Luminance and Contrast for Sign Legibility and Color Recognition

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A laboratory study of sign legibility has shown that a contrast of between 30 and 50 percent is required to maintain 75th percentile legibility. Legibility distance increased gradually with greater contrast to about 80 percent; above a luminance ratio of 5 to 1, legibility did not increase greatly. As ambient levels increased, legibility distance increased linearly with the logarithm of either the letter or the sign luminance, whichever was greater. Five color combinations were measured. This report gives additional results on color recognition and applies the effects of luminance and contrast to legibility distance for 11 color combinations, after corrections were made for letter and stroke width. A method for estimating legibility was developed for black and white letter and sign combinations. The effects of luminance and contrast on color recognition at five ambient levels showed the need to increase luminance and contrast as ambient levels increase. Laboratory luminance data, confirmed by two sets of outdoor measurements, furnished a basis for determining the luminance ratios used in the legibility estimates. A basis for estimating glance legibility distance in relation to ordinary legibility (long viewing time) is suggested.

Results have been previously reported of a study of luminance and contrast effects on legibility of certain highway sign color combinations (1). The study included legibility measurements for five color combinations in the laboratory and for two color combinations in the outdoors.

This paper reports laboratory color recognition results for luminance and contrast measurements of colored targets not included in the previous report (1). It provides estimates of luminance requirements for color recognition and legibility of color combinations. Since data and corrections were used from the earlier report, a brief review is included.

Colored slides were projected in a darkroom laboratory. Each slide carried a series of small target signs. Neutral overlays were used to reduce the luminance of colored materials in the simulated signs, and the signs were then photographed. Average luminance of the slide background was varied to furnish different ambient levels simulating rural, suburban, and brightly lighted city conditions. Two series of target signs in seven colors and two series of target signs carrying a capital letter C or O with different orientations were presented on the slides. Legend and sign luminance in each series varied systematically. Letter width was four-fifths of the letter height, and stroke width was one-fifth of the letter height. Laboratory subjects totaled 150 male and female college students. After adapting to darkroom conditions, the subject called out the color or letter orientation in each series of signs. Each subject, without knowledge of results, viewed a total of 51 slides, which included 8 to 16 target signs, in about 45 min. An experimenter recorded the calls of the subject.

In the outdoor observations, subjects viewed test signs under high- and low-beam headlights. A gray panel beside the test signs was illuminated to furnish three ambient luminances. Each test letter was a square E made of two types of reflective materials modified to provide a range of luminance and contrasts. Two color combinations were used—white on green and black on yellow. Each letter was 30.5 cm (12 in) in height and placed on a 45.7-cm (18-in) sign. Ten signs, all of one color combination, were viewed in each run. Subjects observed in groups of six while riding in a slowly approaching station wagon. Test signs were set up in a different preplanned randomized order for each run. Fifty adult male and female volunteers served as observers, and each observer recorded the orientation of the test letter.

Luminance measurements were made with a Pritchard telephotometer having a photopic correction for human visual sensitivity. The laboratory test signs were projected on the screen and measured from the position of the observer's eye for each of the five studies of ambient levels. Luminances of outdoor test signs and sign materials were measured under headlights from distances of 60.9 and 152.4 m (200 and 500 ft).

Three methods of calculating the contrast between sign and background or between legend and sign were used.

1. Percentage of contrast:

$$(L_1 - L_2)/L_1 \times 100 \quad (1)$$

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where

L_1 = the higher luminance and
L_2 = the lower luminance (letter luminance in the case of white letters and sign luminance in the case of black letters).

2. Luminance ratio (LR):

$$L_1/L_2 \quad (2)$$

3. Contrast as used by Blackwell (2):

$$\Delta L/L_2 = (L_1 - L_2)/L_2 \quad (3)$$

L_1 and L_2 can be easily calculated from LR. It is convenient that $\Delta L/L_2$ = LR - 1.

LABORATORY PROCEDURE

For a given ambient level, a contrast of between 30 and 50 percent (2 to 1 luminance ratio) proved to be the minimum contrast below which 75th percentile legibility was lost. Above that contrast level, legibility distance increased gradually on the average to above 80 percent contrast (5 to 1 luminance ratio). Above that luminance ratio, legibility did not increase greatly.

As the ambient level increased and data points were averaged for different luminance ratios, the legibility distance (D_L) increased linearly with the logarithm of luminance (letter luminance for white letters and sign luminance for black letters on white or yellow signs). The slope of the average trend line was steeper for higher contrast color combinations and flatter for color combinations of lower contrast. This resulted in a fan-shaped set of trend lines.

OUTDOOR PROCEDURE

The outdoor legibility distances under high-beam headlights also showed a linear trend of average and 85th percentile legibility when plotted against logarithm of luminance. These trend lines for the white on green and black on white were essentially similar to the laboratory trend lines for equivalent legibility distances. Legibility distances under low-beam headlights, however, were greater than had been expected from laboratory results. Under both headlight conditions, the lower luminance material gave shorter legibility distances than the higher luminance material.

