4	1	404	5[a]	32	325	6	28	301	14	26	405	10[a]	30	384	9	29	360		32
4	2	260	3[a]	37	188	1	31	187	1[a]	39	228	11	30	206	11	31	196	3	36
4	3	275	17	25	231	6	23	229	15	19	304	4	22	254		24	265	3[a]	17
4	4	348		32	273	2	27	277	15	24	328	20	22	286	15	32	289	4	25
5	1	333	4	43	272	10[a]	56	245	3	34	283	11[a]	34	303	16	36	294	12	24
5	2	185	7	32	153	5[a]	31	142	2[a]	27	162	6	35	155	6	21	163	4	25
5	3	206	9	19	206	10	29	168	1	24	197	7	21	188	3	23	191	7[a]	30
5	4	290	3	27	261	4[a]	33	238	2	22	261	16	21	274	16	26	265	12	27
6	1	255	2	22	226	5	27	189	1	17	233	10[a]	23	241	1[a]	18	238	11[a]	23
6	2	182	11	37	166	9	32	143	6	30	168	11	41	177	12	35	181	4	37
6	3	217	18	26	210	16	22	174	4	22	187	6	32	199	3[a]	28	192	5[a]	26
6	4	266	18	27	252	4	24	238	28	20	298	13	17	248	4[a]	25	255	10	18
7	1	253	3	30	225	6	24	213	5	19	222	2	38	268	12	21	259	7	21
7	2	149	1	28	146	2[a]	25	137	6	28	141	3	30	150	5	26	163	6	23
7	3	166	10	19	175	7	19	153	8	17	148	4	21	172	3[a]	17	172		19
7	4	252	17	40	229	6	26	195	5	27	191	1	38	242	21	19	244	24	23
8	1	281	1	19	270	4	25	252	13	28	264	7[a]	36	298	9	23	302	2	26
8	2	178	4[a]	30	161	3	27	154	3	27	161	8	27	158	4	23	174	3	24
8	3	220	15	17	212	12	16	182	4	16	195	1[a]	22	211	1[a]	17	223	14	14
8	4	275	18	25	254	1[a]	28	239	18	15	255	9	23	284	7	16	286	13	21
9	1	385	7	24	359	33	36	322	25	36	324	6[a]	44	385	17	33	376	23	35
9	2	198	2[a]	32	179	3	30	168	4[a]	28	181	8	26	183	2	22	192	10	28
9	3	252	8	19	245	19	22	204	16	21	217	1	21	250	8	19	236	7	20
9	4	335	15	26	301	15	28	284	27	28	313	16	23	321	1[a]	26	324	17	23
10	1	417	3	26	371	23	32	314	22	41	352	16	50	392	11	34	378	2	35
10	2	213	4	32	187	2	31	176	1	32	198	13	27	200	2	27	201	5	29
10	3	272	8	21	253	18	17	224	18	20	247	4	23	268	4[a]	17	259	10	11
10	4	384	17	55	341	14	51	312	26	51	315	10	28	340	11	32	326	16	30
11	1	449	25	43	366	12	42	292	15	24	343	8	40	391	22	43	358	2	29
11	2	210	6	32	181	1[a]	29	168	8[a]	31	198	5	24	200	2	25	205	12	27
11	3	280	11	20	260	15	36	221	14	22	243		28	267	3	21	249	2	24
11	4	375	11	57	332	24	41	294	15	44	318	20	26	345	23	29	325	17	34
12	1	409	8	37	359	18	36	281	16	27	358	17	36	381	9	24	352	9[a]	34
12	2	222	2	29	196	7	30	180	1[a]	28	208	5	32	210	1	25	212	4	28
12	3	271	2	22	268	11	19	234	15	19	257	17	19	261	10	18	265	16	14
12	4	360	14	49	349	20	42	286	10	39	311	11	35	326	19	25	323	22	32

observations through a heat-absorbing windshield. A standard deviation for each column has been obtained as shown in the table to express the random errors in the individual readings. Assuming normal distribution, the standard deviation means, for example, that there is a 68 percent probability that another reading taken under the same conditions as the data in Column 1 will lie within the range 500 ± 44 ft.

The difference in average seeing distance as deduced from these 60 readings is 5 feet and the standard error of this difference is 11 feet. From this we can say that there are 68 chances out of 100 that the correct value of the difference lies within the band 5 ± 11 ft., or between -6 and +16 feet (this statement assumes that all errors are entirely random). It is noteworthy that even with 30 readings through each windshield on this one target, there is still uncertainty as to whether the seeing distance is greater with conventional or-heat absorbing glass.

The necessity of taking such a large number of readings is further illustrated by the figures on the right side of Table 5. It will be recalled that the readings were taken in sets of six alternately with the two windshields. In Table 5 each set of six has been averaged for the two windshields and the differences obtained. A comparison of the five values of difference, each obtained with a set of six readings, is most interesting. It will be noted that the difference varies from +46 to -30 feet. Thus, had only six readings been taken, one might have drawn the conclusion that the seeing distance was 46 feet greater or 30 feet less with the conventional than with the heat-absorbing windshield, depending upon which set of data one happened to take.

It is thus apparent that accurate conclusions with regard to the seeing distance through these two types of windshields can not be drawn from a small number of observations. Even 30 observations through each windshield are not enough to answer the question, "Which windshield gives the greater seeing distance?" It is for this reason that twelve targets and six observers were used, thus multiplying the data shown in the left of Table 5 by 72 for each condition.

Stated another way, the difference we are trying to measure is so small that it is completely submerged by random variations even when every effort is made to hold test conditions constant.

Table 6 presents the data from all of these tests. This is a direct print-out from the I. B. M. machine. An effort has been made to reduce the table to the smallest number of entries which can be made and still provide all of the data necessary to carry on statistical studies of the results. Entries are arranged according to target number, condition and observer. For example, the three entries in the upper left hand corner 500, 5 and 41 summarize the data in the first two columns of Table 5. The seeing distance through the conventional windshield, 500 feet, and the difference, 5 feet, allow the seeing distance through the heat-absorbing windshield to be derived.

The third number 41 feet, in the illustrative set is an average standard deviation. This is caluclated from two standard deviations, one for the conventional and one for the heat-absorbing windshield to give an average standard deviation for the 60 readings as follows:

$$\sqrt{\frac{44^2 + 37^2}{2}} = 41.$$

Inasmuch as the standard deviations in observations on a given target, under a given condition, by a given observer, have nearly the same values for the two windshields, it is felt that average standard deviations calculated in this way for the 60 readings may be used with either set of 30 readings without altering the significance of statistical studies.

The standard error of the difference may be calculated from this average value of standard deviation as follows:

$$41\sqrt{\frac{2}{30}} = 11$$

There are some other very interesting questions that can be answered by these data. To answer these questions the data have been studied by a statistical procedure known as the analysis of variance. This procedure is valuable because it separates the effects of experimental variables in such a way that their significance can be tested independently of each other. The details of this study will not be included herein but some of the results may be summarized by the following statements:

1. The two values 6 feet and 4 feet in Table 3, representing difference in seeing distance with different target contrast, are significantly different. To be more specific it can be stated that if these average values of difference were redetermined under identical conditions and with the same number of tests there is less than one chance in a thousand that the difference, in feet, for Condition 2 would be larger than for Condition 1.

2. The two values 7 feet and 13 feet in Table 3, representing difference in seeing distance with different illumination and glare, are significantly different. If these average values of difference were redetermined under identical conditions and with the

same number of tests there is less than one chance in a thousand that the difference in feet for Condition 3 would be larger than for Condition 4.

3. The average values of difference in seeing distance between conventional and heat-absorbing windshields vary significantly and systematically with target position. The differences decrease as the cars approach, reach a minimum just after changing from upper to lower beams, and then increase.

4. In trying to study the difference between observers, no way has been found with the present data of separating the variables such as, eyesight, eye glasses, position in car, and car occupied.

THE SIGNIFICANCE OF THRESHOLD VALUES

In discussions of the possible consequences of a small difference in seeing distance with different windshields, one important point is frequently not fully recognized. The point to be emphasized is that the "seeing distances" which have been determined in these tests and which are plotted in curves 2 to 29 represent threshold values. While the term "seeing distance" commonly has been applied, a more descriptive term would be the "threshold seeing distance." The meaning of these threshold values must be clearly understood for any discussion of the importance of the results described in this paper.

In order to explain the significance of these thresholds let us set up a hypothetical case in which two cars are driving side by side down a highway at 40 mph. One is equipped with a conventional windshield, the other with a heat-absorbing windshield. Let us suppose that an obstacle is on the highway and, although it is not yet visible to either driver, that both drivers are looking toward it as they approach the threshold seeing distance. Next, assume that the driver looking through the conventional windshield first sees the obstacle at a distance of 200 feet. If the difference in seeing distance between the two windshields is 3 percent the driver of the car with the heat-absorbing windshield will then first see the obstacle at a distance of 194 feet. This 6 foot difference at this speed is traveled in only $\frac{1}{10}$ of a second. It is only during this tenth of a second that the driver with the conventional windshield has an advantage. It is most important to understand that this difference in the ability to detect the obstacle through the two windshields exists only during this 6 feet or $\frac{1}{10}$ second between the threshold of 200 feet through one windshield and 194 feet through the other, because at distances greater than 200 feet neither driver sees the obstacle, and at all distances less than 194 feet both drivers see the obstacle.

It was assumed in the hypothetical case just described that both drivers happened to be looking in the direction of the obstacle at the exact time the two cars reached threshold seeing distances. But under ordinary conditions the drivers might not be looking in the direction of the obstacle at that particular instant, or the obstacle might be obscured by a rise or curve in the road, or the obstacle might actually enter the road after the two drivers passed their threshold seeing distances. Then the situation would be different than described in the previous paragraph. Let us suppose, for example, that the two drivers both happened to look toward the obstacle when they were 190 feet from it. Neither driver would then have an advantage because they would both see the object at the same time. Thus, it must be remembered in appraising the importance of these test results in terms of driving safety that any loss in the distance at which objects are first detected can occur only at this "threshold seeing distance." After passing this threshold the distance at which the object is seen is identical regardless of whether the car has a conventional or heat-absorbing windshield and is, obviously, the distance between the car and the obstacle.

Therefore, the authors believe that the effect on driving safety of the 3 percent difference observed in these tests is truly insignificant.

PHOTOMETRIC MEASUREMENTS

Two types of photometric measurements were made in connection with this series of tests. First, all the headlamps were photometered and their beam patterns determined according to standard SAE procedures and it was found that they were within specifications. An integrated measurement made by photometering an integrating screen in front of the lamps showed that the used headlamps of Condition 2 gave about 5 percent less illumination than the new lamps of Condition 1. However, since the patterns were different for the two types of headlamps such a simple comparison is not too significant and the actual reduction in illumination on any given target in these tests might have been more or less than 5 percent.

The second group of photometric measurements were made at the test course on the nights of the tests. These measurements leave much to be desired in both accuracy and completeness. It was found impractical with available instruments and methods to measure the lower values of brightness of targets and backgrounds such as those encountered with lower beams at distances greater than about 100 feet. Also the time available between the end of the driving tests and dawn was not sufficient to carry out extensive photometric measurements.

Some photometric measurements are shown in Table 4 to illustrate the order of magnitude of brightness and contrast conditions used in these tests. The data at 200 feet are presented because this distance lies within the range of observed seeing distances with both upper and lower beams, and because it is short enough so that fairly consistent data could be obtained. Measurements of brightness in this table were made with a Luckiesh-Taylor brightness meter through the windshields of the test cars while holding the instrument at approximately the eye position of the driver. The object was to duplicate the seeing conditions of the driving tests. Values of brightness in the table are averages of three readings in most cases. Values of illumination were obtained using a standard white target viewed at close range. There were no approaching headlights when the measurements in Table 4 were being made.

Readings were taken through both the heat-absorbing and conventional windshields as shown in the table. The random variations in readings were large enough that the differences between measurements made through these two windshields are not consistantly different in direction. Thus it appears justifiable to average the readings in order to get more significant data for comparison purposes.

Measurement of background brightness was quite complicated and difficult. In typical laboratory experiments, where threshold visibility is being measured, it is customary to have both the background and target in the same plane. In these road tests, a vertical target was seen against a relatively horizontal background, namely, a portion of the road and/or shoulder at some distance behind the target. Another complication in determining background brightness in these tests arose from the fact that the two headlights set up a shadow pattern on the two sides of the target. This pattern varied with distance between car and target and affected the seeing task in a manner which the authors do not pretend to understand. To give an idea of what is involved, the first row of data in Table 4 shows four values of background brightness. The first two values were measured immediately to the left and right of the target. The observers found that when driving with upper beams the targets first came into view about hand-high on the dummies and when using the lower beams they first came into view about knee-high. Thus the backgrounds to the left and right with upper beams as shown in Table 4 row 1 were measured hand-high. At the left of the target the reading was in the shadow pattern. At the right, the shadow pattern was so narrow that the reading was probably outside the shadow and represented the dirt at some distance behind the target. The other two readings in row 1 represent the pavement brightness at the foot of the dummy, and the brightness of the shoulder of the road just to the right of the foot of the dummy. A number of values of contrast between target and background can thus be obtained and four values have been entered in the table. This indicates the problem which confronts the experimenter who tries to specify the contrast in such road tests.

