SIGN BRIGHTNESS IN RELATION TO LEGIBILITY

T. M. Allen
G. M. Smith
M. H. Janson
F. N. Dyer

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ABSTRACT: Various combinations of black and white letters and backgrounds were night-tested in the field, using an internally illuminated sign, to collect data regarding the relationship between sign luminance and legibility over a wide range of ambient lighting conditions. Observers in three age groups were pretested for visual acuity and daylight sign legibility, before the night tests. Contrast level and direction were controlled, and the sign legend and background luminance were monitored photometrically. Minimum and optimum brightness values over a sign face are suggested for typical rural, suburban, and urban ambient illumination conditions. Recommendations are given for further needed research.

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SIGN BRIGHTNESS IN RELATION TO LEGIBILITY

It has long been known that the brightness required for sign legibility at night depends on ambient lighting conditions. Although modern reflectorized signs have better night legibility than previously used, painted signs, they are not a fully adequate solution in all situations. Engineers have found it necessary to provide artificial illumination in brightly lit urban areas if signs are to have adequate legibility. Since electrical power is usually readily available in such areas, artificial illumination is not excessively expensive. Although it is known that the higher the level of ambient illumination and the more glaring lights there are in the driver's field of view, the more luminance is required; no data have been available upon which standards for sign luminance could be based. A primary purpose of this study was to collect such data.

From previous research (1) it was known that in dark rural areas without headlight glare from approaching traffic, the optimum luminance of a sign is about 10 foot-Lamberts (ft-L). If luminance drops to about 1 ft-L, the decrease in legibility distance is not great, but further decreases in luminance result in serious loss of legibility. Even in dark rural areas, more sign luminance may be required where the driver faces the glare from headlights of approaching traffic, and certainly higher luminances are required in brightly lit areas with many glaring lights. This study was intended to find the relation between sign luminance and legibility, over a range of ambient illumination conditions from the darkest to the brightest a driver is likely to encounter.

In addition, the effect of reduced contrast, which occurs when the background as well as the legend of the sign is illuminated, was investigated. Such information would permit comparison of legibility of reduced contrasts with that of colored sign backgrounds, which were planned for study in a future experiment. Since signs with a dark legend on a white background are of interest, as well as white letters on a dark background, both were included in the experiment. Since changes in vision take place with age, different age groups were compared in their sign-reading performance. Although the findings of this study have indirect implications for reflectorized signs, such applications are beyond the scope of the present study. Although other characteristics of the sign legend (such as stroke width, letter width, and spacing) are of interest, and the luminance required may be affected by changes in such characteristics, this study is concerned only with Bureau of Public Roads "Series E" letters with stroke width and spacing as used for large signs on the Interstate System.

Previous Research

Beginning with the work of Forbes and his collaborators (2, 3), a number of studies of the legibility of highway signs have been reported. A complete review of this and related research, and an annotated bibliography, are given by Forbes, Snyder, and Pain (4). The relation between sign luminance and night legibility has been studied in the laboratory (5), and in a field validation study (1) on a dark open road without headlight glare. The present study can be considered an extension of this work, to encompass the range of ambient illumination a driver is likely to encounter.

To understand the effect of the luminance of a sign on the distance it can be read, consideration must be given to the adaptation level of the eye. On a dark open road the driver's retina is adapted to a low level, and his pupil is enlarged. In a bright urban area his retina adapts by becoming less sensitive to light, and his pupil is reduced in size admitting less light to the eye. At a given adaptation level and pupil size, acuity (the ability of the eye to see detail) increases with increasing luminance, up to a point beyond which further increases in luminance result in no further increase in acuity, or even a decrease in acuity. A simplified explanation of this relationship, and reference to basic literature was given in an earlier paper (5). Even for optimum sign luminance, however, the maximum legibility distance for a driver adapted to a dark rural road is about 15 percent less than in the daytime (3, 5); higher legibility distance should be obtainable in well-illuminated areas if the sign has optimal luminance.