The longer than expected legibility distances under lower luminance (low-beam headlights) were attributed to the effects of unlimited viewing time rather than the short viewing time allowed in the laboratory method. Therefore, it appeared that short-time glance legibility, which is important for automobile driving, requires high luminance. Greater legibility (in the laboratory) at high luminance for black letters on yellow than for white letters on green was attributed to a spreading effect of light in the eye. This hypothesis was confirmed in the outdoor observations by comparing the height of test letters of wider and narrower strokes (7 to 1 versus 5 to 1 ratios of height to stroke widths).

COLOR RECOGNITION RESULTS

Before interpreting and applying the legibility results to the new sign and legend color combinations, it is necessary to examine in some detail the results of the color recognition study. Proper color recognition is important because color coding is used to indicate the type of sign and message. The luminance values of the colored target signs furnished data for estimating legibility.

Two series of colored target signs were used to determine the sign luminance needed for color recognition that was 75 percent correct. Table 1 gives the sign luminance required for each of the five background luminances for 75 percent correct color recognition. It also gives the luminance ratios of the sign to background-luminance level. The zone beyond which colors were confused (less than 75 percent correct color recognition by the 30 subjects in each of the five studies) was determined by a visual comparison of graphic tabulations of the results for each sign color and luminance level.

Since the background luminance increased from study to study, higher sign luminance for each of the seven colors in this part of the experiment was required for color recognition (Table 1). For a given background level, green and blue were recognized at a lower luminance than were white, yellow, and orange. The larger red signs were recognized at luminance similar to that for yellow and orange, but the smallest red signs were recognized at lower luminances.

The luminance ratio of sign to background was somewhat higher for the darkest ambient luminance than for the four studies with higher ambient luminances. Conversely, with a few exceptions, the luminance ratio was lower for signs viewed against higher ambient luminances.

Since brown was often confused with other colors (red and orange especially), a 75 percent correct performance was not obtained. Red and orange were confused with each other to a considerable extent. The smallest red signs were correctly recognized at low luminance levels. This relation was contrary to relations established for the other colors.

Discussion of Color Recognition Results

Although color recognition was achieved at low luminance levels against a low ambient background, the luminance ratio of sign to background was higher for the lower luminance levels than for the higher luminance levels. For the higher luminance levels, the sign-to-background luminance ratio was between 4 and 5 to 1 for green and blue and from 10 to 20 to 1 for red, orange, yellow, and white. These ratios were similar for the four higher luminance levels (within the variation to be expected of the type of subjective judgment inherent in this type of experiment).

At the highest ambient level—15.25 cd/m^2 (4.45 ft-L)—orange, red, yellow, and white may have suffered from a gold tone in the projection of the dark background slides on the high-gain screen. The fact that green and blue were most easily recognizable at low luminance levels can be expected from the known sensitivity of the human eye for these wavelengths under dark-adaptive conditions.

Application of Color Recognition Results to Highway Signs

From the results given in Table 1, it may be concluded that up to the medium background level of study 5—1.54 cd/m^2 (0.449 ft-L)—a luminance of 8.57 to 30.8 cd/m^2 (2.5 to 9.0 ft-L) will give satisfactory color recognition for all colors. This medium background would simulate a lighted suburban condition. For the higher brightness backgrounds, the luminance required for satisfactory color recognition is between 34.3 and 102.8 cd/m^2 (10 and 30 ft-L), with some possible exceptions. These luminances make possible signs of sufficient contrast for legibility in both darker and medium levels of luminance.

The range of 82.2 to 343. cd/m^2 (24 to 100 ft-L) required for color recognition against the highest luminance background would cause no problem of satisfactory

contrast for legibility with white letters on green or blue signs or for black letters on signs of other colors. There might be a problem if white letters are used on red or brown signs. Since brown signs were confused at all luminance levels, this indicates that brown is not a good color to use for a sign when to distinguish it from a red or orange sign is critical to transmitting meaning.

OBSERVED LEGIBILITY AND LUMINANCE OF COLOR COMBINATIONS

As previously mentioned, the equivalent legibility distance (calculated from visual angle) for 75 percent correct responses in the laboratory when plotted against the logarithm of luminance resulted in a family of straight lines. Since square letters were used for the outdoor legibility observations and stroke-width comparisons in the previous studies, it seemed best to make estimates for square letters in this study. From the previous daylight studies, it is known that legibility distance increases with letter width if letter height is constant. Accordingly, our laboratory legibilities were corrected for square-letter width (laboratory letter width was four-fifths the letter height), resulting in the average trend lines shown in Figure 1. The trend line for black on yellow in the laboratory fitted the outdoor black on yellow 85th percentile fairly well, but the white-on-green line indicated lower legibility distances than those obtained from the outdoor observations. These comparisons were made with the higher luminance under high-beam conditions.

There was a possibility that by averaging all data points (all contrasts), the legibility trend lines might be unduly influenced by aberrant data points. Therefore, the higher data points of the legibility versus luminance plots were averaged to produce trend lines; the legibility points that appeared to be too low were omitted. The average trend lines appeared to fit the outdoor data equally well. Since the average is more conservative, the average trends were used for estimating legibility of the different color combinations and contrasts.