The brightness of the target under Condition 2 with 3 percent reflection is shown in the second set of data in Table 4. The observed change in target brightness between Conditions 1 and 2 is in line with change in reflectance. It is not known why the background readings to the left and right of the target increased as compared to the first set of data but it probably was due to the shadow pattern being so narrow that it was difficult in taking the readings with the brightness meter to duplicate positions in the

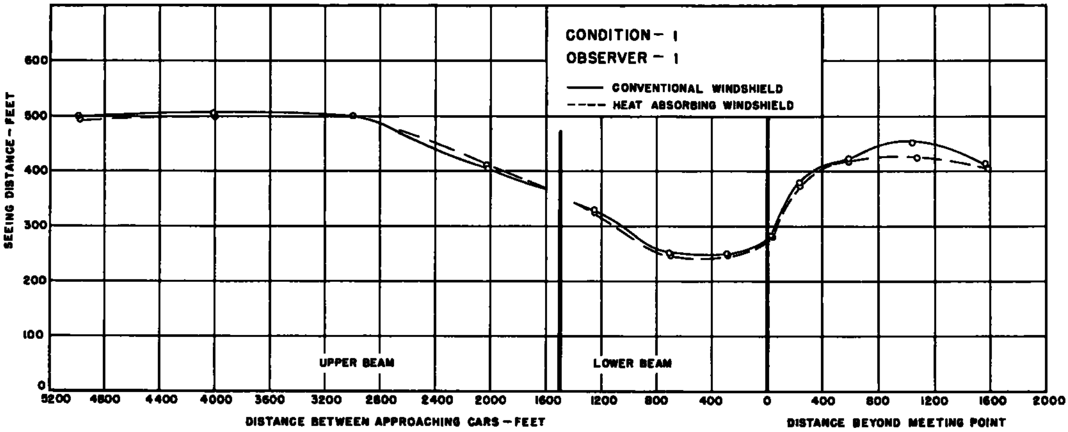

Figure 6.

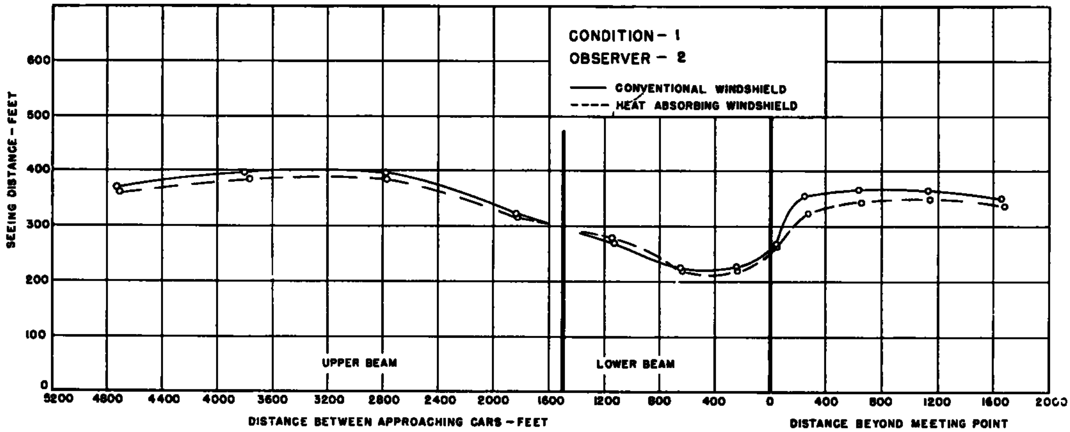

Figure 7.

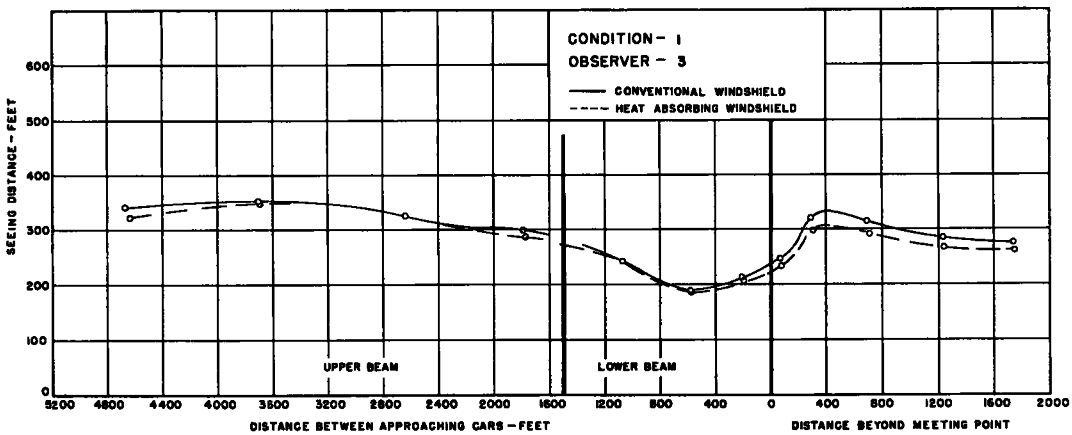

Figure 8.

background from one night to another. Large random variations due to the low brightness levels are also involved.

With the lower beam lighting, (Table 4) consistent readings could only be obtained with the 7 percent reflectance target; 3 percent targets were too dark to read at this

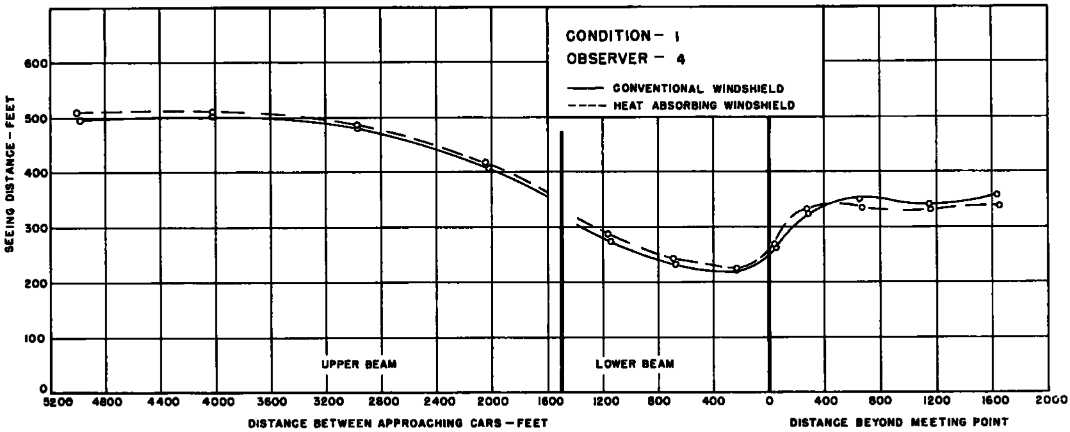

Figure 9.

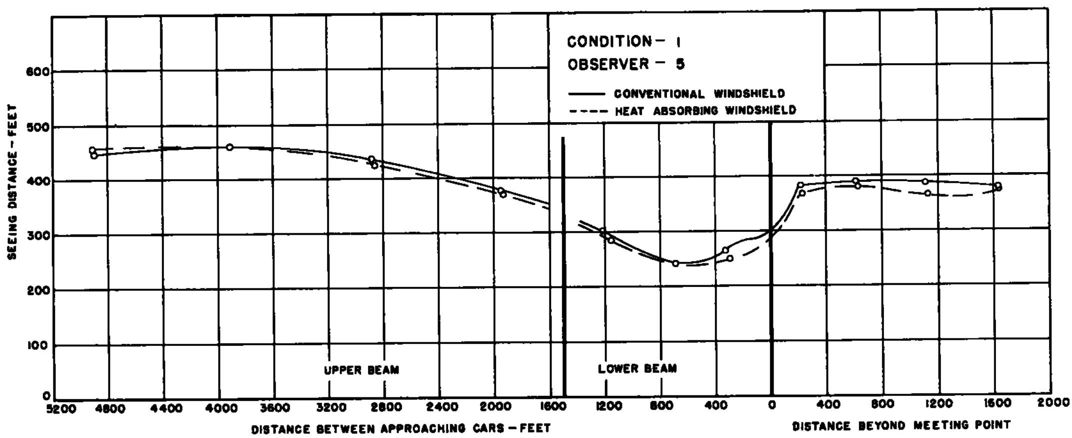

Figure 10.

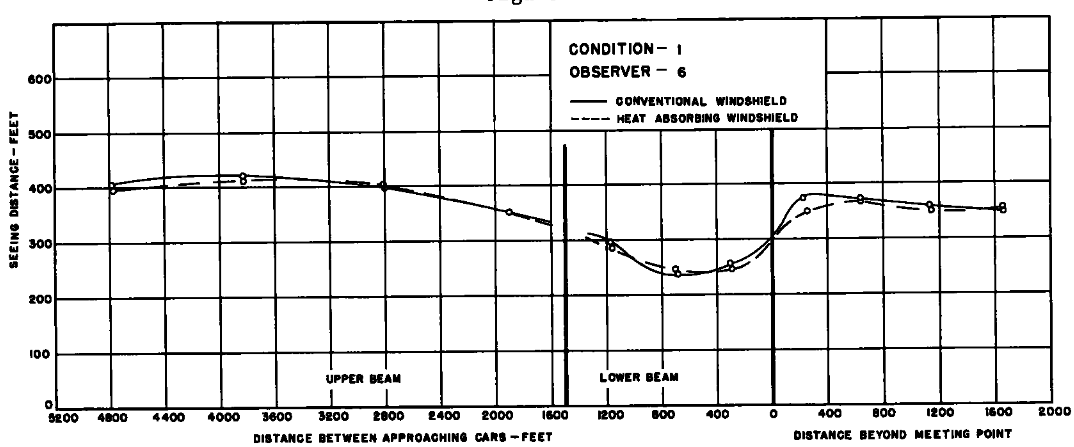

Figure 11.

distance even though they were detected by the observers in our tests. The one reading obtained on the background is too low to represent good accuracy; thus the value of contrast given under this condition is subject to doubt.

The two illumination values included in the table show that the change brought about

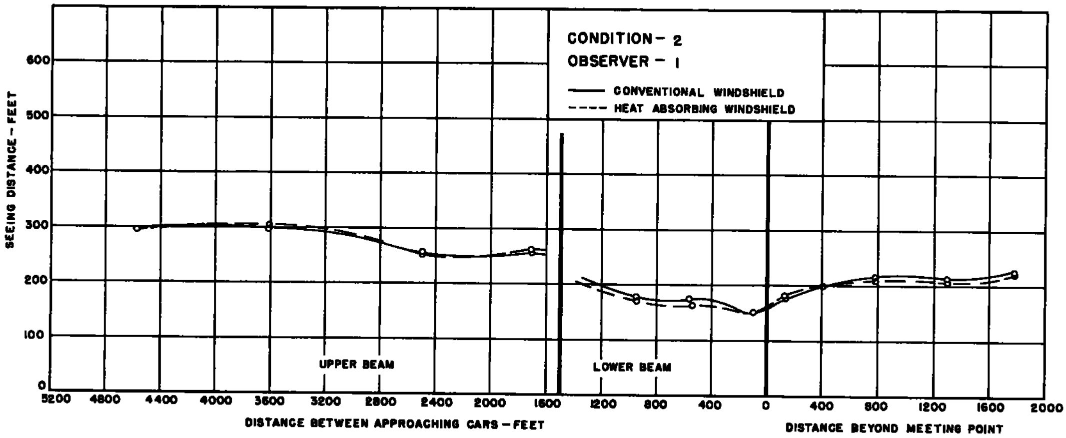

Figure 12.

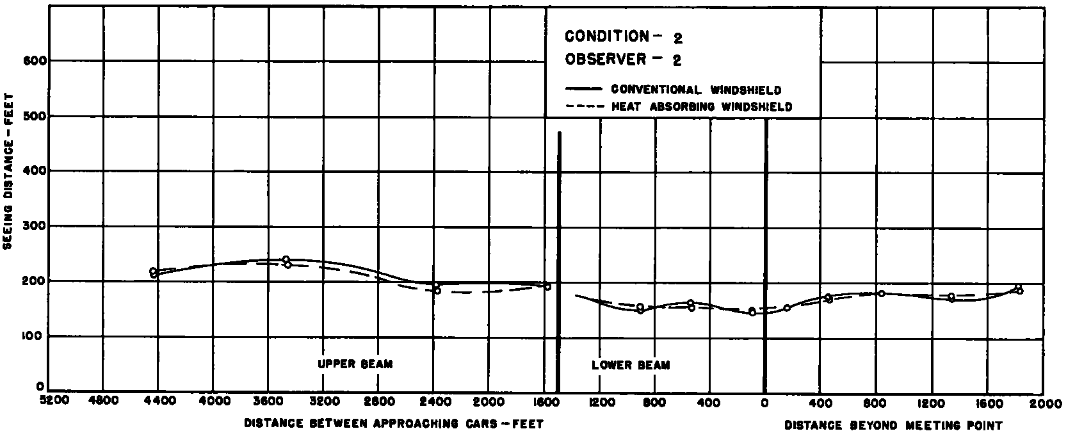

Figure 13.

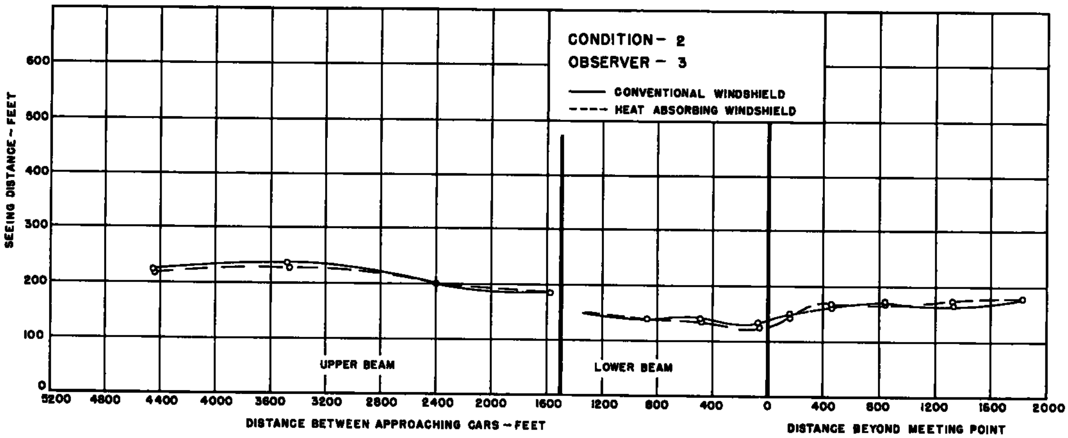

Figure 14.

by going from new headlamps to used headlamps (of a different make) was about 13 percent at this particular distance. This does not agree with the 5 percent difference between new and used lamps obtained by integrating methods, probably due to differences in beam patterns.