In addition to adaptation level and pupil size, another factor affecting sign legibility is the presence of glaring light sources in the driver's field of view. In addition to headlights of opposing traffic, street lights, advertising signs, and even the sign being read may be sources of glare. Two types of effects of glare have been distinguished--discomfort glare and disability glare (6)--which behave quite differently. Although discomfort glare may affect the effort a driver will make to read a sign, the reduction of his ability to read it if he tries is a function of disability glare. The main source of disability glare is reduction in contrast of the visual image (6, 7). However, glare sources may also change the adaptation of the retina and the pupil size (8). It may even be possible for glare to improve the ability to see a very bright image when the eye is dark-adapted (9); such a phenomenon was reported by Forbes, Moscowitz, and Morgan (10), who found that observers could read a very bright sign better with headlight glare than without it.

Finally, the age of the driver may affect the luminance-legibility relation at various ambient illumination conditions. The aging eye has a smaller maximum pupil size (11, 12), and reduced retinal sensitivity in the fully dark-adapted eye (13). In addition, the reduction in acuity caused by glare increases very considerably with age (14). Since the effects of such variables on sign legibility cannot adequately be predicted from laboratory data, they must be investigated in the field.

Project Background

The proposal for this research project was submitted to the Bureau of Public Roads in February 1963, was approved in April 1963, and work began in July 1963. The intent of this study was to determine the background or legend brightness and legend-to-background brightness contrast, for optimum legibility of illuminated highway signs. From these determinations, recommendations and specifications were to be prepared for legend and background brightness of these signs.

The project's specific objectives were stated as follows:

"1. Determine a standard level of observer perceptive ability so that testing and interpretation of results can be standarized.

"2. Determine in the laboratory (or the field) the optimum combination of background and legend brightness for maximum legibility.

"3. Determine quantitatively the level of environmental illumination representative of three areas: rural, suburban, and urban.

"4. Determine the effect of environmental lighting on the proper level of brightness of the background and legend.

"5. Determine the influence of certain glare conditions on legibility.

"6. Determine the effect of legend size and design, and background color on legibility.

OBSERVERS, SIGNS, AND TEST PROCEDURE

Before considering the experimental procedures developed for day and night testing, the composition of the observer group and nature of the signs will be discussed.

Observers

The observers used in this study were Michigan Department of State Highways employees and retirees. They ranged in age from 18 to 81 years, and each possessed a valid driver's license. For test purposes, they were divided into three age groups: 18 to 37, 38 to 57, and 58 and above. They were predominantly men and were of high occupational status; almost all were from the Office of Testing and Research and the Office of Design.

Average acuity of observers, measured (with eyeglasses, if normally used for driving) using a Bausch and Lomb Orthorater, was 10.0--equivalent to 20/20 Snellen acuity. Although one would expect the younger group to have average acuity above 20/20 and the older group below 20/20, they were nearly equal--the younger and middle age groups averaging only slightly above 20/20 and the older group only slightly below.

Test Sign Messages

Test sign letters were made to specifications for Interstate guide signs. The sign permitted only three-letter words, which might differ greatly in legibility distance. To obtain words of nearly equal legibility, a preliminary experiment was conducted in the laboratory. The ten letters most frequently used in place names on Michigan's Interstate highways are A, D, E, I, L, N, O, R, S, and T. Sixty common words were constructed using Bureau of Public Roads "Series E" 1-in. high white letters on black cards. Sixteen highway employees were tested individually by walking toward each word until they read it correctly, and the distance recorded. Means and variances were calculated for each word; means ranged from 75 to 101 ft, and variances from 25 to 253 ft.

Eighteen words with nearly equal means and low variances were selected for use: AID, ARE, DEN, NOT, ONE, RAT, RED, ROT, SAD, SET, SIN, SIT, SOD, SON, TAR, TEN, TOE, and TON. Legibility distances for these words were obtained again in the daylight legibility trials, and corresponded closely to those obtained in the laboratory. The word AID had a large variance, however, and was replaced by NOD in the night experiment. All words with the letter L proved overly legible, so this letter was not used in the day or night experiments.

On both the day and the night test signs, the words were presented three at a time, with letters of 13.3-in. height at the top, 10-in. at the center, and 7-in. at the bottom. Spaces between lines were 6-1/2 and 4-in., and the top and bottom margins were 2-1/2 and 4 in. Margins at the sides varied with word length from 2-1/2 to 8 in. for the 13.3-in. letters, and were more than 6 in. for the smaller letters.

