Sign Brightness and Legibility

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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.

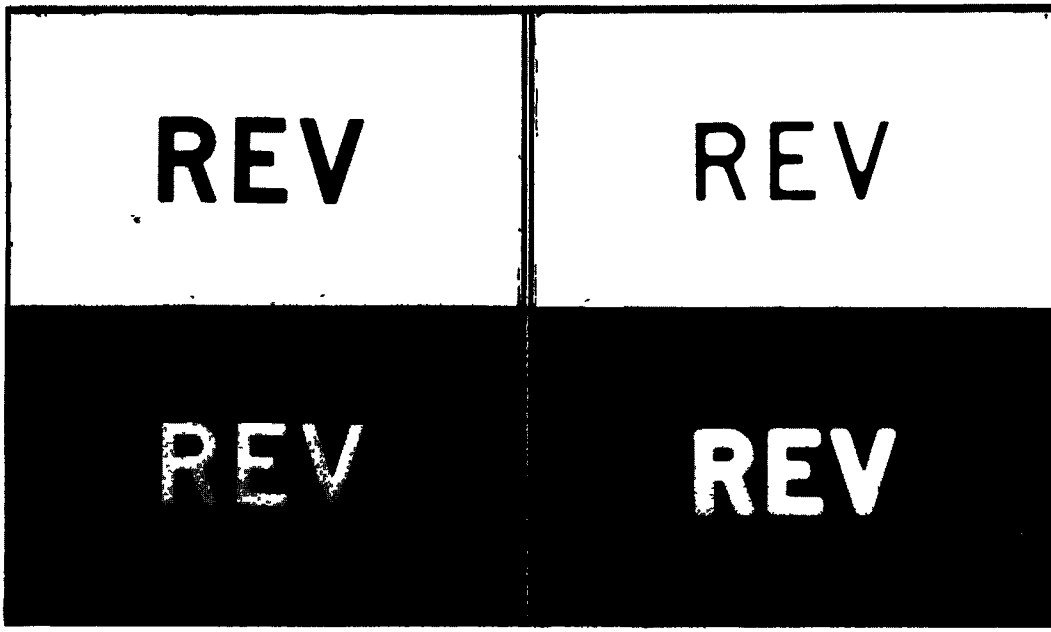

Figure 1. Appearance of signs of optimum and high brightness.

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 mate rials 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 be tween 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 charac teristics 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.

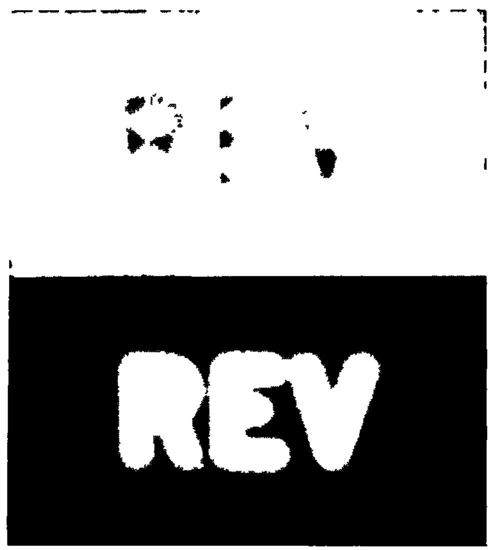

Figure 2. Irradiation.

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
	I x S	7		38.500		5.50		
	R x B x S	21		200.688		9.56		
Error	R x I x S	21	77	118.063	544.813	5.62	7.075	
	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-