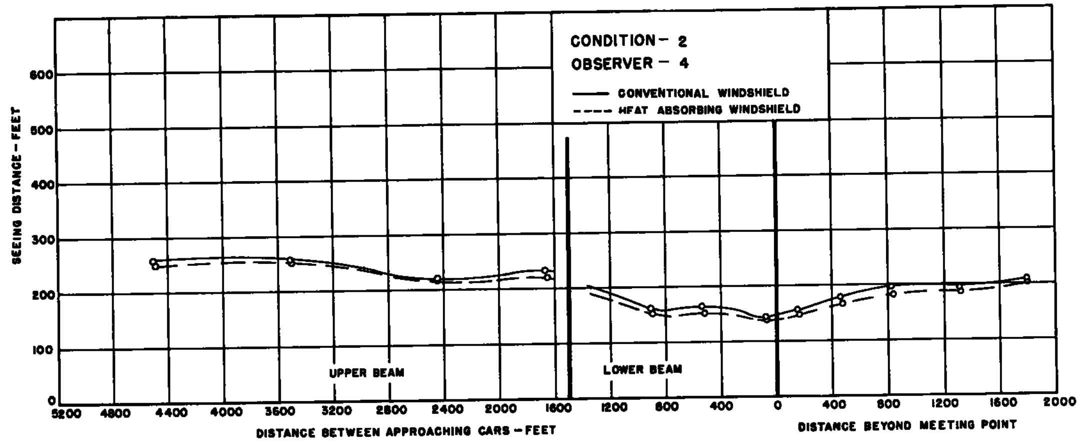

Figure 15.

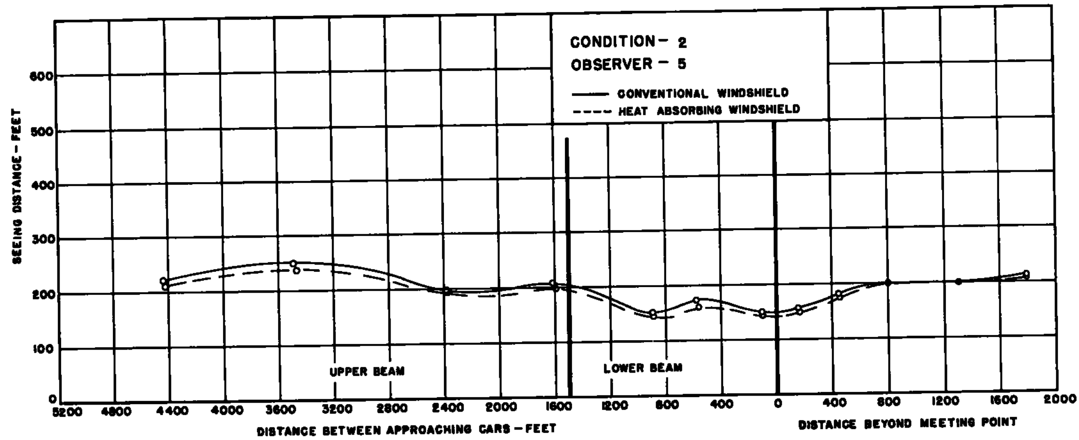

Figure 16.

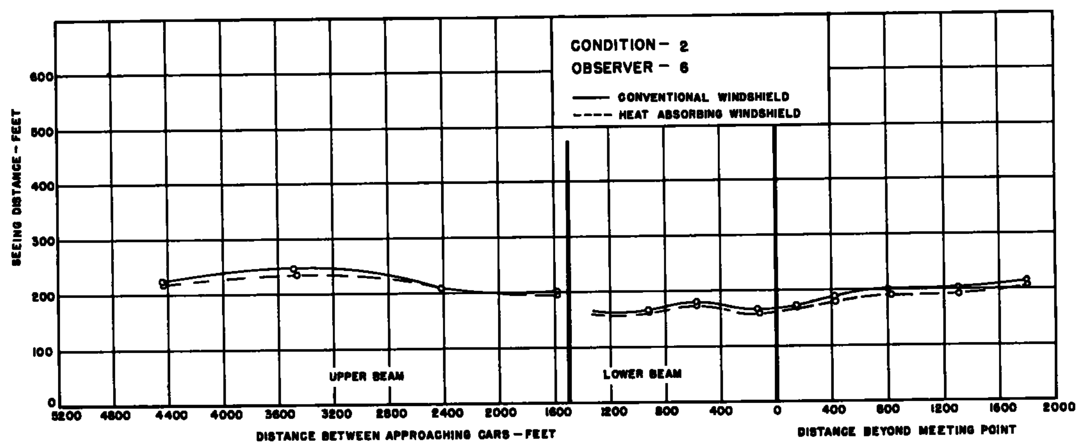

Figure 17.

The data in Table 4 show that brightness and contrast were very low even when the target was only 200 feet from the car. But measured seeing distances under many conditions were considerably greater than this with correspondingly lower target brightness. For example, with upper beams and 7 percent reflectance targets, seeing dis-

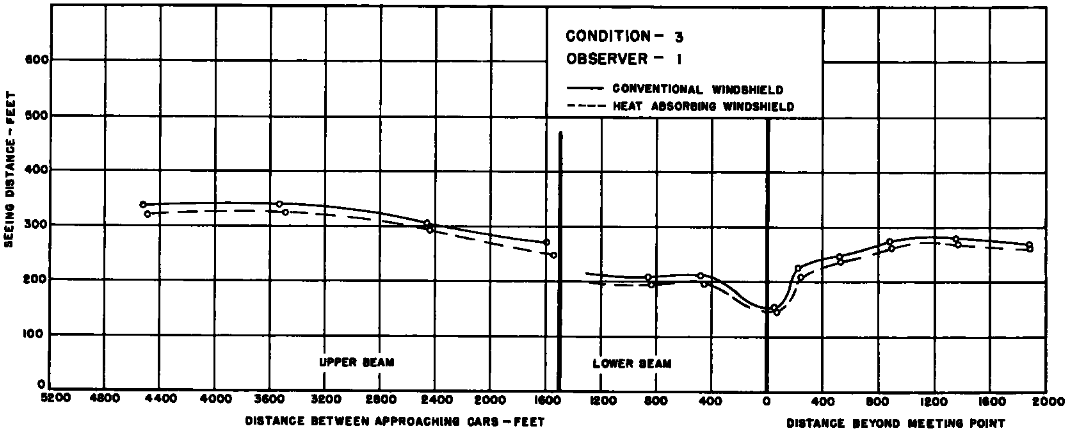

Figure 18.

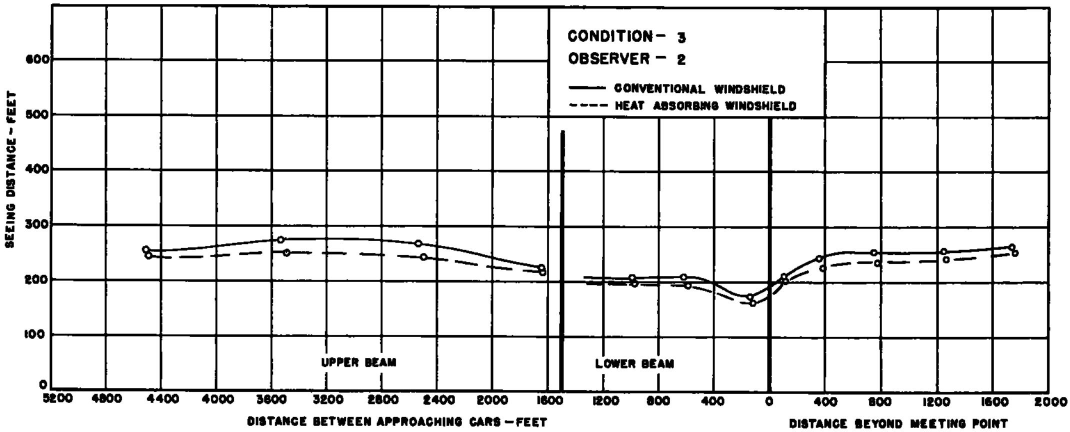

Figure 19.

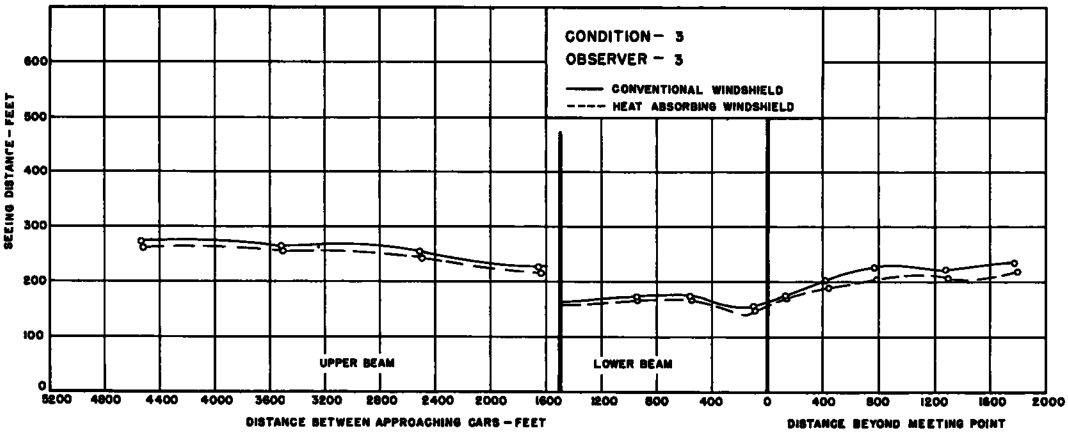

Figure 20.

tances in Figure 2, never dropped as low as 200 feet and averaged 450 feet when there was no glare interference from opposing headlights.

Target brightness at other appropriate distances and target reflectances can be calculated approximately from the data in Table 4. However, the contrast probably cannot

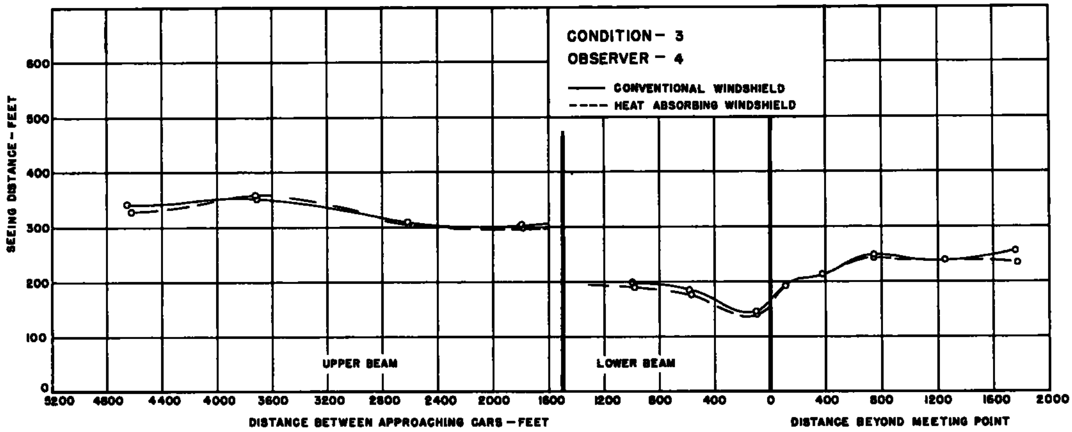

Figure 21.

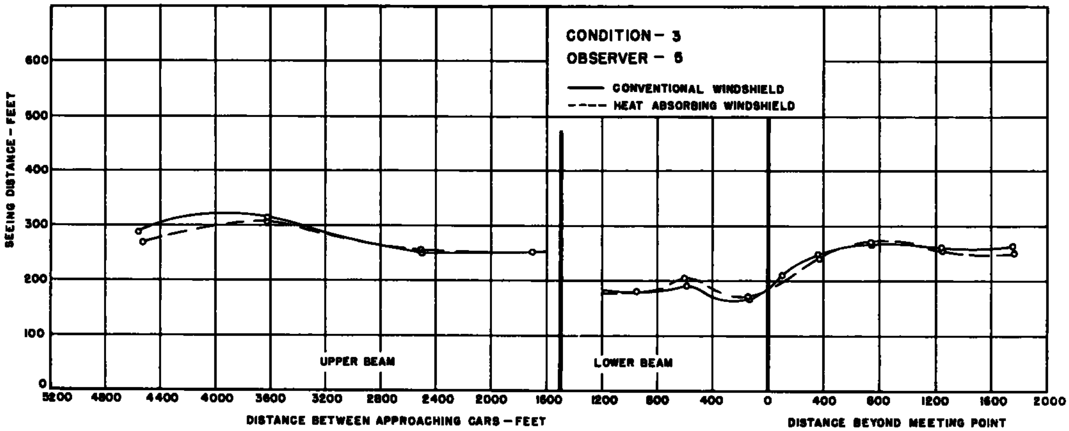

Figure 22.

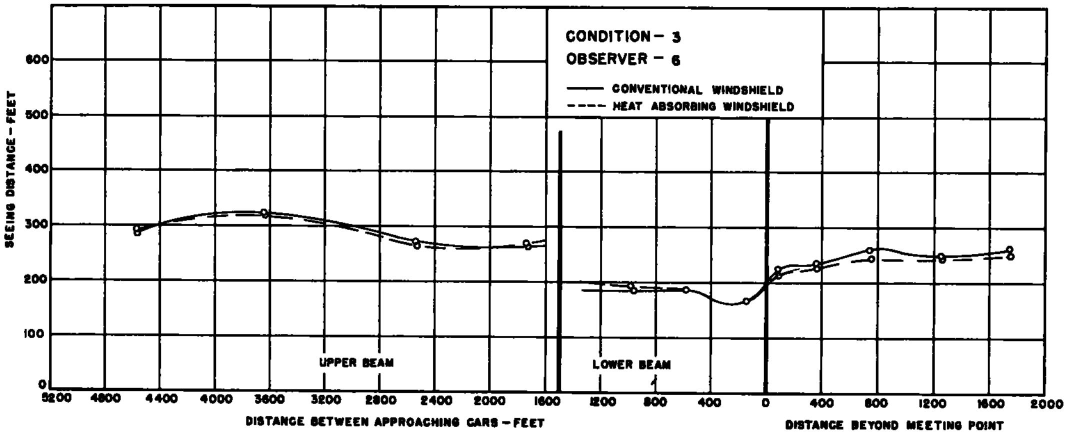

Figure 23.

be so calculated and the data obtained do not permit a very intelligent guess as to what these contrasts were.