Daylight Testing

One hundred and fifty observers were tested on their sign-reading ability during daylight hours a few weeks prior to the night experiment. This was done by making trips past a truck-mounted sign and recording legibility distances for words displayed on the sign. These runs were made with two purposes:

1. To obtain acuity and sign-reading ability information on the observers, for use in the night experiment. These data were used to match groups for that experiment so that a given observer group would not accidentally contain persons of either all high or all low acuity.

2. To familiarize observers with the night testing situation, which was basically the same as used during the day. It was anticipated that a large portion of any learning and performance increment that would result from successive trials would occur during these daylight runs.

The 18 words selected for this experiment were presented three at a time on a 48-in. square sign face. This sign face was mounted at a height of 7 ft above the pavement on the back of a pickup truck parked at the curb of a little-traveled residential street (Fig. 1). White letters were presented on a black background for these daylight runs.

Observers were driven past the sign one at a time at 15 mph, starting each run 3000 ft from the sign. Observers read the words as soon as they could. This reading distance was recorded by an experimenter in the back seat, from an odometer that measured distance in thousanths of a mile and was connected to a fifth wheel. Each observer made four runs past the sign face. Between runs, the three words were changed so that each observer viewed 12 different words.

Means for legibility distances were computed for each observer and for each word. Legibility distances were divided by letter height in inches to make them equivalent for different letter heights. Average daylight

Figure 1. Daytime test area (above), with view of truck-mounted sign.

legibility for the observers was 73 ft per inch of letter height. As previously noted, average Orthorater acuity was 10.0, equivalent to 20/20 Snellen acuity. The correlation between the two measures was 0.7.

A variance estimate for each observer was obtained by taking the range of his reading distances after eliminating the most extreme legibility distance from the 12 per observer. An observer for whom this figure exceeded 25 percent of his average legibility distance was classed as an alternate in the main experiment and used only if no one else was available.

Night Testing

In the main experiments, which were conducted at night, the effects and interactions of six variables were investigated: observer age, sign luminance, ambient illumination, contrast direction, contrast level, and letter height. Included in the ambient illumination conditions were situations in which the signs were read with and without headlamp glare from vehicles placed to simulate opposing traffic.

Sign Design and Construction. The internally illuminated sign constructed for the night portion of the test program is shown in Figure 2. It was mounted on a hydraulically lifted platform on a 1-ton truck, which also carried a 110-volt generator with automatic voltage control.

The sign face itself was again a 48-in. square. Ordinary illuminated signs may have luminance variations of ten to one or more across the sign face, and are designed for a single luminance level. This sign face was designed to produce sign luminances from 0.02 to 2500 ft-L, with variation across the sign face not more than ± 15 percent at each luminance level. In addition, messages could be quickly changed for either white letters on a dark background or dark letters on a light background. Also contrast between legend and background could be either "high" (near 100 percent with legend or background black) or "lower" (near 75 percent), with the light portion of the sign having a luminance four times that of the dark portion.

Illumination was provided by use of twenty-six 40-watt cool-white fluorescent lamps (Fig. 3). Twenty-four of these were mounted horizontally, and two vertically at the ends of the horizontal lamps. Crinkled aluminum foil, lining the area behind the lamps, permitted adjustment

Figure 2. Illuminated case sign mounted on lift platform for night testing.