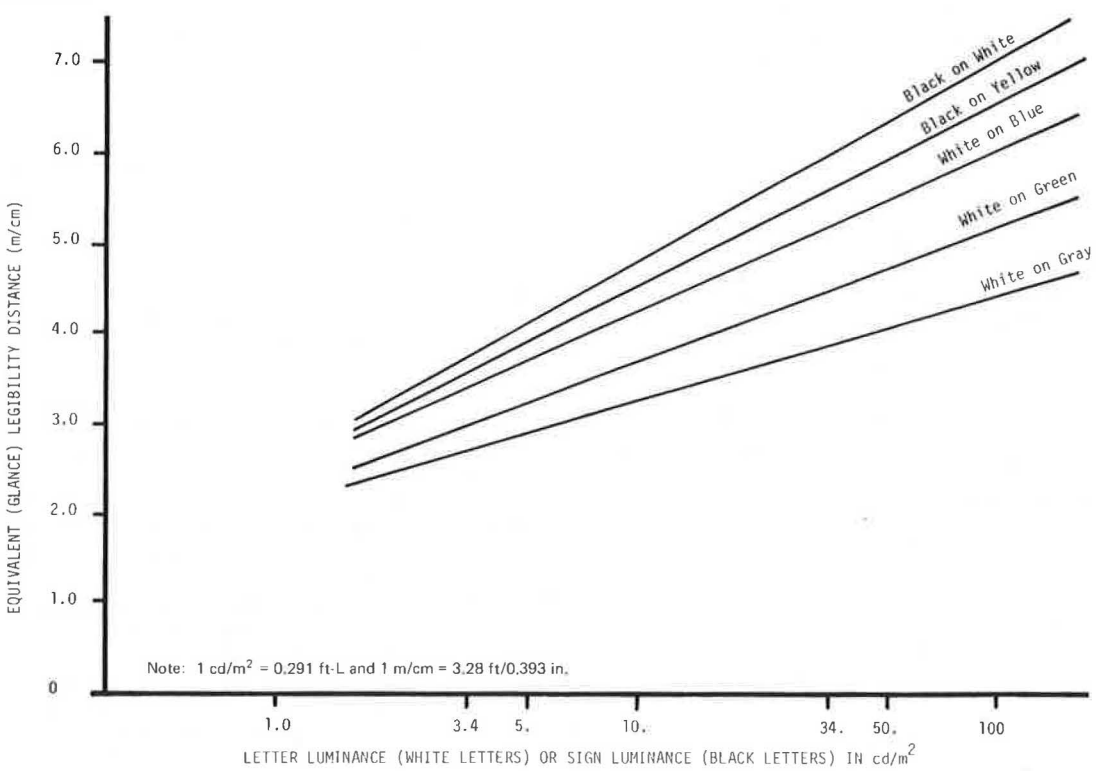
Table 1. Summary of color recognition and luminance.

Study Number	Average Ambient Background Luminance (cd/m²)	Color: White (cd/m²)[a]	White LR[b]	Yellow (cd/m²)[a]	Yellow LR[b]	Orange (cd/m²)[a]	Orange LR[b]	Red (cd/m²)[a]	Red LR[b]	Brown (cd/m²)[a]	Brown LR[b]	Green (cd/m²)[a]	Green LR[b]	Blue (cd/m²)[a]	Blue LR[b]
1	0.127	2.98	23.5	6.17	48.6	3.22	25.4	2.12	16.7	>2.40	–	1.71	13.5	1.30	10.6
2	0.466	7.26	15.6	9.49	20.3	11.0	23.6	7.26	15.6	>8.22	–	2.91	6.3	1.13	2.4
5	1.54	26.24	17.1	20.9	13.6	32.4	21.1	11.1	7.3	>37.7	–	8.91	5.8	8.57	5.6
4	7.30	87.36	12.0	217.6	30.0	113	15.5	95.9	13.1	>109	–	34.3	4.7	41.1	5.6
3	15.25	274	18.0	274	18.0	479	31.5	343	22.5	>363	–	115	7.5	83.9	5.5

Note: 1 cd/m² = 0.291 ft-L.

[a] Luminance. [b] Luminance ratio.

Figure 1. Average legibility for color combinations.



DISCUSSION AND APPLICATION OF STROKE-WIDTH EFFECTS

The stroke width used in the laboratory study (stroke width equal to one-fifth of the letter height) is similar to that of the modified series E and F of the U.S. standard alphabets. Our laboratory results suggested that the effect of spreading of light in the eye from the higher luminance white letters tended to reduce legibility of the white letter on a darker sign. A reverse effect would be expected with black letters on a light sign. The outdoor results that compared legibility of four narrow-stroke letters with that of four wider stroke letters confirmed that hypothesis. The narrower stroke width of the narrow square letters used outdoors was one-seventh of the letter height, which is similar to that of some of the narrower stroke U.S. standard capital letters.