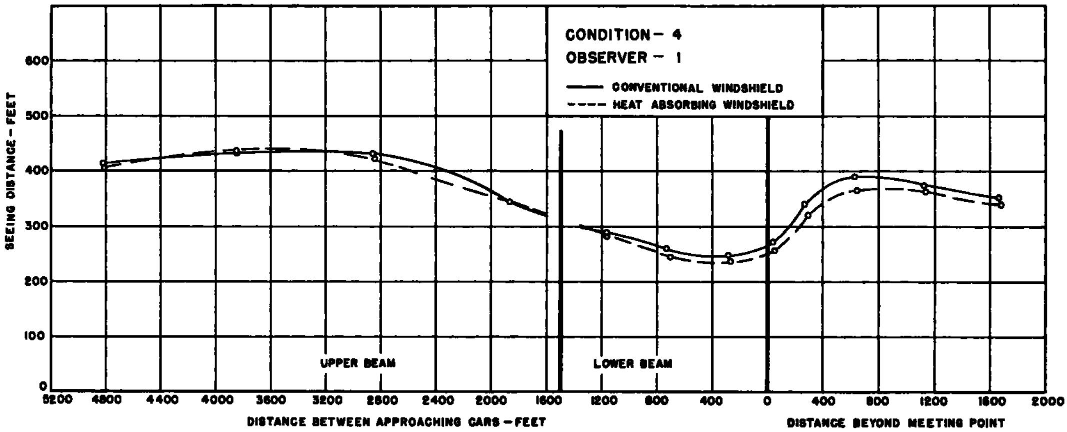

Figure 24.

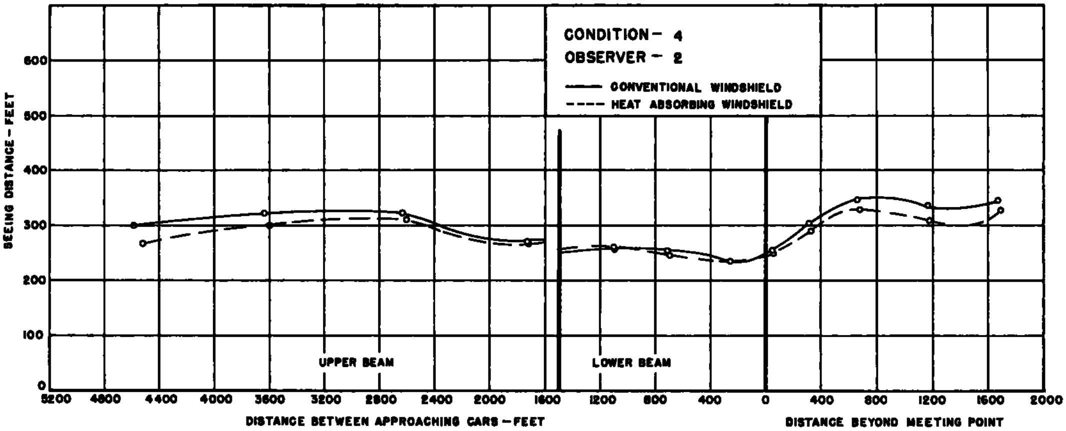

Figure 25.

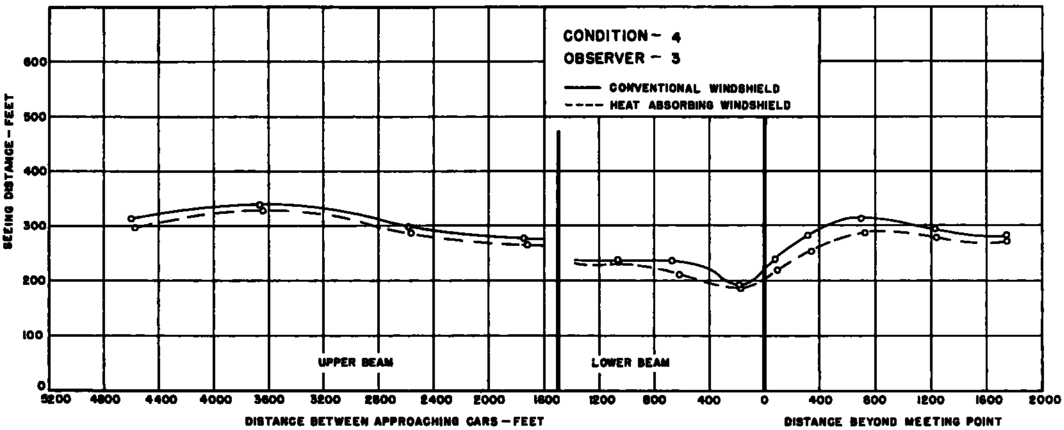

Figure 26.

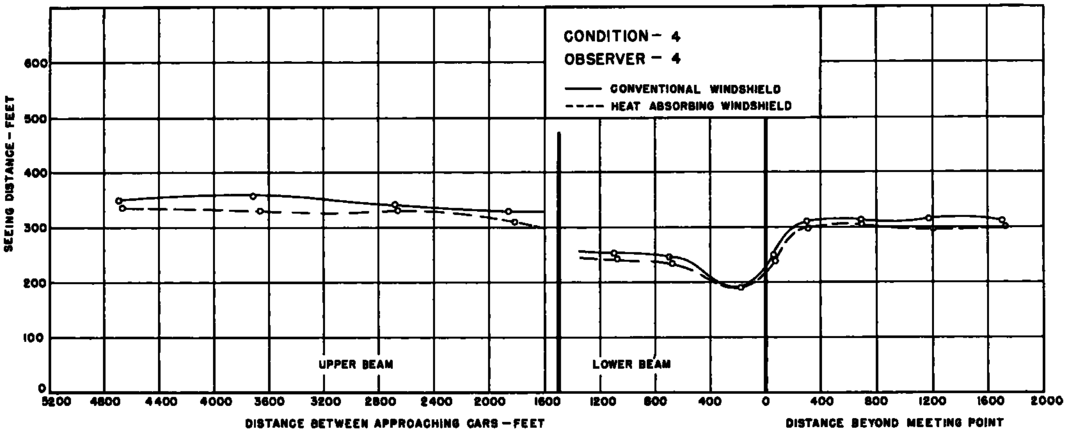

Figure 27.

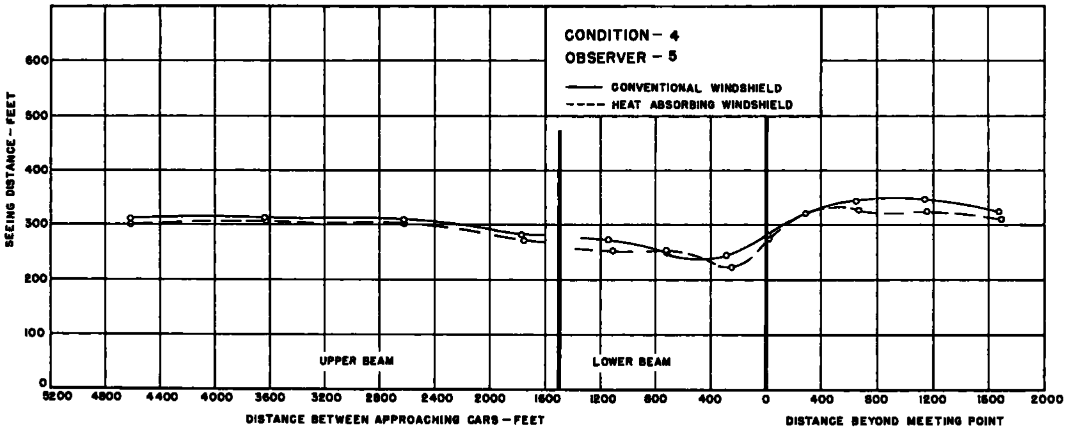

Figure 28.

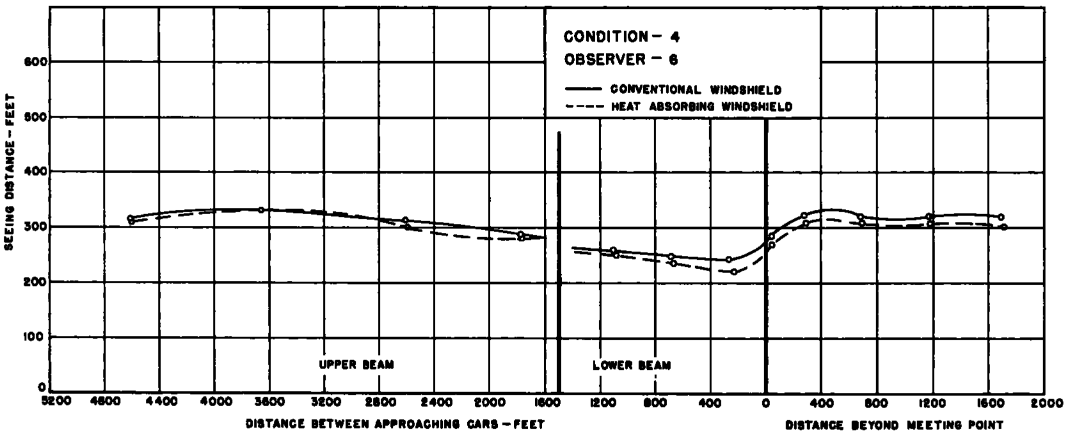

Figure 29.

CONCLUSIONS

1. In road tests of the type described in this paper the random variations between individual observations of seeing distance are exceedingly large. Thus it is necessary to make many observations under each set of test conditions before reliable conclusions can be drawn regarding differences between windshields, or regarding the effect of changing conditions on these differences.
2. More than 17,000 observations have been made in these tests to reduce to a negligible amount the uncertainties due to random variations. Repeating the same tests would not result in significantly different average values.
3. The average reduction in nighttime seeing distance observed in these tests on changing from conventional to heat-absorbing windshields was 3 percent.
4. This is in agreement with earlier road tests described by Roper.
5. The test data show no consistent trend toward any greater reduction in seeing distance even when illumination and target contrast are reduced to make the seeing task very difficult.
6. The data indicate that the reduction in seeing distance with heat-absorbing glass is not affected consistently by good or poor eyesight.
7. For the driver of a moving car, the 3 percent difference exists only at the instant of "threshold seeing" when the object is just coming into view. From then on, the driver can see the object through a heat-absorbing windshield at the same distance as through a conventional windshield.
8. A change in average night driving speed of only 3 percent would completely compensate for the observed change in threshold seeing distance. The authors believe that drivers generally adjust their night driving speeds to values which they consider safe under existing conditions including visibility, and thus on the average they may automatically apply this correction.

Discussion

OSCAR W. RICHARDS, American Optical Company, Research Center, Southbridge, Massachusetts — The fundamental problem in relating the laboratory and road tests is equating the variables, as other basic data for the eye hold for varying conditions. The laboratory work is freely questioned. As the only member of the laboratory group present, some comment seems called for.

The Cooperative Road Test seems planned to produce small differences. The driver had no competition other than the approaching car. The positions of the dummys were fixed. No randomization of observers or targets was done. The seeing distance curves are crowded together on the graphs (a well known statistical technic for minimizing differences). Many experiments were made to average out considerable variation. The usual technics of psychological research for measuring thresholds and visual phenomena were apparently not used.

This experiment seems to me to be essentially a learning experiment, where, despite a great deal of practice there remained a small difference when the clear and tinted windshields were used. It is possible that various clues at each target were part of the recognition. To make it a visibility test the targets, observers, etc. should be randomized. Since information is added in proportion to the square root of the number of measurements, it is possible that a smaller number of experiments that could be done in available time, might be more definitive than trying for great numbers.

Although done outdoors, driving under the protected conditions of this experiment hardly is equivalent to usual auto driving. A well planned test under various road conditions may yield information that can be related to the use of the eyes indoors. A wider range in age and visual defects that closely represents the driving public, should be used.

HARRY C. DOANE and GERALD M. RASSWEILER, Closure — The authors hope that future work will help to clarify the relationship between road test results and laboratory data. At present the only way we know of duplicating driving conditions is by means of road tests and thus we must depend on such tests to give us information of the type described in this paper. Many road test variations of the type suggested by Richards were carefully considered by the committee who did the planning. This group had the benefit of direct knowledge of previous tests. They felt that most of the suggestions would lead to greater random variations in the data and might completely submerge the small differences observed between the two windshield materials.

Tests certainly were not planned to minimize the differences. On the contrary, the seeing task was made very difficult, as described in the paper, to accentuate any difference which might appear.

With regard to effects of "learning," an examination of the data, such as is illustrated in Table 5, shows no consistent change in the "differences" observed as the test proceeded.

The possibility of "clues" seems remote in view of the uniformity of the road and shoulder over the length of the test course and because the darkness of the moonless nights allowed no extraneous objects to be seen.

Safety Hazard of Tinted Automobile Windshields At Night*

HEINZ HABER, Institute of Transportation and Traffic Engineering
University of California, Los Angeles

The effects of tinted optical media, particularly of heat-absorbing automobile windshields, upon visibility distances on the highway at night are analyzed theoretically. The loss percentages in visibility distances caused by replacing clear windshields with tinted ones are calculated as functions of the variables involved, viz., transmittance of the tinted optical medium, isocandle profile of the headlamp, angular size and reflectance of the target. It is found that the loss percentages in visibility distances are further dependent upon the distance of the target itself, with the losses increasing with decreasing distances. Losses in visibility distances caused by commercial brands of tinted windshields amount to between 9 and 15 percent at visibility distances ranging between 1000 and 200 feet. These results agree fairly well with the data of Blackwell and with data obtained experimentally in the field by other authors. The analysis shows further that the losses in visibility distances are greatest for targets so nearly matched to the background that they may be seen even with clear windshields only at short distances. Under these conditions the losses may be as high as 30 to 45 percent. A reconsideration of the 70 percent minimum transmittance requirement for windshields in the American Standard Safety Code Z26.1-1950 is recommended.