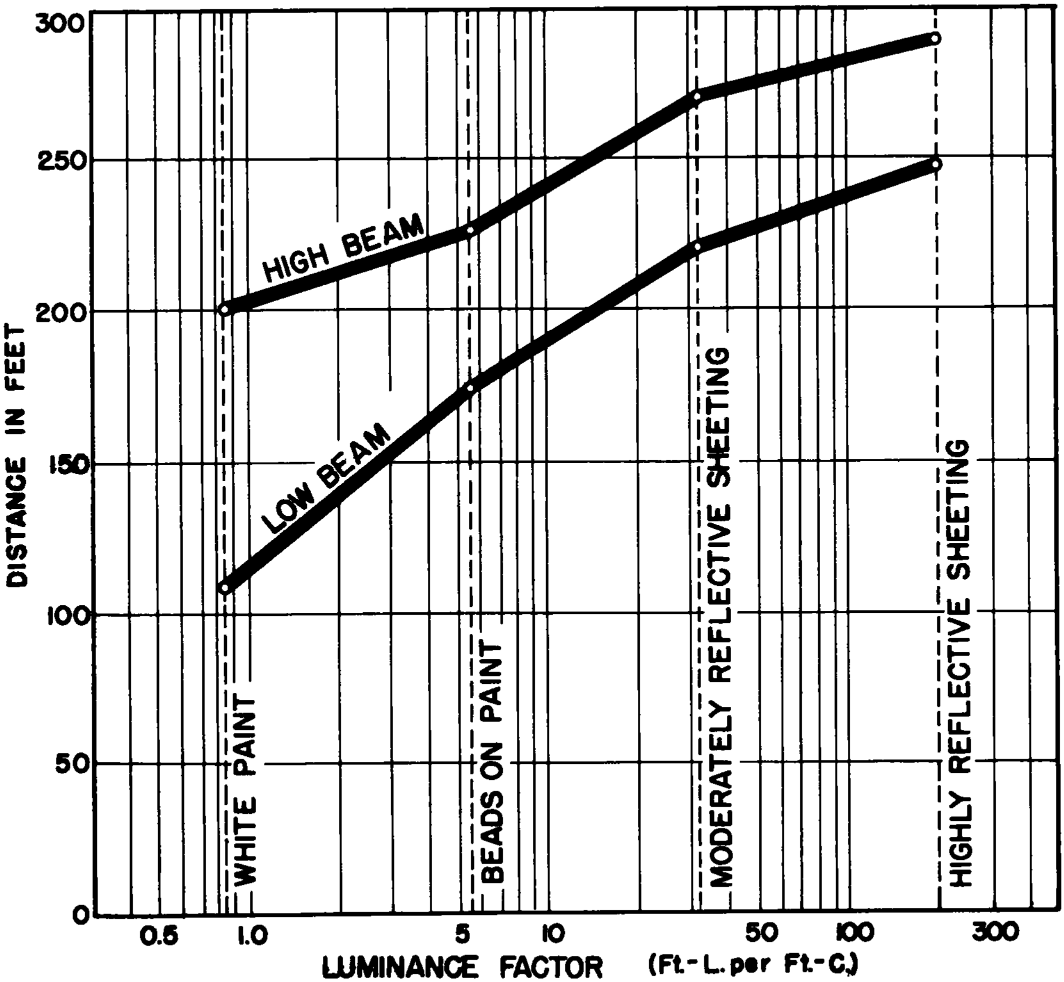

Figure 3. Field experiment results for the rural intersection.

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.