The increased legibility under high luminance of narrow-stroke white letters on a dark sign and the reduced legibility of black letters with a narrower stroke width are consistent with experimental results reported by others (1, 2, 3). Also, Anderton and Cole (4) used a red annulus on a speed sign and compared a standard, a wide, and a narrow stroke width. The narrow stroke width caused the red annulus to become washed out. This gave a shorter legibility distance for the narrow-stroke red-on-white combination, an effect similar to that with our black-on-white narrow stroke width.

On the average, the legibility distance for the narrow stroke increased about 10 percent for the white letters and decreased a similar amount for the black letters. Thus, a stroke width one-sixth of the letter height would be the best compromise, for practical purposes, if the same stroke width is to be used for both color combinations.

Accordingly, the laboratory trends were corrected for stroke width before estimating relative legibility distances of color combinations. Figure 2 shows the average trend lines corrected for a stroke width of one-sixth of the letter height. This correction results in a logical series of trend lines in which black on white is highest and white on blue and black on yellow are relatively close together. The correction for one-seventh of the letter height yielded a series of trend lines for the color combinations that was not as logical. Therefore, the one-sixth letter height correction was used for estimating the relative legibilities of the different color combinations.

To estimate the legibility trend lines for colors other than those described above, the luminances and luminance ratios for all the colors are needed. The open colors (i.e., without the neutral overlays used to reduce luminance) of the target signs used in the laboratory procedure furnished the needed data. Measurements of actual traffic signs in and around East Lansing, Michigan, were examined; the luminances of these signs were similar to those in the laboratory for intermediate levels of background luminance. Furthermore, shoulder-mounted sign luminances measured by Woltman and Youngblood (5) at 182.8 m (600 ft), using high and low beams, indicated that the laboratory mid-range luminance levels were in the same range as outdoor measurements.

ESTIMATED LEGIBILITY OF OTHER COLOR COMBINATIONS

Legibility levels and the trend-line slopes for the five color combinations in the previous report showed a relation to luminance ratio for each color combination. For a given luminance, a maximum and a minimum range of legibility can be obtained. By assuming that the luminance ratios from study 2 were representative, estimates of legibility distance were made for each color combination measured in the previous report and also for the new color combinations. Maximum and minimum legibility distances were determined from the average trend lines that had been corrected for square-letter width and for a stroke width one-sixth of the letter height as shown in Figure 2. After correction for this stroke width, white on black and black on white were assumed to give the same legibility distance. Based on these trend lines, maximum and minimum legibility distance values for 34.2 and 3.4 cd/m^2 (10 and 1.0 ft-L) were recorded. The difference between maximum and minimum legibility distance was proportioned according to luminance ratio to give ΔD_L. This amount was then subtracted from the maximum legibility distance to give the estimated legibility distance for the color at that luminance.

These calculations, using values for square letters, resulted in the trend lines shown in Figure 3. For series D letters, legibility distance would be four-fifths the values derived. It should be remembered that these estimates are for the glance legibility and for the colored materials measured in the laboratory. If there is a high negative contrast (white and yellow signs with black letters of very low luminance), it will be necessary to assume a luminance for black that is one-twentieth of the white-sign luminance.

The procedure for estimating legibility in terms of factors involving luminance ratios of legend to sign is based on reductions from maximum legibility distance (2). For an observer with 85th percentile visual acuity, 6.6 m/cm (55 ft/in) of letter height is a reasonable maximum, since 7.2 m/cm (60 ft/in) with a stroke width of one-fifth of the letter height corresponds roughly to normal acuity of 1.0 min of arc. The trend lines should not be used beyond such maximum values. These maximum values were also confirmed by the outdoor legibilities. The luminances of the projected target signs, even though they were carefully measured with a Pritchard photometer, were more variable than is desirable. Therefore, average trends and intermediate-level luminance ratios that were generally similar to our measurements outdoors were chosen for the estimates.

GLANCE LEGIBILITY IN LABORATORY AND FULL-SCALE LEGIBILITY RESULTS

As previously mentioned, the outdoor observations confirmed the laboratory results for high-luminance 85th percentile legibility distances. Distances were similar to the laboratory (equivalent) legibility distance values and to the luminance relationships for high luminance (high-beam headlights) for both standard- and high-luminance sign materials. However, for low-luminance (low-beam headlights) legibility distance, the outdoor full-scale observations gave longer legibility distances than the laboratory results would predict for both materials.

The laboratory measurements involved glance legibility because the observation time was limited and the subjects were required to call out letter orientation as each group of test signs was shown. For full-scale outdoor observations, the observation time was not limited. Each subject recorded his or her observations and looked at the signs when desired.

The laboratory trend lines fitted the outdoor high-luminance trend lines quite well. Previous studies by Forbes (5) and Hurd (6) have shown glance legibility to to give shorter legibility distances under high luminance (outdoor, daylight) conditions. This indicates that legibility under these conditions is a more difficult visual task. Therefore, it is reasonable to assume that glance

legibility would require higher luminance under night viewing conditions. This interpretation conforms qualitatively with the finding that shorter exposure gives a steeper curve of visual performance plotted against the logarithm of luminance (2). This led to the use of a 0.2-s exposure in measuring the effectiveness of illumination for visual tasks.