● IN recent years the automobile user has been offered various devices using tinted optical media which are designed to alleviate the discomfort of glare and to reduce transmission of radiant heat. Tinted optical media are presently finding widespread application in automobiles which are being equipped with tinted windshields by the manufacturer upon option of the consumer. In addition to tinted windshields, various other manufacturers advertise so-called "night-driving glasses" which are offered as a solution to the glare problem on the highway. The interposition of a light-absorbing medium between the eye of the driver and the highway, of course, poses the question to what extent this has an adverse effect upon seeing, particularly during night. Various authors have discussed this question (1, 2, 3) and experimental studies in the field have been carried out by Roper (4) and, from this Institute, by Heath and Finch (5). In the following an attempt is made to evaluate further the work done here as well as elsewhere[1] by attacking the problem theoretically.

Two types of tinted windshields are presently in use: (1) laminations having a uniform density and (2) laminations having a graduated density with a horizontal band of greatly reduced transmittance (0.18) at the top of the windshield, designed to eliminate glare from the sky. Tinted windshields are greenish with the maximum of transmittance at 515 mμ; a typical spectral transmittance is shown in Fig. 1(A). "Night-driving glasses" (e.g., brand A) have a sigmoidal spectral transmittance favoring the long wavelengths as shown in Fig. 1(B); their tint is amber. Tinted windshields having transmittances between 0.15 and 0.40 in the 0.8 to 6-μ region, are fairly effective infrared absorbers. Their optical properties vary somewhat from sample to sample; representative transmittance values of various tinted optical media used in the automo-

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[1] While this paper was in the process of being published, the results of a further series of field experiments were reported at the January, 1955, meeting of the Highway Research Board by H. Doane and G. M. Rassweiler (Cooperative Road Tests of Night Visibility Through Heat-Absorbing Glass). The experimental setup used by these authors and their results are essentially the same as those of Roper (4) so that the conclusions drawn in this paper are not affected by this new series of field experiments.

TABLE 1

TRANSMITTANCES OF VARIOUS TINTED OPTICAL MEDIA[a]

	Luminous transmittance (equal energy spectrum) T_V	Luminous transmittance (CIE source A[b]) T_A	Infrared transmittance (0.8 - 6μ)
1. Safety plate (clear windshield)	0.883	0.881	0.436
2. Tinted windshield (brand I)	0.730	0.692	0.153
3. Tinted windshield (brand II)	0.667	0.614	-
4. Night driving glass (brand A)	0.534	0.704	0.636
5. Rayban sunglass	0.395	0.410	-

[a] Instrumentation: Range 400-700 mμ: GE recording spectrophotometer; range 0.8-6μ: Beckmann spectrophotometer.
[b] CIE source A was used to represent the spectral distribution of sealed-beam headlamps, although their color temperature averages about 150 degrees K higher. However voltage differences can be expected to produce variations greater than this difference.

bile field are given in Table 1, according to measurements made in this Institute.

Although tinted windshields offer fair protection against radiant heat and thus afford a more comfortable climate inside a car during the summer, their transmittances in the visible region of the spectrum are inadequate for glare protection. According to Farnsworth (6), sunglasses with transmittances as low as 0.25 furnish negligible glare protection; to be effective, transmittances of not more than 0.12 are recommended. On the other hand, tinted windshields must have a transmittance of not less than 0.70 in order to meet the recommendation of the ASA Safety Code (7). These two specifications, of course, are incompatible, and the conclusion must be drawn that there can be no tinted windshield that affords glare protection and simultaneously meets safety standards.

Perhaps the most critical among the potential hazards of tinted windshields is that they may cause a reduction of visibility distances on the highway at night. The object of the aforementioned field studies was to measure this potential hazard. In their study, Heath and Finch (5) placed various objects of different sizes, shapes, and spectral reflectances on the road and measured the distances at which each of the objects was first seen from the approaching car when viewed through a clear safety plate windshield and tinted windshield, respectively. The targets

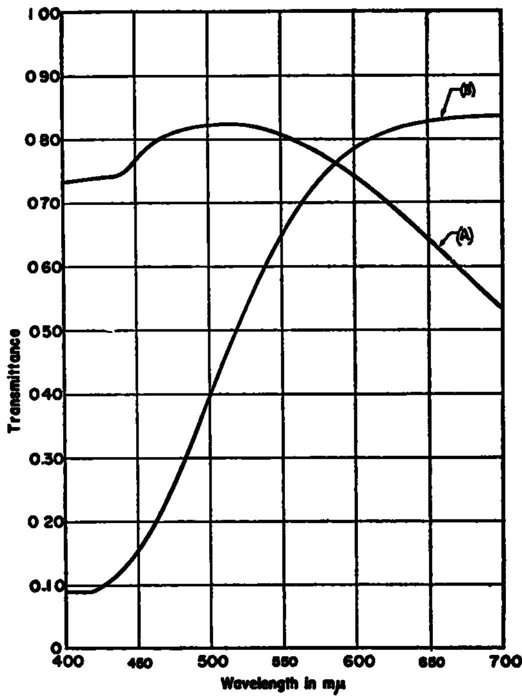

Figure 1. Transmittances of tinted optical media used in the automobile. (A) Typical tinted windshield. (B) Sample of "night-driving glass."

consisted of various objects, such as road signs, boxes of various colors, stakes, dirt piles, and the like. Roper (4) applied essentially the same method, but the targets used were identical 16-in. square paper panels having a reflectance of 0.075. Roper's measurements were mostly concerned with determinations of target visibility distances against the glare of an oncoming automobile.

The results and conclusions of these authors are conflicting. Heath and Finch found a reduction of visibility distances of up to 22 percent when the clear windshield was replaced by the tinted one. Roper, however, found an over-all reduction of less than 6 percent for observations with no approaching vehicle, and an average reduction of 2 percent with the glare of an oncoming automobile. Heath and Finch conclude that "it does not appear feasible to assign an over-all percentage value to represent the difference between the two types of glass," even though they point out that a significant reduction in visibility distance exists. Roper concludes that "the daytime benefits to be derived from the heat-absorbing glass windshields offset the small reduction in seeing distance at night."

Both authors point out that their results exhibit great variations in the effect of tinted windshields on visibility distances. These variations are due to the great number of variables having an influence upon the results, such as light sources other than the headlamps (e.g., the moon), variations of target illumination owing to the moving vehicle, the size, reflectance, color, shape, and location of the target objects, and physiological and psychophysical factors involved in the performance of the observer. In addition, it can be shown that the loss percentage in visibility distance caused by tinted optical media in night-driving is a function of distance, but the authors did not attempt to separate their data to account for this effect.

In the following treatise an attempt is made to attack the problem by theoretical analysis with the expectation of arriving at a better understanding of its nature. The analysis is based on the fact that the brightness contrast threshold rises steadily with decreasing levels of the brightness of target and background. This relationship holds over a wide range of luminances, in dark surrounds (8), light surrounds (9), and if the surround is equal in luminance to that of the background (10), at least so far as luminance levels below 1 footlambert (that is, luminance levels encountered on the highway at night) are concerned. The luminance contrast between target and background is defined by the ratio

$$C = (B_t - B_b)/B_b,$$

in which B_t is the luminance of the target, and B_b the luminance of the background. Obviously, C is independent of the illumination. For a target of a given angular subtense, then, to become visible it is required that the illumination be great enough, so that luminances B_b and B_t are reached for which C becomes equal to or greater than the contrast threshold. Let us now assume that a target on the nocturnal road is illuminated by the headlights of the driver's car with an illumination sufficient to produce luminances corresponding to the contrast threshold that is valid for the given angular subtense of the target; this threshold condition may be reached at a distance D_o. If, then, a filter having a transmittance of T is interposed between the target and the eye of the observer, the apparent luminances of both the target and the background are reduced by the factor of T. This reduction causes the target to dip below the threshold, and it is no longer visible. Since the illumination of the target and background as well as the angular subtense of the target are increased if the car approaches the target, there must exist a distance $D_t (D_t < D_o)$, at which the apparent size and luminances of target and background are rendered sufficiently great to lift the target above the visibility threshold. It follows that D_t depends only upon the following quantities and relationships: (1) the original visibility distance D_o; (2) the transmittance T of the filter interposed; (3) the relationship (for a certain position of the target) between distance and illumination (and depending on target reflectance, luminance) afforded by the headlights of the car; and (4) the relationship between distance and angular subtense of the target. A determination of D_t, of course, requires information concerning visual thresholds in terms of luminance, contrast, and angular size. All other variables can be neglected because their combined effects must be assumed to be equal in both cases.

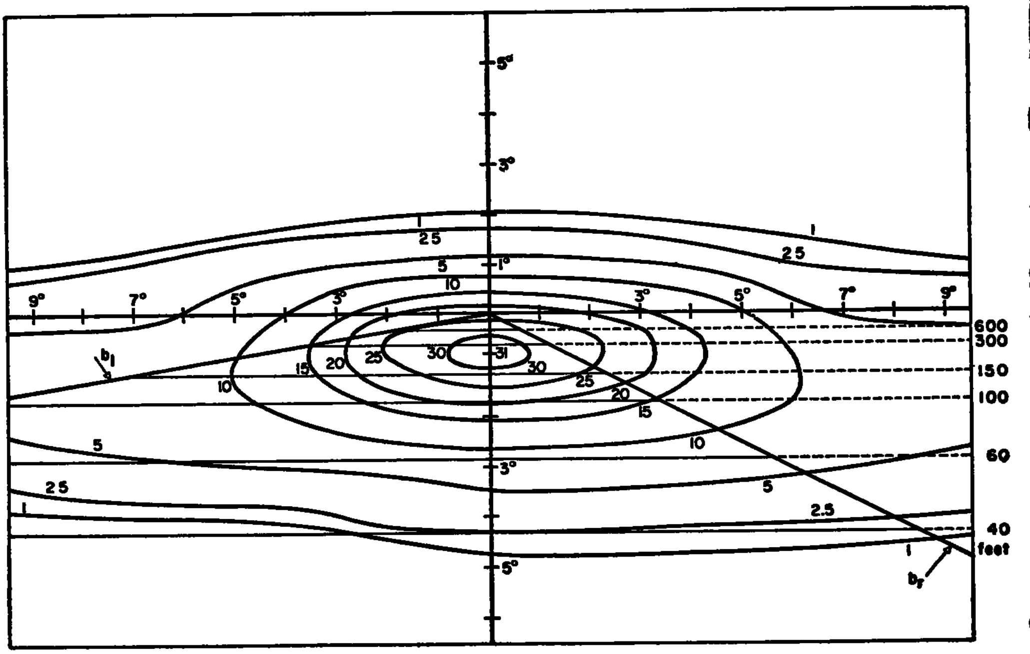

Figure 2. Isocandlepower diagram of an American-made sealed-beam headlamp, upper beam. Values are in thousands. For details see text. (After Finch (11) and de Boer and Vermeulen (12).)

Only if all variables are assumed to be equal, does a comparison between viewing with and without the filter become meaningful. This is the reason why a theoretical analysis of this kind can be expected to yield meaningful results, particularly since the many variables involved cannot be controlled satisfactorily in experimental studies.

The relationship between target luminance and distance can be obtained from measurements made by Finch (11) on American-made sealed-beam headlamps. Figure 2 shows the isocandlepower diagram of the upper beam of one of the headlamps measured. The solid lines b_r and b_l are the perspective images of the right-hand and left-hand roadbank, respectively, while the horizontal lines are the projections of transverse lines on the road at the indicated distances. This kind of graph was first used by de Boer and Vermeulen (12) in studies of automobile headlamps. Diagrams of this type from two different brands of headlamps were used to determine graphically the desired relationship between the luminance of targets located at the right-hand roadbank and the distance from the driver. Assuming a certain reflectance R of a target, its luminance can be represented as a function of its distance from the car. The results are shown in Figure 3 giving the desired relationship for two different brands of headlamps based on a reflectance of R = 0.15 for the target. Different target reflectances would be represented by identical curves shifted parallel to the horizontal (luminance) axis by a corresponding amount.

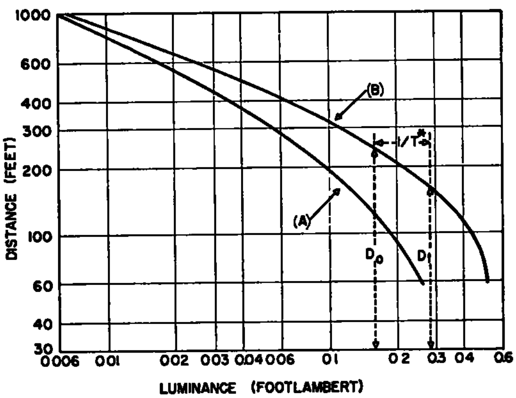

Figure 3. Relationship between distance and luminance of a target (of reflectance R= 0.15) located at the right-hand roadbank, (A) headlamp brand I; (B) headlamp brand II

The relationship between the thresholds of the three visual parameters — luminance, contrast, and angular subtense —

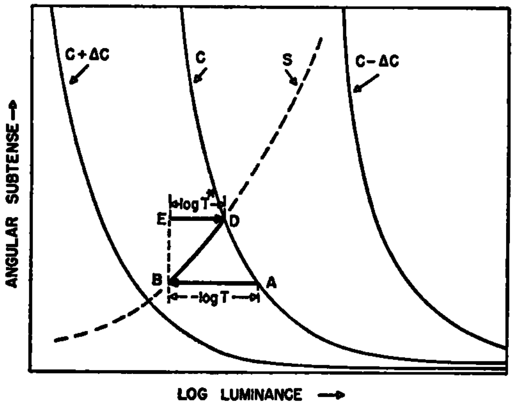

Figure 4. Graphical determination of log T*, for details see text.

has been determined by various authors (3, 10, 13, 14); of these data those by Blackwell (3) are the most suitable ones and were used in this study. The relationship between the three parameters can be represented in several ways; the representation best suited for the purposes of this study gives curves pertaining to different contrast values (C) in a coordinate system with luminance and angular subtense as axes. A graph of this kind is shown in Blackwell's paper. [2]

The relationship between angular subtense of the target and distance is easily computed for any target of given physical size. For the purpose of this study, however, this relationship must be expressed in terms of luminance of the target rather than of distance. This latter relationship is easily derived by means of Figure 3.