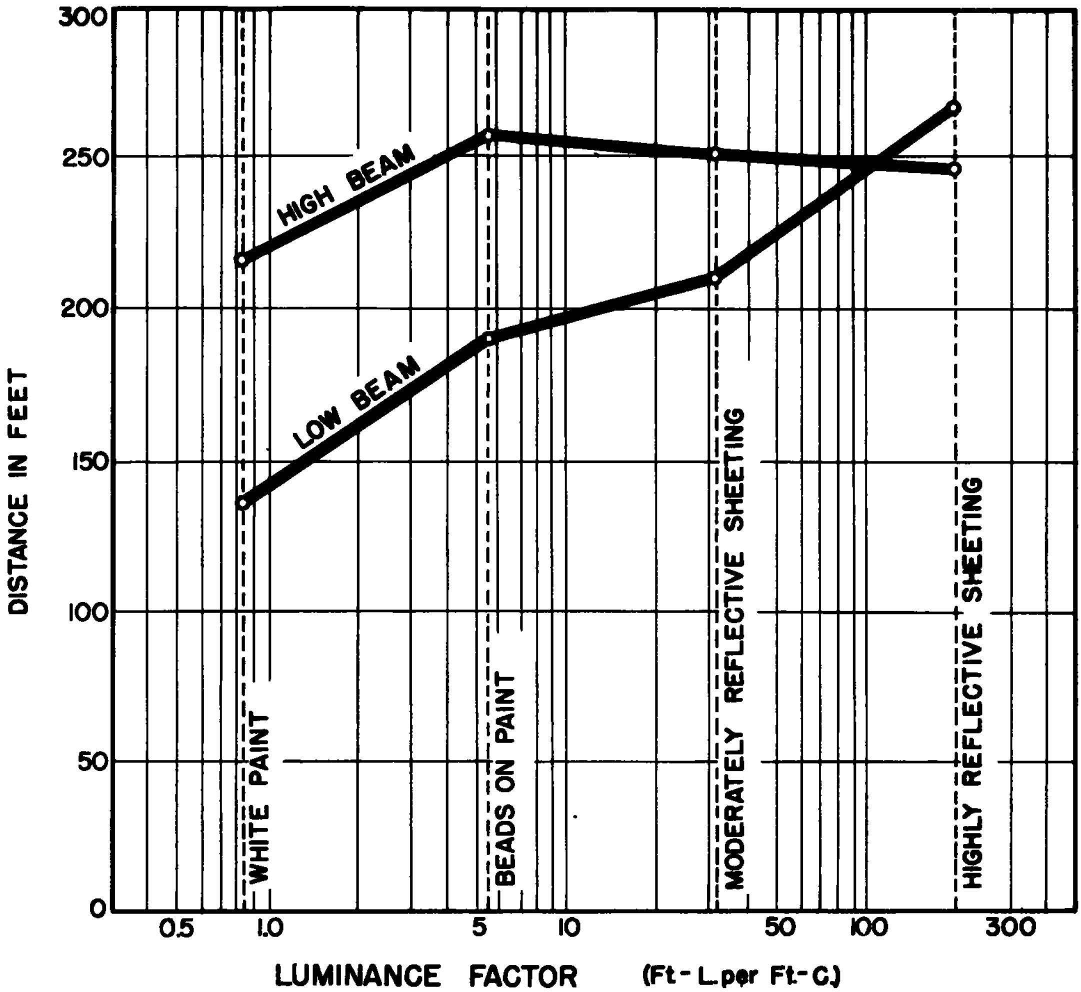

Figure 4. Field experiment results for the open road.

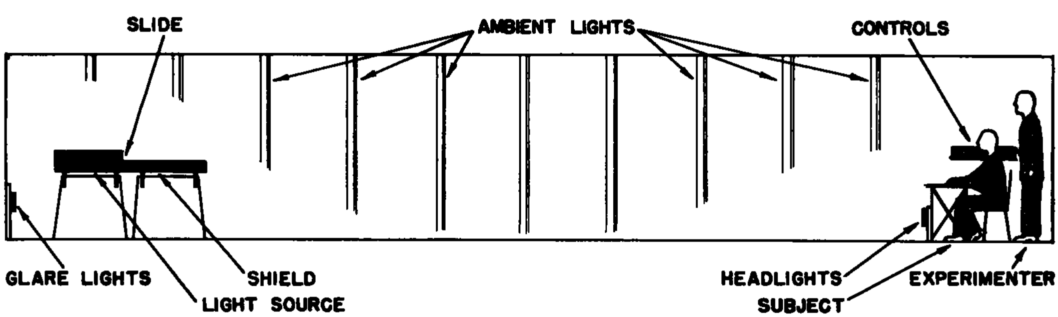

Figure 5. Diagram of laboratory test tunnel.

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.

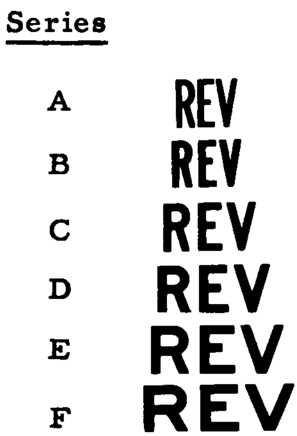

Figure 6. Examples of the six standard letter series.