ORDINARY AND GLANCE LEGIBILITY REQUIREMENTS

Because the results of the laboratory procedure were used, the estimates are for glance legibility of the different color combinations. Ordinary (long) legibility and glance legibility relations were examined in outdoor observation data and trend lines (7). By assuming that the high luminance trends represent glance legibility and

Figure 2. Laboratory legibility and luminance.

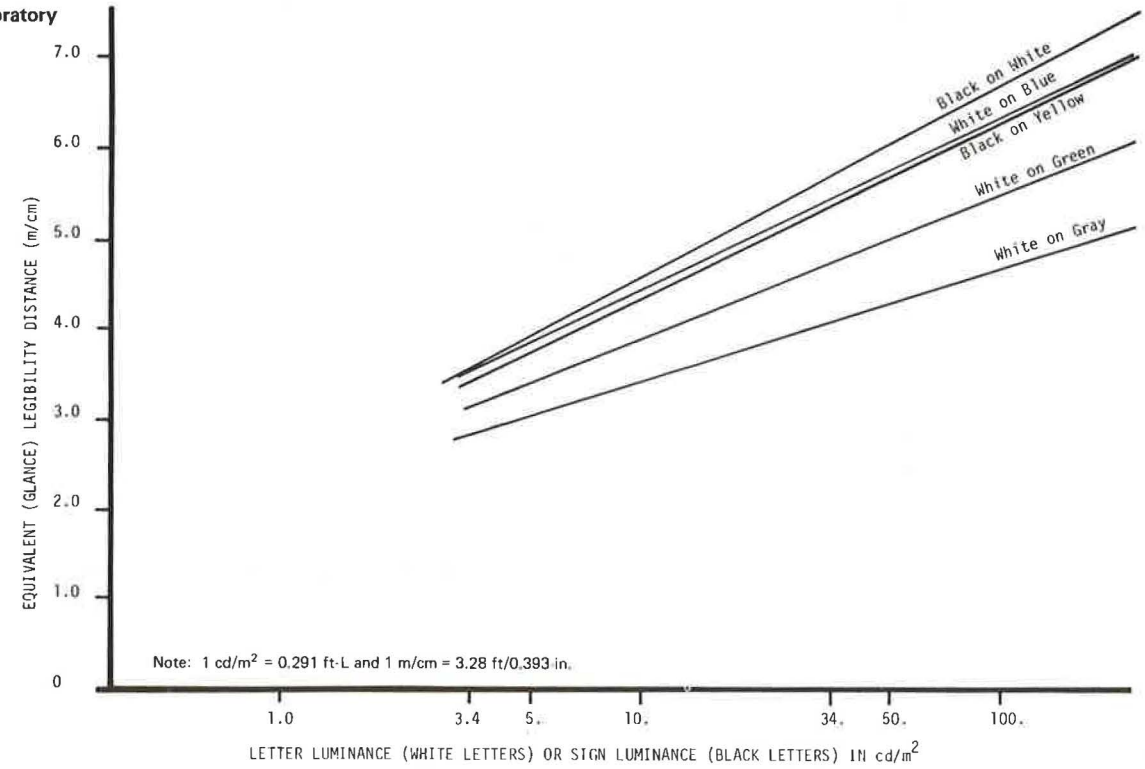


Figure 3. Legibility estimates for laboratory color combinations.