The previously described conditions of a target at the threshold of visibility are now represented by a point A in the diagram of Figure 4. This figure indicates how the plot of angular subtense against log luminance may be used to determine the effects of apparent target size on visibility distance. The solid lines define the combinations of angular subtense and luminance at which a target of some fixed contrast C, C + ΔC, or C - ΔC, with its background, is at the threshold. The dotted curve indicates the angular subtense of a target of some fixed size as a function of luminance, the latter in turn being a function of distance as represented by Figure 3. If a target of some given size and contrast represented by point A is viewed through a filter having a transmittance of T, the apparent luminances of the target and the background are reduced by the same factor leaving contrast, C, unchanged. Since the luminance is plotted logarithmically in Figure 4, the condition achieved by interposing the filter is represented by a horizontal shift from point A by the distance of -log T to the point B. The point B, however, represents the conditions of a target which is below the threshold of visibility. The target can be made visible again by increasing its luminance, which in our case means by approaching the target with the car. However, while the car advances the angular subtense of the target increases simultaneously according to their mutual relationship, as is represented by the curve S in Figure 4. The curves S and C intersect at the point D which represents the threshold conditions for which the target becomes visible again when viewed through the filter. Obviously the increase in brightness ED = +log T* is required to render the target visible again after it had been dipped below the threshold by the interposition of the filter.

The value T* which can be determined graphically in this fashion can then be used to determine the distance D_t at which the target becomes visible when being viewed through the filter. This is done by means of Figure 3. Since the luminance values in this graph are plotted logarithmically, the distance D_t can easily be read from the graph for any value of D_o in the manner indicated in Figure 3. The relationship between luminance and distance is not linear when plotted on log-

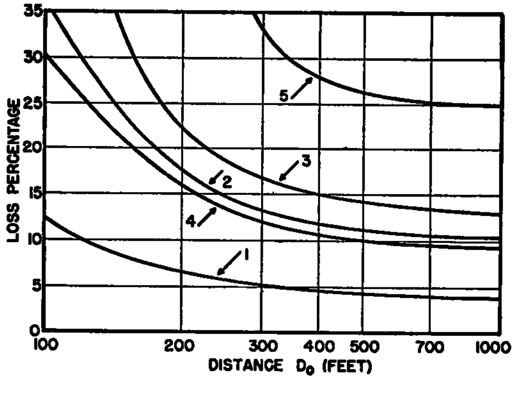

Figure 5. Loss percentage of visibility distance as function of distance for various absorbing media. (1) Clear safety plate. (2) Tinted windshield brand I. (3) Tinted windshield brand II. (4) " Night-driving glass." (5) Rayban sunglasses.

[2] See Reference 3, Figure 13, p. 58.

log paper and consequently, the loss percentage LP in visibility distance, i.e.,

$$LP = 100 [1 - (D_t/D_o)],$$

becomes a function of the initial visibility distance D_o.

Figure 5 shows some representative values of loss percentages in visibility distances for various tinted optical media as a function of the initial visibility distance D_o assumed to exist without any interposed medium (the air, of course, is assumed to be perfectly clear). The results are valid for a target having the mean linear dimensions of three feet, and a reflectance R = 0.15 — that is, the target may represent a dark-clad human figure. The graphs show that even a clear safety plate windshield causes an appreciable reduction in visibility distance, whereas tinted windshields, night-driving glasses, and normal sunglasses cause significant reductions. In all cases the reduction in visibility distance rises more or less steeply as the initial visibility distance D_o becomes smaller. This effect is perhaps the most significant finding of this analysis, because the loss in visibility distance due to a tinted windshield is most critical under conditions of small initial distances. Take, for instance, a dark-clad person projected against a dark pavement: in such a case the luminance values of target and background may be such that the initial visibility distance D_o is only 150 feet. A driver of a car equipped with tinted windshields of brand II would then detect the person at a distance of only 100 feet (see Figure 5).

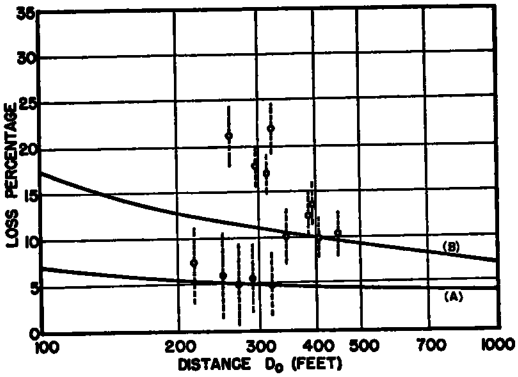

Figure 6. Loss percentages in visibility distances as functions of distance, resulting from replacing clear safety plate by tinted windshield, brand I. Curve (A) and solid dots refer to data by Roper (4), curve (B) and open circles refer to data by Heath and Finch (5).

The values presented in Figure 5 are related to no windshield at all as a base line. In order to make the theoretical results comparable to experimental findings, curves must be derived which compare a clear windshield with a tinted one. If, for instance, a clear safety plate is replaced by a tinted windshield of brand I, the base line must be represented by visibility distance D_o obtained initially while viewing through a clear windshield. The experiments previously mentioned (4, 5), were carried out by comparison between these two types of windshields. Figure 6 shows the experimental data obtained from the applicable test series in both experiments (e.g., test series without external illumination and glare). The targets used by Roper (solid dots) and by Heath and Finch (open circles), respectively, were grouped together according to their D_o values furnishing a total of 4 and 10 points, respectively. The range of the probable errors is indicated in all cases. In the case of the experiments of Roper, who used targets uniform as to size and reflectance, a theoretical curve ((A) in Figure 6) can be derived which represents the experimental results. In the case of the experiments of Heath and Finch, who used a variety of targets of widely differing sizes and reflectances, no single theoretical curve can be derived which would be completely representative of all the targets used. However, by use of a mean value of target size (major dimension: 3 feet) and available data on headlamp profiles, a theoretical curve ((B) in Figure 6) was derived that corresponds to this set of experiments. It appears from Figure 6 that the experimental data of both Roper and of Heath and Finch agree fairly well with the theoretical results, considering the difficulties of controlling the many variables involved in the experimental determination of the D_o and D_t values, as shown by the relatively large probable errors in both sets of experiments.

The experiments cover only a few isolated, special cases of the seeing task of the driver during night. These cases are characterized mainly by four variables: the specific brand of (1) tinted windshield and (2) headlamps, and the (3) size and (4) reflectance of the targets used in the experimental studies. The highly selective conditions of the experiments are also characterized by the fact that the majority of the targets are confined between the limits D_0 = 250 feet and D_0 = 400 feet. In particular, no experimental data exist for D_0 values smaller than 200 feet, which could verify the most critical reductions in visibility distance caused by tinted optical media.

It appears desirable, therefore, to analyze theoretically the relative importance of the aforementioned four variables. This was done in this study by choosing four pairs of variables, namely, (1) two windshields, brand I and brand II (W_1 and W_2); (2) two headlamps, brand I and brand II (L_1 and L_2); (3) two targets assumed to be disks 2 feet and 12 feet in diameter, respectively (S_1 and S_2); and (4) two values of reflectance, 0.15 and 0.075, respectively (R_1 and R_2). It is further assumed that all targets are located at the right-hand roadbank and that the background reflectance does not vary with the distance between D_0 and D_t. The precentage reduction of visibility distances was then calculated for five combinations of the 8 variables listed in the foregoing; the calculations are based upon original visibility distances D_0 as they would result from viewing through a clear windshield. In other words, the results are representative of the losses in visibility distances as they would result when a clear windshield is replaced by a tinted one. The following combinations of the 8 variables listed previously were taken:

(1) W_2 - L_1 - S_1 - R_2,
(2) W_1 - L_1 - S_1 - R_2,
(3) W_2 - L_2 - S_1 - R_2,
(4) W_2 - L_1 - S_2 - R_2,
(5) W_2 - L_1 - S_1 - R_1.

If case (1) is taken as a reference case, it is seen that in cases (2) through (5) only one variable has been changed. As a result of the comparisons between these cases, it was found that varying the target reflectance between 0.075 and 0.15 did practically not change the results, so that a total of three comparisons, namely (1)-(2), (1)-(3), and (1)-(4) were obtained.

The results of these comparisons are shown in Figure 7. Graph (A) of Figure 7 shows the effect of changing the transmittance of the filter; as expected, the losses in visibility distances decrease with increasing transmittance of the filter applied. Graph (B) of Figure 7 shows the effect of changing the brand of headlamp; here the results indicate that the losses in visibility distances are particularly sensitive to changing the isocandlepower distribution of the headlamp. A lamp, for instance, having a steep angular gradient in its isocandlepower distribution (Figure 2), will cause a steep increase of the losses in visibility distances for decreasing D_0-values. This fact, namely the pronounced influence of the type of headlamp upon the losses in visibility distances, may also explain the differences in the experimental results obtained by different observers. Graph (C) of Figure 7 shows the effect of changing the size of the target with the result that the losses in visibility distances increase with increasing target size.

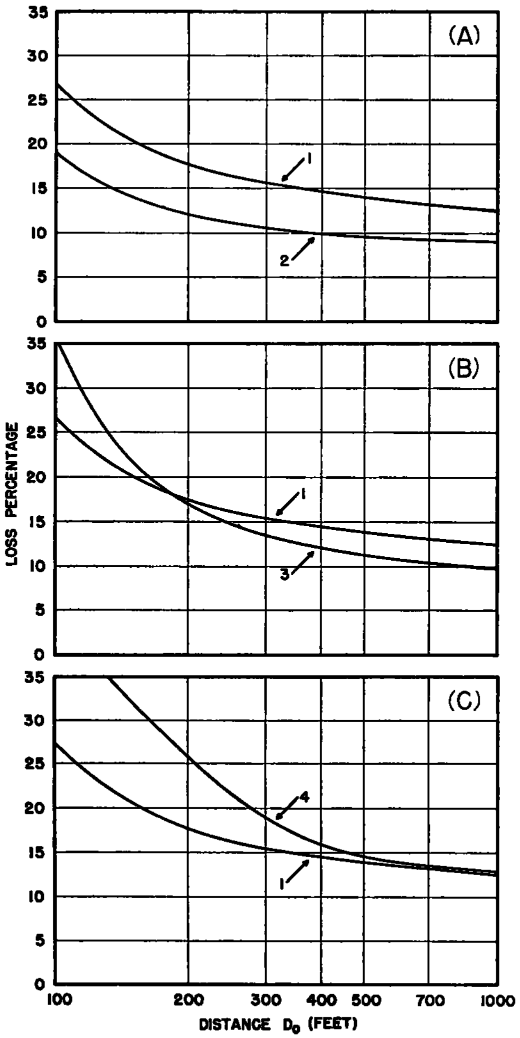

Figure 7. The effects upon visibility distances caused by varying: (A) transmittance of the filter, (B) brand of headlamp, and, (C) size of target. For details see text.

The results of this study indicate that tinted optical media, particularly the darker brands of tinted windshields contribute significantly to the hazard in night-driving, particularly under conditions of low luminances and, consequently, small visibility distances caused by poorly reflecting targets and backgrounds. Similarly dangerous reductions in visibility distances were obtained by Blackwell (3) for twilight conditions, that is, when the driver has not yet turned on his headlamps — a condition which is not considered in this study. Furthermore, because of their relatively high transmittance, the effectiveness of tinted windshields as a protection against glare during the day is negligible. Thus, their only advantage seems to be their ability to absorb radiant heat. As can be seen from Table 1, however, the clear safety plate also absorbs up to 50 percent of infrared radiation between 0. 8 and 6 μ, indicating that the advantage of the tinted windshield over a clear one, in this respect, does not seem to warrant increasing the hazards in night driving. The best compromise appears to be the use of dark sunglasses for glare protection during the day, and clear windshields of the highest attainable transmittance. In closing, the author wishes to endorse strongly the recommendation made by Heath and Finch (5), namely that the 70 percent minimum transmittance requirement for windshields in the American Standard Safety Code Z26. 1-1950 be reconsidered.

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Visual Efficiency in Monocular Driving

THORNE SHIPLEY, Research Center
American Optical Company

It is estimated (7) that 2 percent and 5 percent of the drivers on the roads today are effectively monocular. There are at present almost no regulations concerning the safety restrictions, if any, which should be placed upon such drivers. Moreover, those few suggestions which have been made appear at best unsystematic and at worst unrealistic. This is so largely because our understanding of the nature of driving efficiency in general, and of monocular driving efficiency in particular, is very meager. The present paper is directed to this issue.

Psychological and physiological factors are always coordinated in such a manner as to determine the general confidence with which one approaches a physical task such as driving, and, being much more significant than the purely mechanical difficulties involved, the psychological forces largely determine the efficiency of one's performance in relation to safety criteria. The severely handicapped yet mature driver will recognize his unique limitations and act accordingly. The accident prone driver is so prone only because of the psychological meaning which driving has for him, e.g. its very obvious power implications. It is not the eye which perceives, but rather the total integrated self.