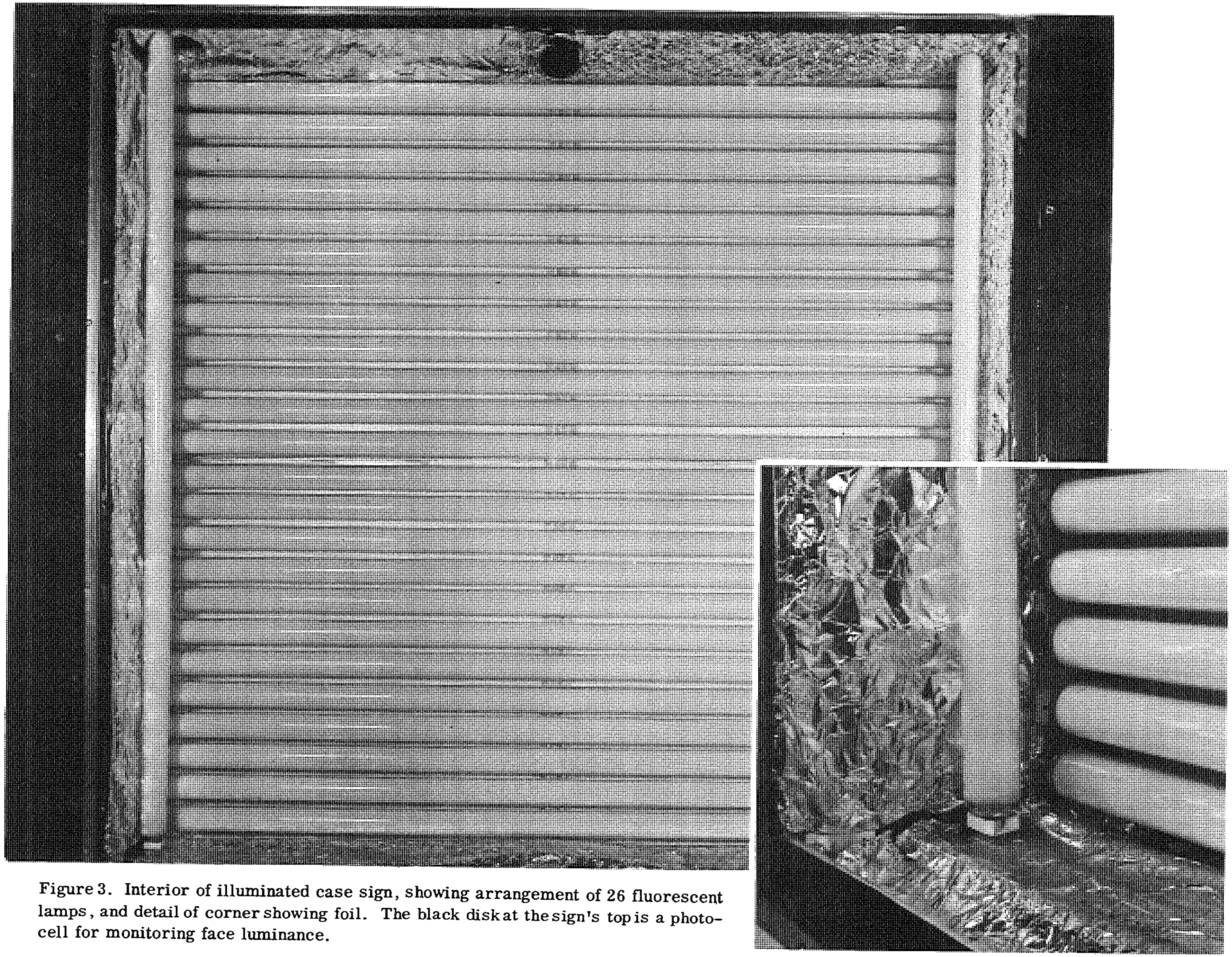


Figure 3. Interior of illuminated case sign, showing arrangement of 26 fluorescent lamps, and detail of corner showing foil. The black disk at the sign's top is a photocell for monitoring face luminance.

for even luminance across the translucent plastic face of the sign. Large changes in sign luminance were obtained by lighting different numbers of lamps (Fig. 4), and fine adjustments by variations in voltage. To obtain low luminance levels and maintain contrast levels in brightly lit areas where there was specular reflection from the shiny plastic face, a neutral density filter consisting of a large sheet of fine black broadcloth covered the sign face.