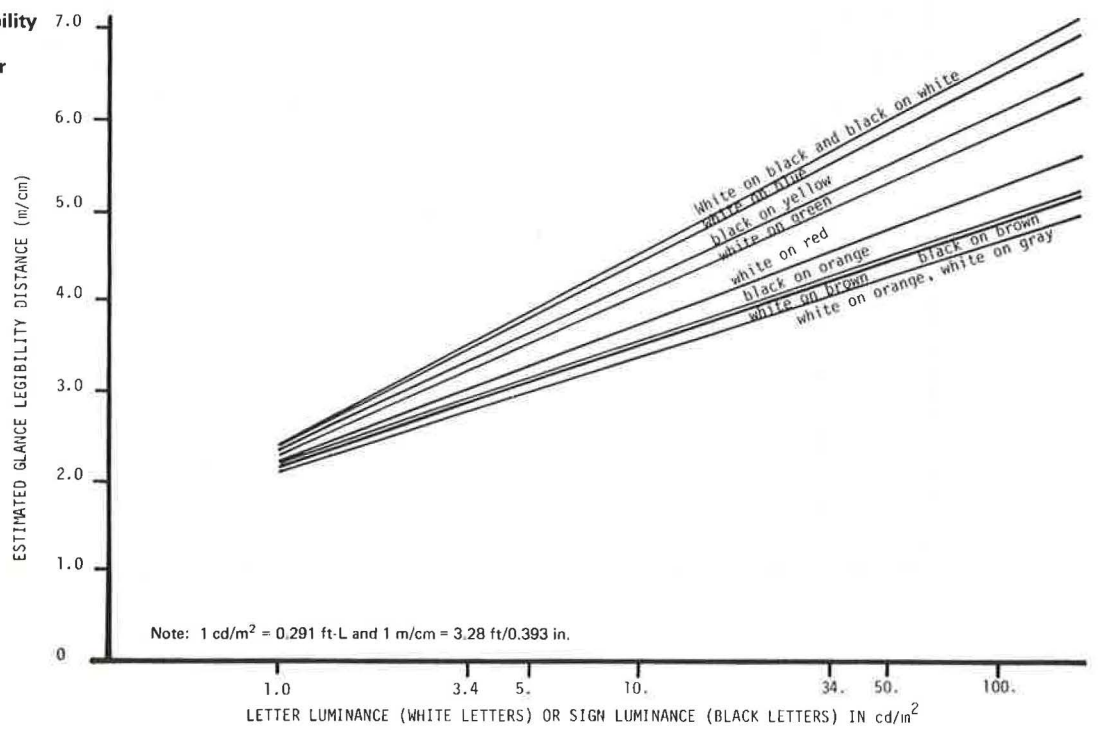


Figure 4. Sign and background luminance.

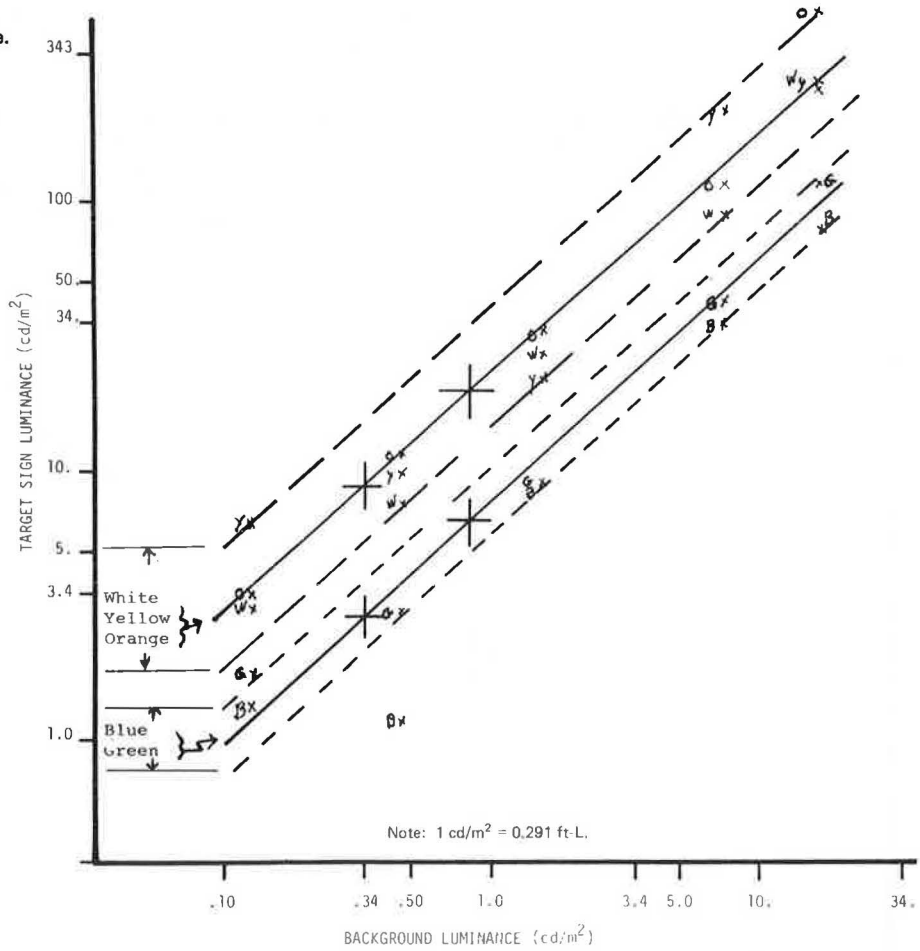
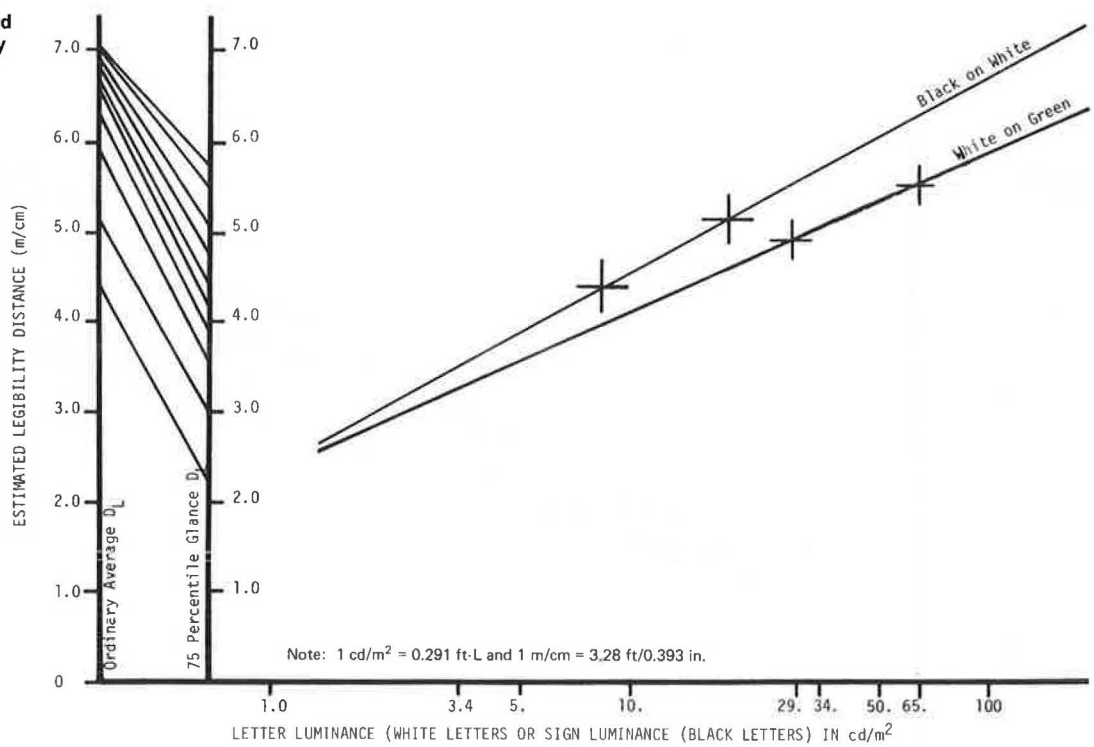