The contribution of visual prowess to driving safety has been rather fully documented (2, 3, 7, 8, 9, 10, 11, 13, 14, 15, 27, 28, 30, 33, 35). But the fundamental psychological events seem much less understood (exceptions: (16, 18)). The question of exactly what a driver experiences on the road when handicapped by some physical disability has received perhaps less attention than it ought to. Furthermore, clinical tests of visual efficiency are not always valid measures of actual performance in the field. Consequently, the present study was undertaken for at least two reasons: to familiarize the author with the experience of the monocular driver and with certain of the more significant problems with which he may be confronted; and to develop certain safety procedures which may be of service to a monocular driver in his everyday driving.

● BETWEEN November, 1953 and December, 1954, the author has driven approximately 5,000 miles with one eye occluded, sometimes the right eye and sometimes the left. Most of the critical driving conditions were sampled: city driving (e.g. in New York and Boston), highway driving (e.g. on the Merritt Parkway), short hops and long hauls, daylight, dusk, and late evening drives. No specific attempts were made to change my normal driving habits, so that any changes which were made had to be deliberately introduced in the interest of safety. These changes were thus highlighted, and could be recorded for study and discussion. Except when noted, all observations refer to monocular experiences in the visual fields of both the right and left eyes.

RESULTS

The monocular driver's visual field is illustrated in Figure 1. It is immediately clear that the basic organization of visual space is monocular. Segregation of forms, relative direction and distances, and the externality of objects are all basic aspects of monocular visual experience. The contributions of binocular fusion are generally overemphasized, perhaps because of the recent success of stereoscopic devices, but binocularity adds only a superficial aspect to visual experience. We may call this aspect "solid seeing," the feeling of solidity which objects have, of "thingness," of absolute depth (the etymological meaning of stereopsis), and oppose to it the perception of relative depth which certainly exists in the monocular visual world. Thus, we may more fruitfully break down our discussion into rather specific questions.

1. Are the Loss of Binocular Stereo-Cues and the Contraction of the Visual Field the Only Things Which We Need to Consider in Understanding the Monocular Driver?

The fact (Figure 1) that the lateral and vertical positions of an object remain the same for monocular and binocular drivers is of far greater significance; it is this fact which enables the experienced monocular driver to handle his car in complete safety.

2. What Is the Relative Magnitude and Significance of the Loss of Visual Field?

This varies somewhat with the shape of the face, e. g. the height of the bridge of the nose, but approximates, in general, a shift from about 190 degrees down to about 150

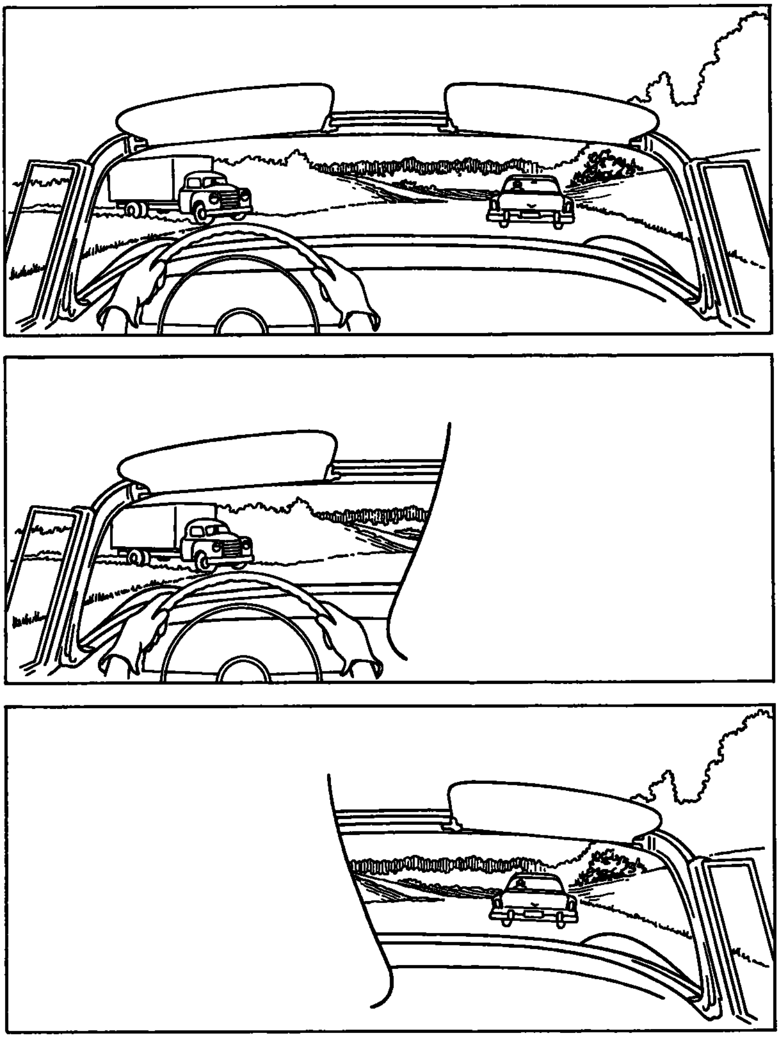

Figure 1. The monocular driver's visual world (A) as seen with the left eye, (B) as seen with the right eye.

degrees. The significance of this may partially be seen in the finding of Fletcher (13) that out of 71 cross-road accidents in monocular drivers, 61 occurred on the side of the defect (see also Figure 1).

3. Does It Make Any Difference Which Eye Is Lost?

There is some evidence (26) p. 447, that loss of the dominant (sighting) eye brings with it a slightly greater spacial disorientation and defect in stereo-acuity than loss of the passive eye, but the present author was unable to conform this. However, a very different asymmetry did arise. If one looks at two lights of different intensities, one in each eye, the resulting impression of brightness contrast of the image fused in the brain will be somewhere between that of the two lights when viewed separately (the so-called Fechner effect). Now we make a distinction between two kinds of blindness: one in which the patient is conscious, i.e. sees a blackness or scintillating greyness before the blind eye (positive blindness); and one in which the patient sees nothing at all before the blind eye (negative blindness). The former is the type of blindness which results from monocular occlusion, as in the present study, and from peripheral eye injuries; the latter more probably results from damage to the optic nerve or to the brain itself (a less common cause of monocular vision). Thus, in any case of positive blindness, the interference of the grey visual field before the blind eye with that visual field before the good eye (by decreasing the contrast) would be particularly annoying in recent blindness and in those patients with intact retinas where the complete dominance of the seeing eye is still challenged (21). In fact, the author observed that when his dominant eye (right) was occluded, the blind field might not only fuse with and lower the contrast of the normal field (left eye), but it might entirely suppress it, leaving him momentarily totally "blind." However, whereas the shielded eye may dominate throughout the short period of the experiment in the case of occluded binocular subjects, in long-term monocular subjects the good eye will eventually become dominant and the Fechner effect cease (24) p. 399.

If one's left eye is good and one's right eye is blind (Figure 1A): one may feel confident in passing cars on one's left, e.g. those going in the other direction from oneself on a two-lane road, but only under extreme circumstances, e.g. a stalled or parked vehicle, should one pass a car on one's right, for one simply cannot see it. When driving on a dual highway, it is a continual strain to drive in the left lane, for the position of all the cars one is passing on one's right, or which may pass you on that side when your lane becomes jammed up, must remain ambiguous and serve as a constant source of serious concern. The author has repeatedly found it intolerable to drive in this manner for more than a few minutes; in cities it is especially disconcerting, because one is, in effect, always doing just this. This is almost certainly the greatest single danger in city driving for the monocular driver. And, although the monocular's confidence in the other driver's ability to stay neatly within his own lane may well increase with time, and the tension thereby abate, nevertheless the danger does not. Moreover, parking for such a driver is a particular chore, although not nearly as dangerous because of the slow speed at which one is moving.

It is interesting to note, and in accord with well understood psychological mechanisms, that the apparent significance of having cars pass one on one's blind side, where the leading role of responsibility is taken by the other driver, is much less than when you yourself assume this responsibility by initiating and carrying through the act of passing. Moreover, the large number of accidents which occur on the right side due to faulty timing when cutting back into lane (15) attests to the obvious inadequacy of the perception of this responsibility even in binocular drivers. This suggests that one perhaps takes on a greater psychological responsibility in driving when blind in the right eye than when blind in the left (reversed, of course, in England). This is clearly a point for further study.

If one's right eye is good and one's left eye is blind (Figure 1B): one may confidently pass cars going in the same direction as you are, because you pass them on your right and they can be kept constantly in view. However, this is quite dangerous when it is possible that other cars may be approaching, e.g. on a two or three-lane road, because such vehicles approach close on one's left and cannot be seen unless you turn your glance away from the car you are trying to pass. Similarly, of course, starting up from the curb is a very special problem, and the danger is quite real because one is blindly entering a fast-moving lane.

4. Does the Monocular Driver Have Specific Problems in Daylight Driving?

The crucial visual cue of monocular daylight driving is the surface gradient. This is also true of the pilot, and of binocular vision in general when the significant objects lie beyond the range of binocular vision (say, roughly, 700 feet). Surfaces, e.g. icy road-beds, rear-ends of trucks, soft shoulders, are perceived when patterns of shadow and color are perceived. Disorientation of skiers, pilots and others in very thick snowstorms, and of automobile drivers particularly in fog, is notoriously a function of their having no real visual surfaces with which to orient themselves.

Thus, the depth of orientation of a daytime monocular driver may be helped, as in the author's experience, by attention to these surface gradients. The issue in such orientation is not so much how far away is the object, say a truck, but rather where am I with respect to it. One is always located at the beginning of a surface gradient. Nearby, the texture of the road, the blades of grass, the telephone poles, fenceposts, etc., are all clearest, most individualized, most separate. At the horizon, or the most distant point towards which one is steering, all these textural qualities vanish — one can no longer distinguish the different patterns on the road or in the neighboring terrain. An object thus takes its egocentric position (i. e. position with respect to the self) from the fact that it overlies and occludes a certain region of this gradient. The farther one is from the object, the less discreet are the aspects of the surrounding surface texture.

A second cue which the monocular driver may use in daylight driving is that of linear perspective. Consider the situation when there are two guide lines on the road, one on the right side as well as the usual one on the left. The self is again at the beginning of the convergence of these lines (e.g. the edges of the road in Figure 1). The point of aim is the convergent point of the pattern, and the egocentric position of an object is given by its juxtaposition to a specific region of the converging lines. It was the author's experience that his efficiency in steering was markedly increased when two such lines were available. In fact, a short vertical rod attached to the hood or fender of the car directly in front of the driver would serve a very similar function, when the line on the right side is missing, by giving the driver a second reference with which to orient himself. Such an orientation becomes necessary when the contour between the edge of the road and the shoulder is not sharp, in which case although the lateral position of the edge is seen exactly as in the binocular driver, its actual distance from the driver tends to be ambiguous. Such guide lines are thus to be particularly recommended in the case of monocular drivers, because of their aid in distance orientation and their contribution to steering efficiency.

Another perspective cue is the perspective of motion (17, 18). As one approaches an object it appears to grow in size, and the rate of this expansion increases as one gets nearer to it. Furthermore, one seems to move past nearby objects at extraordinary visual speeds in comparison to the rate at which one seems to approach these objects from a distance. Brown has found that visual velocity is a function of the rate of change of relative contours, and such changes are always greatest for nearby objects. Thus the same physical velocity seems faster along a straight and narrow city street than along a similar open road across a plain. Brown has also shown that the apparent velocity of an object varies inversely with its distance from the observer, in exact accord with the present author's qualitative experience. This phenomena may be a source of fright or uneasiness until one recognizes it as a manifestation of the generally inefficient monocular depth localization. For example, in the complex case of an approaching vehicle, the true speed of its appraoch may not be realized until it is superimposed, because of the increasing angle at which it appears, on the commonplace stationary environment of streets and scenes which then serve as visual frames of reference. Of course, the distance at which such a superimposition is possible depends on how far to the right or to the left the approaching vehicle is. If it is approaching at right angles to the road, as at an intersection, then the distance is at its maximum; if it is approaching parallel along a two-lane road, then this distance is at a minimum. Thus, motion perspective is more commonly recognized with respect to objects moving past one at some large angle, e.g. the truck in Figure 1, than for objects which are coming directly along one's path of motion at some very small angle, e.g. the car in Figure 1. But the point of aim, i. e. the point towards which one steers does not expand, it remains visually fixed. Attention to this center and the surrounding patterns of motion may help to localize oneself both in depth and in lateral position, by clarifying one's direction from and one's rate of approach to any momentary steering goal.

However, there is an inherent danger in the excessive use of this cue. If one attends exclusively to the unexpanding point of aim, i. e. the steering goal, one may become fascinated by the rushing motion of irregular patterns and gradients on the side, somewhat like when one stares into a waterfall or a fire and finds it hard to turn away. Clark et al (p. 1) state: "Fascination appears to be fundamentally a matter of heightened attention, but some experiences also included compulsive types of the behavior and blocking." It is not simply the monotony of the road which encourages fascination, but many more complex factors. The author, for example, not unlike some of Clark's subjects, has often found himself fixating on the rear of a car and attempting to keep it symmetrically centered in his field of view, until suddenly he was too close to the car and had to apply his brakes abruptly. Furthermore, it is likely that the monocular driver may be seeking even greater reassuring anonymity in the use of his car than the driving situation usually entails, and thus may tend to fixate more rigidly such significant steering cues as the car in front, or some other point of aim.

Happily, of course, these patterns generally shift and flex with the changing patterns of the terrain, with the road population, the illumination, and so on; but then their efficient use as driving guides requires alertness and constant attention. The apparent complexity of the motion perspective cues may be somewhat reduced with the help of motion parallax. When two objects appear at equal distance, and if it is important to know whether or not this is actually true, one can move one's head from side to side a few times, and the nearer object will seem to move laterally much more so than the farther object.