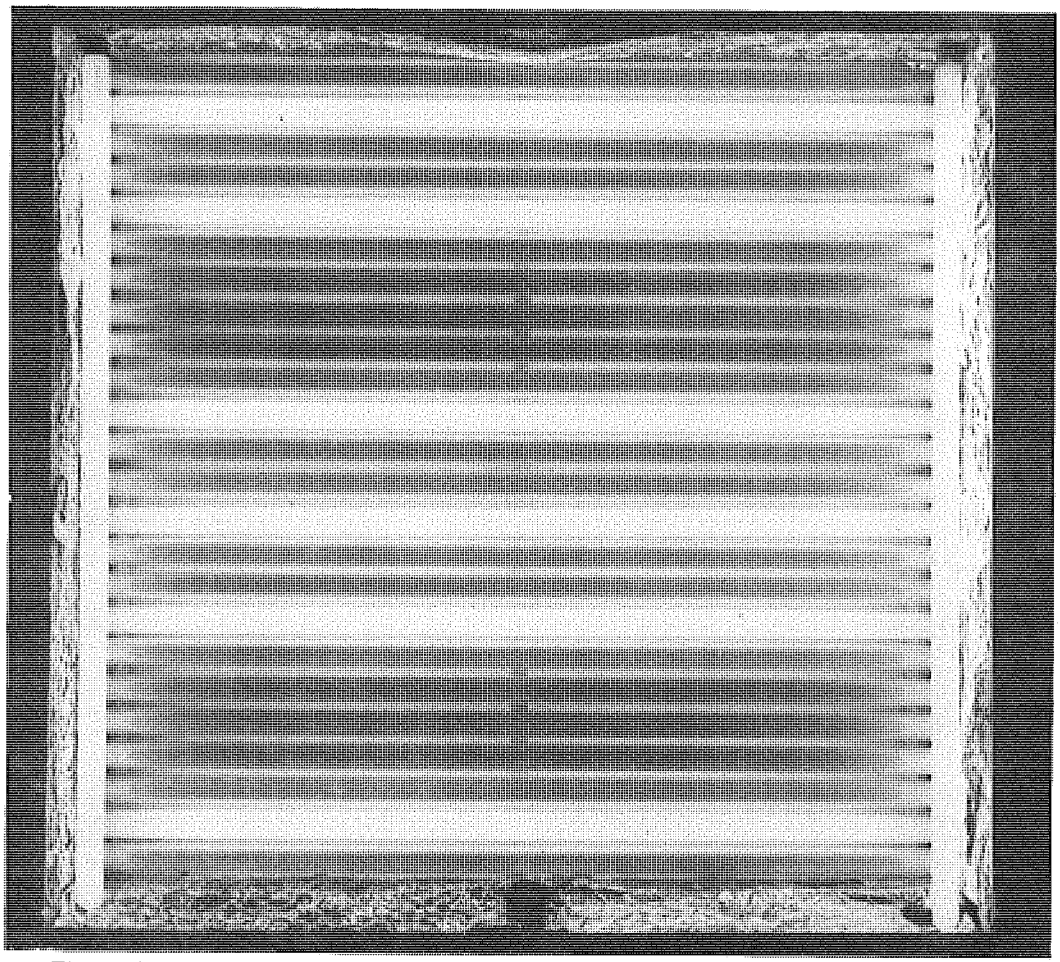


Figure 4. Large changes in face luminance were obtained by lighting varying numbers of lamps.

The fluorescent lamps were operated through standard "rapid start" ballasts and dimming ballasts, powered by a 2500-watt, 115-volt portable gasoline generator. A Sorensen Model FRLD 750 voltage regulator with maximum 0.35-percent distortion and one-cycle recovery time prevented flickering caused by the unregulated generator source. The variable transformer and switching arrangement depicted in Figure 5 were installed in