Figure 5. Estimated glance and ordinary legibility.



low luminance represents ordinary legibility, the relations of glance legibilities to those obtained with long target exposure can be roughly estimated as follows:

$$D_L = 1.5 \times D_{L(glance)} \quad (4)$$

The maximum legibility distance is 6.6 m/cm (55 ft/in).

Since the measurements for legibility distance were based on 75 percent correct responses of subjects in the laboratory, the 85th percentile responses obtained outdoors were more comparable than average distances as a check of the laboratory results. Legibility estimates were made in terms of the 75th percentile values determined in the laboratory. The 75th and 85th percentile values are ordinarily similar and are most applicable since they provide for most drivers. In comparing these values with average values obtained in other studies, however, it should be remembered that our outdoor observations showed average legibility distances to be about 1.2 m/cm (10 ft/in) of letter height greater than the 85th percentile values or from 15 to 20 percent greater for maximum values of D_L.

In the outdoor observations, the use of a single test letter with four possible orientations is similar to the use of scrambled letters under the same conditions. Previous studies have shown that familiar words and syllables are read (in daylight) at 7.2 to 8.4 m/cm (60 to 70 ft/in) and scrambled letters are read at about 6 m/cm (50 ft/in).

The legibility versus logarithmic luminance value lines of Figure 2 were calculated from the value lines of Figure 1 that averaged observations across the five backgrounds. As would be expected, the range of observed data points in the five studies overlapped. The background average luminances for each study are given in Table 1.

APPLICABILITY OF LEGIBILITY ESTIMATES

The calculated trend lines of Figure 3 approximate legibility distances for our colored materials, which are similar to those in traffic signs. The following example illustrates an estimation method that can be used for different sign color combinations if appropriate measurements of background, letter, and sign luminance (corrected for human color recognition) are available.

The legibility distances observed and those estimated are based on luminance and the luminance ratio between sign and legend. These quantities vary for highway signs according to the mounting position (by the roadside or overhead) and whether headlight beams are low or high. However, if luminance measurements for these conditions are available or can be made, the estimates from this procedure should be applicable.

The following is the method for relating glance and ordinary legibility estimates to background, sign, and letter luminance and to color recognition. The color recognition results shown in Table 1 and the equivalent legibility of color combinations shown in Figure 3 must be used together for adequate application. Figure 4 shows a plot of two color groupings that require similar luminance and contrast for color recognition. Sign luminance is plotted against the background luminance from Table 1. The white, yellow, and orange values give the upper band and the blue and green values give the lower band on the graph.

Figure 5 shows the estimated glance legibility trend lines for black on white and for white on green from Figure 3. Scales for estimating ordinary legibility from glance legibility data are shown on the ordinate. As previously mentioned, a very rough estimate of ordinary legibility can be obtained by multiplying the equivalent glance legibility by 1.5 with a ceiling of 6.6 to 7.2 m/cm (55 to 60 ft/in). The double ordinate gives an approximation derived by an averaging process from the trend lines (obtained from outdoor observations) that were related to glance legibility laboratory estimates from Forbes (5).