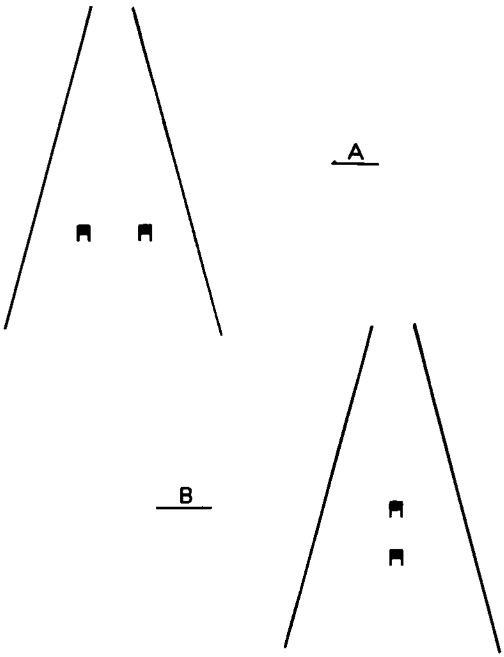

Figure 2. The effect of height on apparent distance.

A second type of motion parrallax requires careful attention to the rate of change of angles in the monocular visual field. Since the self is at the bottom of the visual field (e. g. at the origin of all the gradients), all real objects between the self and the horizon lie at different apparent heights. Different horizontal distances are, by linear projection, equivalent to different heights. For example: as a car approaches, it can be seen to move downwards if one attends to the changing angle between the edge of one's own car and that of the approaching vehicle. Essentially, one projects the two moving objects onto a stationary ground, e. g. the highway, and then uses the changing size of this ground between these two objects as a clue to changing distance. Similarly, if there are two or more objects involved, comparisons between the various changing angles and their respective rates of change will immediately establish a confident egocentric localization. Although this is a highly intellectualized cue, and requires real practice in daylight driving, it is much easier for the monocular driver to learn than for the binocular driver, because the convergence function in the binocular will operate against it. The present author has found this to be one of the most significant aids for steering efficiency. It is particularly important when following another car in one's own lane. In this latter instance, one may exaggerate the parallax by following the car somewhat asymmetrically, so that as the distance between oneself and the car changes, not only does a change in height appear, but also a change in lateral position.

5. Does the Monocular Driver Have Specific Problems in Night Driving?

As we have noted, under daylight conditions, it requires an overt intellectual effort to perceive height changes as distance changes, but under night levels of illumination this becomes the rule. What is lost under low illumination is most of the perspective information from gradients and motion patterns. At night one steers primarily by alignment and not by aim; and the interpretation of depth changes as height changes occurs almost too easily. In Figure 2 we represent the illusion, which may occur with varying degrees of realism, of the road seeming to stand almost vertically somewhere in front of the driver; it seems to proceed from the bottom of the perspective field, i. e from the driver, its origin, up to the top of the perspective field, i. e. to its vanishing point or point of aim. Thus (Figure 2A) we see that the horizontal displacement of two objects gives no information whatsoever as to the relative distances of these objects. However (as in Figure 2B), the vertical displacement of the two objects in the perspective field gives compelling information as to their relative distances. In general, this cue may be quite helpful (as noted above), but sometimes it is a source of disturbance. For example: the high lights of a nearby truck will appear farther away than the low lights of a more distant car; the high traffic lights which appear over the tops of vehicles will seem further away than the low vehicles which, for example, may actually be stopped at these lights; it has happened to the present author that light reflections at various heights in the windshield were projected out into space and seen as real objects at various heights, and so distances, with respect to the actual headlights or taillights which were causing these reflections in the first place. In view of these illusions, it may be advantageous to standardize the heights of taillights, headlights, street lamps, and traffic signals, so as to reduce the need for guessing just what and where they are.

Another crucial problem in night driving is glare. Glare factors are clearly magnified in monocular driving (1). The obvious reason seems to hold: with a decreased visual field a glare source of a given size, once seen, will quite simply dominate a greater percentage of that field. And the common techniques for amelioration, such as blinking, turning one's head, shielding one's eyes, and so on, seem only to add to the danger. Any interference with the vision in the remaining eye will be of extreme harm. It is not really important (7, 8, 9) whether the monocular retina is more sensitive to glare than the binocular retina, the issue is whether or not glare is psychologically more traumatic to the monocular individual considered as a whole. It has been the author's experience that this is so. It is not unlikely that part of this increase sensitivity to glare is due to a slight pupillary dilation in the functioning eye, caused by reflex response to the dark field (positive blindness) before the occluded eye (20); although it may well be that this reflex will fade and gradually cease to operate at all in long-term monoculars. However, regardless of the cause, the overwhelming significance of glare was one of the most important determining factors of the author's monocular driving habits. It was simply impossible, on a two-lane road, to continue driving in the face of a car using its high beams. Particularly annoying was the continual glare from city street lights, e.g. in Times Square, New York, or from headlights in heavy evening traffic. Indeed, in the author's opinion, these conditions represent the only driving situation where one must very seriously caution the monocular driver.

Probably related to this are the problems of the absolute visual threshold (the smallest intensity of light which is just visible) and of dark adaptation (the gradual increase in the light sensitivity of the eye in the dark). For example, in shifting his gaze from the bright dials (inside) back to the dark road (outside), the author has felt the need for a short period of adaptation. This observation may be of importance in view of the experimental finding of Cook (5) p. 69, that if both eyes of a binocular observer were dark adapted, the binocular light threshold is about one-half the monocular threshold. This, of course, may not hold for negative monocular blindness (see above, No. 2), and we are certainly not fully justified in extrapolating (as DeSilva does) to all long-term monoculars with either positive or negative blindness. However, until we have dark adaptation curves available on these latter subjects we are forced to fall back on this type of work for confirmation of findings from the road.

6. Is the Monocular Driver Particularly Subject to Visual Illusions?

Directly related to the loss of confident distance perception for nearby objects is the greater prevalence of visual illusions. One of the most important of these is the tendency of monoculars to underestimate distances. For example, Guilfoyle states (p. 432): "The ground seems invariably nearer to me than it really was" so that to land correctly after my accident I had to learn to fly ". . . straight into the ground" (23, 25, 26, 32). Similarly, although the underestimation of distances is seldom as dangerous in the driver as in the pilot, the present author has often slowed down much sooner than necessary, or stopped quite far from a light, or followed a leading car in traffic at far greater distances than was usual for him.

Other illusions, however, are more startling. The road, for example, may seem to be coming up at one instead of lying flat; it tilts up to the edge of the hood or steering wheel. This occurs in a compelling manner in spite of the usual tendency for a monocularly viewed plane to rise up gradually to eye level in the distance (Figure 2).

The cross-lines may grow markedly in size as they approach, especially if one is driving too fast (6). The guide lines at the edge of the road may appear to converge towards one (in contrast to the operation of perspective) and, with the center line, to "rush" up to one's face.

When one stops suddenly as for a light, after staring for some time at the rapidly approaching road, stationary objects such as houses, trees, or hillsides, may seem to move away from one, just as the sides of a waterfall seem to go up as the water comes down — an after-image of motion (22). If one looks too long out of the side of the car, the landscape may seem to be moving while one is standing still. Under such conditions, a driver may become lax in his awareness of his own responsibility for all the motion which is actually present in the field, because it is now somehow visually located outside of himself.

These illusions are harmful because they increase the discrepancy between the driver's interpretation of the road and the actual road conditions, and thus prevent him from correctly anticipating succeeding events. However, if one can anticipate such illusions, their occurrence need not be upsetting. They occur most frequently in early dawn, at twilight, when one is tired, or when one has been driving for a long time. When they appear, simply slow down and relax your eyes. Constantly shift your glance over the road, do not fixate any given object or pattern longer than necessary, watch the car in front, read its plate number, glance at the cars approaching, take notice of the makes of the car or of the number of passengers, glance back to the first car, look into rearview mirror, check the road in the distance, and so forth.

7. Are the Posted Speed Limits Safe for Monocular Drivers?

A monocular driver may be said to be moving psychologically faster than a binocular driver going at the same physical speed. This is particularly important if it can be shown, as the author felt, that monocular visual reaction times are longer than the equivalent binocular reaction times. For example, Poffenberger has shown (although for only three observers) that finger response time to visual stimuli is approximately 0.015 seconds faster for binoculars than for monoculars. More recently, Richmond and Ebert have concluded on a large sample (using flashing visual acuity targets) that "form speed perception for both eyes is twice that of monocular vision" (31) p. 151. In addition, we may call attention to Teichner's recent conclusion on the simple reaction time (34) p. 141: "For visual . . . RT's (reaction times) the greater the extent of the stimulus in space," i. e. the greater the number of receptors stimulated," the faster the speed of reaction up to some limit"

8. Is There Any Special Danger from Windshield Defects?

Obstructions on the windshields are quite hazardous, because they contract the monocular visual field even more. The increasingly popular practice of placing state tax stamps, inspection stickers, tourist labels and the like, on the front windshield is to be deplored. Even the operation of the windshield wipers may be disturbing; the author has had to slow down whenever he tested their use, with or without additional hazard of actual rain.

9. Are Special Mirrors a Solution?

Individually designed wide-angle, one-piece, rear-view mirrors may be of some help in broadening the field of view. This is particularly so, because, as the mirrors are now conventionally placed, neither the inside mirror nor the outside mirror (depending upon which mirror is on the same side as the blind eye) may be seen without turning one's head from the road. Thus, simply a slight shift in the position of these mirrors may help. The author has also found that a standard central mirror with two independently rotatable side wings is of definite value, although its proper use entails much more practice than a single wide mirror.

GENERAL SUMMARY

There is nothing in the author's experience which would warrant the denial of a license simply on the basis of monocularity. The suggestion (2, 30, 33) that we wait approximately a full year before we permit monocular driving to be attempted is entirely too severe even in the case of professional drivers. A month or two at most would be adequate in general, with some driver's needing much less. The significance of monocular blindness, as of all physical deficiencies, varies enormously with the individual. The phenomenological importance of the physical limitation, being a function of its visibility to others, its psychological penetration into the personality core (particularly impressive in those patients who have not even realized that they are effectively monocular), and many other complex psychological factors, will almost exclusively determine the subject's behavior in situations relative to the handicap. The purely physical limitations are secondary. For example, for some patients a slight dimming of vision may be psychologically more disastrous than total monocular blindness, particularly if it is associated with an obvious facial disfigurement. Such a person may be more cautious in driving, although less necessary, than some patients with only one eye, for whom greater caution is imperative. Thus, no recommendations, such as speed limitations and night-driving restrictions, can be made to any patient without first taking the personal meaning of the physical limitation into consideration. In view of my own experience, I simply cannot be as generally pessimistic as others have been on this issue. Monocular driving did not seem to be particularly hazardous after a few days of practice. It is quite possible that those of us who have never tried monocular driving have thereby built up a certain awe of it which is not really justified, nor shared by those who do so regularly.

Recommendations: (1) An approximate 20/20 correction in the good eye, with strictly enforced insistence that the glasses be worn. If the patient cannot be corrected to about 20/20, the granting of a license will be particularly hazardous unless there are very favorable extenuating circumstances (28). (2) No constriction at all in the visual field of the good eye (also recommended by Black). (3) No other physical handicaps of safety significance, such as slow reaction times, loss of limbs, or seriously impaired hearing. (4) It may be of value to have a pamphlet on hand at licensing bureaus, to be freely distributed to monocular drivers, which includes a general discussion of certain of their special driving problems and makes suggestions as to particular safety procedures which they may follow.

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Stray Light in the Eye

ROBERT M. BOYNTON, University of Rochester

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

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

Neural Interaction

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

Stray Light

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

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

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

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

Physical Measures of Stray Light

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

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

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

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

Sources of Stray Light

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

Comparison with Glare Experiments

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

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Some Highway Research Board Publications Relating to Night Visibility

BULLETIN 11: THE POLARIZED HEADLIGHT SYSTEM (1948) 36 pp. $.60
The Polarized Headlight System; The Automobile Industry Survey of Polarized Headlighting; The General Electric Co. Tests on Polarized Headlighting.

BULLETIN 34: REFLECTORS AND NIGHT VISIBILITY (1951) 54 pp. $.90
An Acrylic Reflecting Material Which Offers New and Unique Applications for Traffic Signs; Automobile Glare and Highway Visibility Measurements; Reflex Reflector Performance Criteria; Photometric Tests for Reflective Materials.

BULLETIN 43: STUDIES IN NIGHT VISIBILITY (1951) 51 pp. $.90
Factors Affecting the Perception of Relative Motion and Distance between Vehicles at Night; A Study of the Relationship between Photopic and Scotopic Visual Acuity; Field and Laboratory Evaluation of Roadside Sign Surfacing Materials; Filter Study of the Effect of Certain Transmission Filters on Visual Acuity with and without Glare.

BULLETIN 56: NIGHT VISIBILITY (1952) 77 pp. $1.20
Determination of Windshield Levels Requisite for Driving Visibility; Effect of Exposure to Sunlight on Night-Driving Visibility; Effect of Pattern Distribution on Perception of Relative Motion in Low Levels of Illumination; Vision at Levels of Night Road Illumination; Spherical Lens Optics Applied to Retrodirective Reflectio

BULLETIN 68: EFFECT OF TINTED WINDSHIELDS AND VEHICLE HEADLIGHTING ON NIGHT VISIBILITY (1953) 61 pp. $.90
Effect of Tinted Windshields on Nighttime-Visibility Distances; Nighttime Seeing Through Heat-Absorbing Windshields; Development of the Guide "Autronic Eye;" Design of the Meeting Beam of the Automobile Headlight; Glare from Passing Beams of Automobile Headlights.

BULLETIN 89: NIGHT VISIBILITY (1954) 75 pp. $1.05
A Substitute for Road Tests of Automobile Headlights; Sign Placement to Reduce Dirt Accumulation; Effect of Planting in Median Strip on Night-Visibility Distances; Reflection Characteristics of Pavement Surfaces; Evaluating Disabling Effects of Approaching Automobile Headlights; Visual Detection at Low Luminance Through Optical Filters; Effect of Wave-Length Contrasts on Discrimination Thresholds under Mesopic Vision; Signal Lighting for the Movement of Traffic in Fog; Effective Use of Reflectorized Materials on Railroad Boxcars.

BULLETIN 127: NIGHT VISIBILITY - 1955 (1956) 65 pp. $1.20

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