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

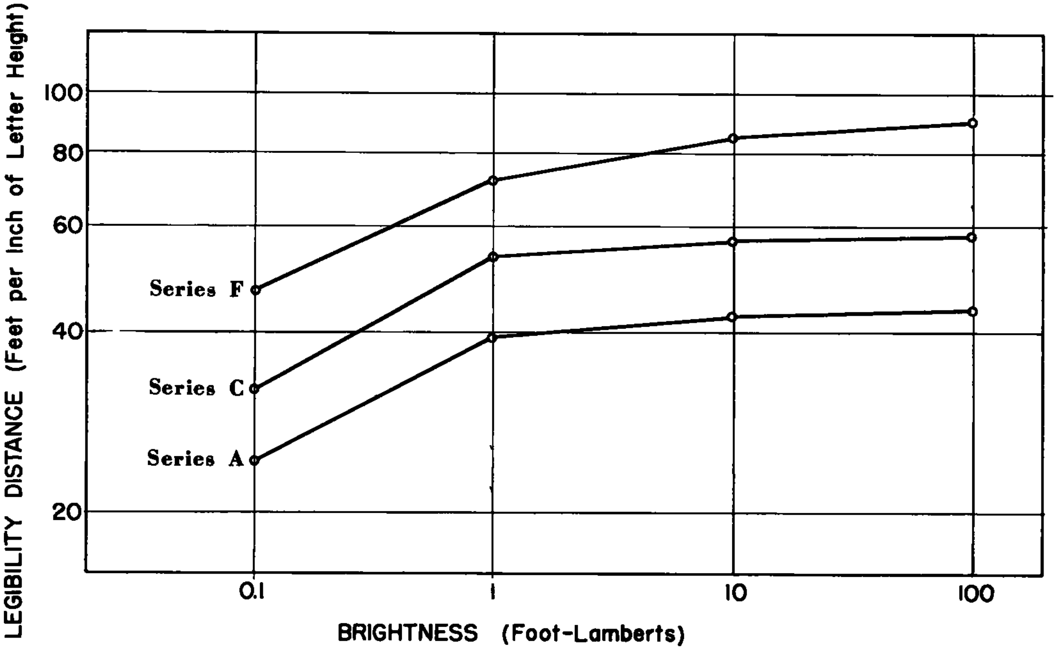

Figure 7. Results for letter series by brightness.