The ceiling of about 7.2 m/cm (60 ft/in) for average legibility distance is indicated by the convergence of the lines joining the two ordinate scales in Figure 5. This ceiling represents what would be expected from 20/20 vision. Greater ordinary legibility distances may be obtained by using a message familiar to subjects and by using subjects with higher acuity than normal.

To apply the combined results, the ambient luminance against which the sign will be viewed must be known. Figure 4 indicates the background luminance on the abscissa and, for the appropriate color trend line, the target sign luminance for satisfactory color recognition, on the ordinate. Figure 5 presents the sign or letter luminance on the abscissa and the equivalent glance legibility on the first ordinate. The slanting line to the left ordinate scale shows the ordinary legibility distance.

In the case of white letters on green or blue, the letter luminance must be determined from the sign luminance. The sign luminance determined from Figure 4 must be multiplied by the letter-to-sign luminance ratio (LR_{LS}). The luminance ratio for white on green used in the estimates was 11.4 (5). However, legibility levels off above 80 to 90 percent contrast; therefore, the more convenient figure $LR_{LS} = 10$ can be used. Figure 5 shows the resulting letter luminance on the abscissa and the white-on-green trend line indicates the estimates of glance and ordinary legibility distance on the ordinates. Examples of these procedures for a rural background with 0.34 cd/m^2 (0.1 ft-L) luminance follow.

1. Black-on-white sign: (a) For color recognition, read up on Figure 4 from 0.34 cd/m^2 (0.1 ft-L) to W-Y-O trend line and read across to ordinate = 8.6 cd/m^2 (2.5 ft-L) luminance for color recognition of white, yellow, or orange sign; (b) for legibility distances, read up on Figure 5 from 8.6 cd/m^2 (2.5 ft-L) to B/W trend line and read across to ordinate = 4.4 m/cm (37 ft/in) distance estimated for glance legibility or 6.6 m/cm (55 ft/in) for ordinary legibility.
2. White-on-green sign: Read up on Figure 4 from 0.34 cd/m^2 (0.1 ft-L) to G-B trend line, read across to ordinate = 2.9 cd/m^2 (0.85 ft-L) luminance for color recognition of green sign, and multiply by 10 (letter-to-sign luminance ratio) = 29.1 cd/m^2 (8.5 ft-L); read up on Figure 5 to W/G trend line from 29.1 cd/m^2 (8.5 ft-L) for letter luminance and read across to ordinate = 4.9 m/cm (41.0 ft/in) distance for glance legibility or 6.8 m/cm (57 ft/in) for ordinary legibility.

CONCLUSIONS

1. Viewed against five different ambient luminance levels, signs required increased luminance for color recognition as background luminance increased.
2. A contrast between the sign and the ambient background luminance levels of 80 percent to more than 90 percent yielded 75 percent correct color recognition under night conditions. Minimum contrast levels of at least 65 percent are recommended for maintaining a minimum level of sign visibility.
3. Legibility of the five sign color combinations at each ambient luminance level were lowest at a 50 to 60 percent contrast (legend to sign). Above an 80 percent contrast, legibility leveled off for each color combination

and ambient background level.

4. Ordinary outdoor legibility was approximately 1.5 times glance legibility for this study. It leveled off at about 7.2 m/cm (60 ft/in). A better estimate that includes the ceiling effect is given in the example of application of results. Both legibility functions increased as signs and surround luminances increased toward daytime levels.

5. Corrections for the effect of narrow versus wide strokes, for bright letters on darker backgrounds, and bright backgrounds having dark letters respectively were included in legibility estimates.

6. The method developed for estimating the glance and ordinary or static legibility of different color combinations is applicable when sign, legend, and ambient luminance values are available.

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REFERENCES

1. T. W. Forbes, B. B. Saari, W. H. Greenwood, J. G. Goldblatt, and T. E. Hill. Luminance and Contrast Requirements for Legibility and Visibility of Highway Signs. TRB, Transportation Research Record 562, 1976, pp. 59-72.
2. A Unified Framework of Methods for Evaluating Visual Performance Aspects of Lighting. International Commission on Illumination, CIE 19, Part 3, Appendix A, 1972, pp. 43-52.
3. C. Berger. Strokewidth, Form, and Horizontal Spacing of Numerals as Determinants of the Threshold of Recognition. Journal of Applied Psychology, Vol. 28, 1944, pp. 201-231 and 336-346.
4. P. J. Anderton and B. L. Cole. A Study of Alternative Designs for the Metric Speed Regulatory Sign. Road Safety and Traffic Authority, May 1974.
5. T. W. Forbes. A Method for Analysis of the Effectiveness of Highway Signs. Journal of Applied Psychology, Vol. 23, 1939, pp. 669-684.
6. H. L. Woltman and W. P. Youngblood. Indirect Factors Affecting Reflective Sign Brightness. Paper in this Record.
7. F. Hurd. Glance Legibility. Traffic Engineering, Vol. 17, 1946, pp. 161-162.
8. T. W. Forbes. Luminance and Contrast Requirements for Legibility and Visibility of Highway Signs: Interpretation and Application. Michigan State Univ., Final Rept., Part 3, April 1975.