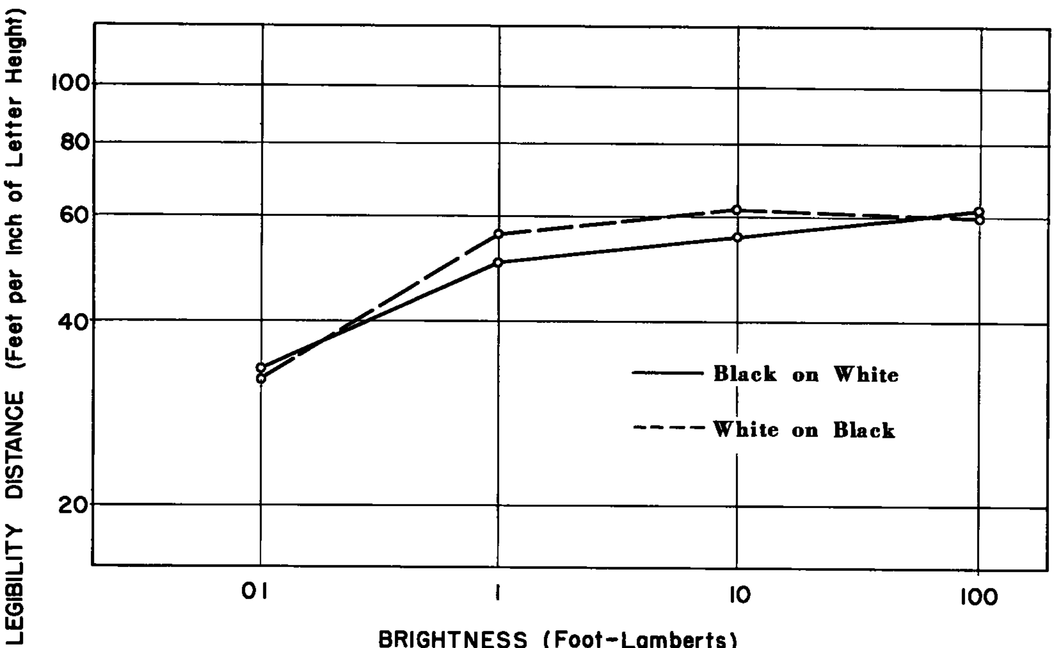

Figure 8. Results for contrast direction by brightness.

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-

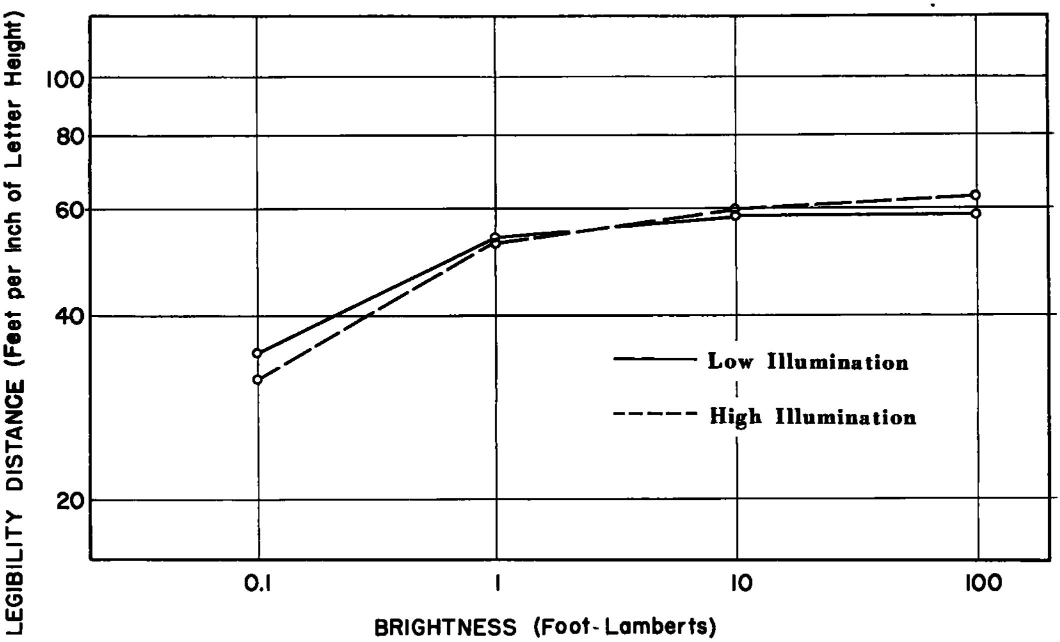

Figure 9. Results for surrounding illumination by brightness.

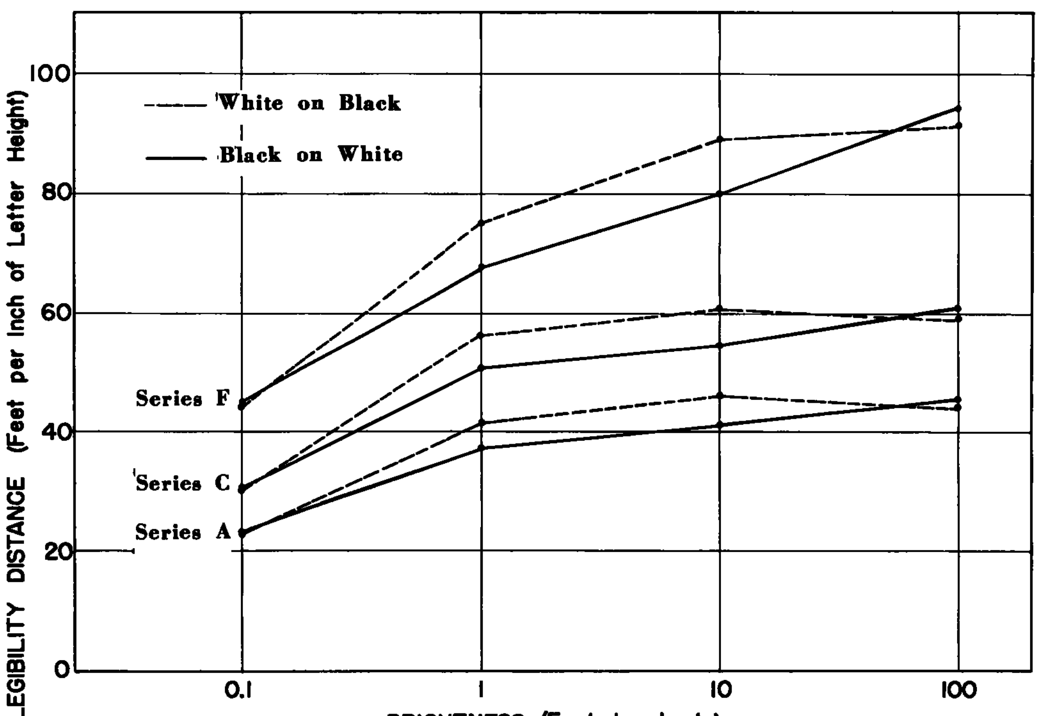

Figure 10. Overall results for high surrounding illumination.

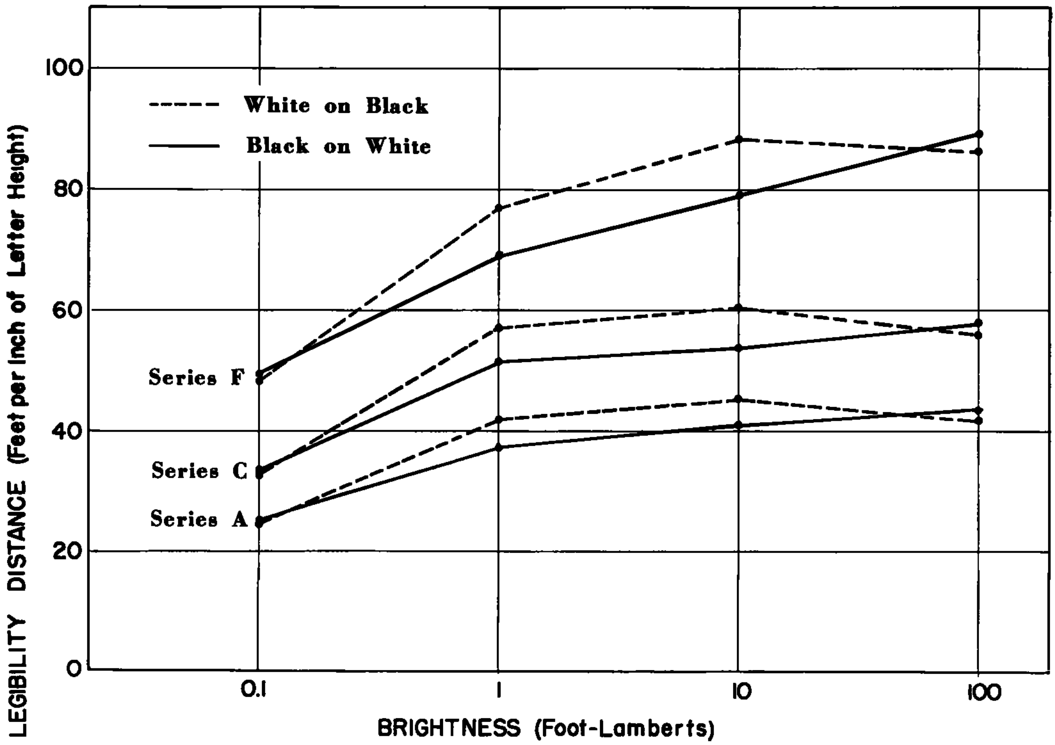

Figure 11. Overall results for low surrounding illumination.

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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