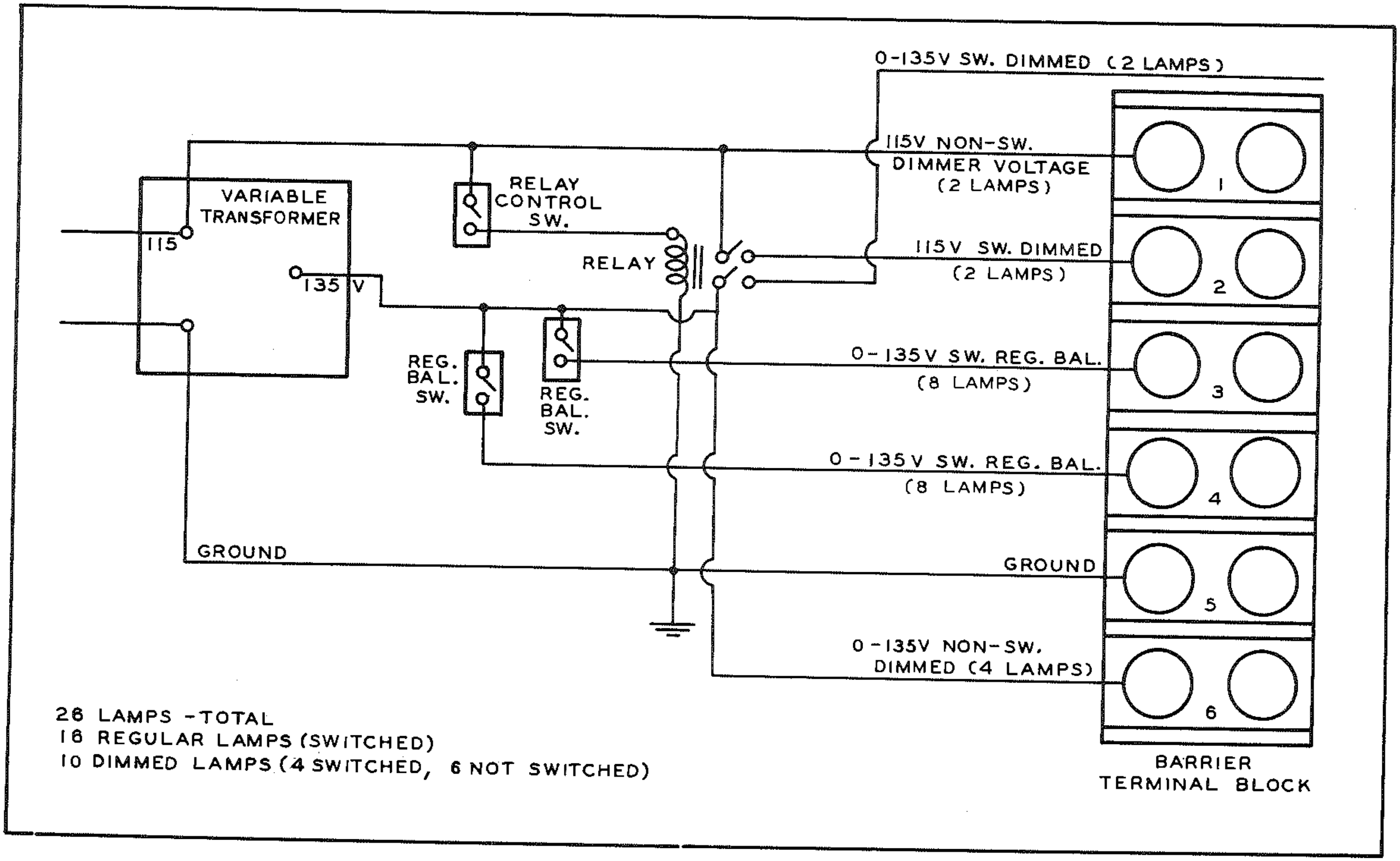


Figure 5. Voltage control and switches for test sign lamp ballasts.

a control van parked next to the sign truck, and connected to the sign case itself by a 20-ft, seven-wire signal cable. The wires were connected to the barrier terminal strip in the sign module and distributed to various ballasts and lamps as shown in Figure 6.

Levels of face or legend brightness were controlled by a combination of switching and dimming the array of 26 fluorescent lamps. The operator could obtain a coarse adjustment of sign brightness by an internally mounted photocell, or by an externally mounted photocell on an arm that swung on hinges in front of the face. A Pritchard photometer mounted on a truck 75 ft from the sign was used to monitor face brightness, and final adjustments were relayed by the photometer operator through an intercom to the control van. Figure 7 shows a typical array of vehicles involved in the night tests.

The combinations of variable voltage, switching off certain lamps, and the eight dimming lamps permitted continuous values of sign luminance throughout the entire range. Exact voltages and numbers of lamps lighted for each luminance level varied with ambient temperature and humidity. The lamps operated from standard ballasts could be reduced in brightness to 60 to 70 percent of their normal value by reducing voltage, and lamps operated from dimming ballasts could be reduced in this way to approximately 5 percent of original brightness without flickering.

Three different sign faces and four sets of letters were used to produce two contrast directions and two contrast levels. The faces were made of acrylic plastic. Letters were made of acrylic plastic or pressed board, formed on panels which were sized to obtain proper letter spacing within each word. The letter panels were slipped into position on tracks glued to the sign face. Typical faces and letters are illustrated in Figures 8 and 9.

For light letters on a dark background with 100-percent contrast, letter outlines were cut and removed from pressed board panels which had been painted black. Clear acrylic strips were glued to the pressed board panels to hold isolated letter portions in position. The dark background was completed by applying black opaque tape to sign face areas outside of the letter panel areas.

For light letters on a dark background with 75-percent contrast, the letter outlines were cut and removed from pieces of polyethylene film (25-percent transmittance). The remaining portion was glued to a clear

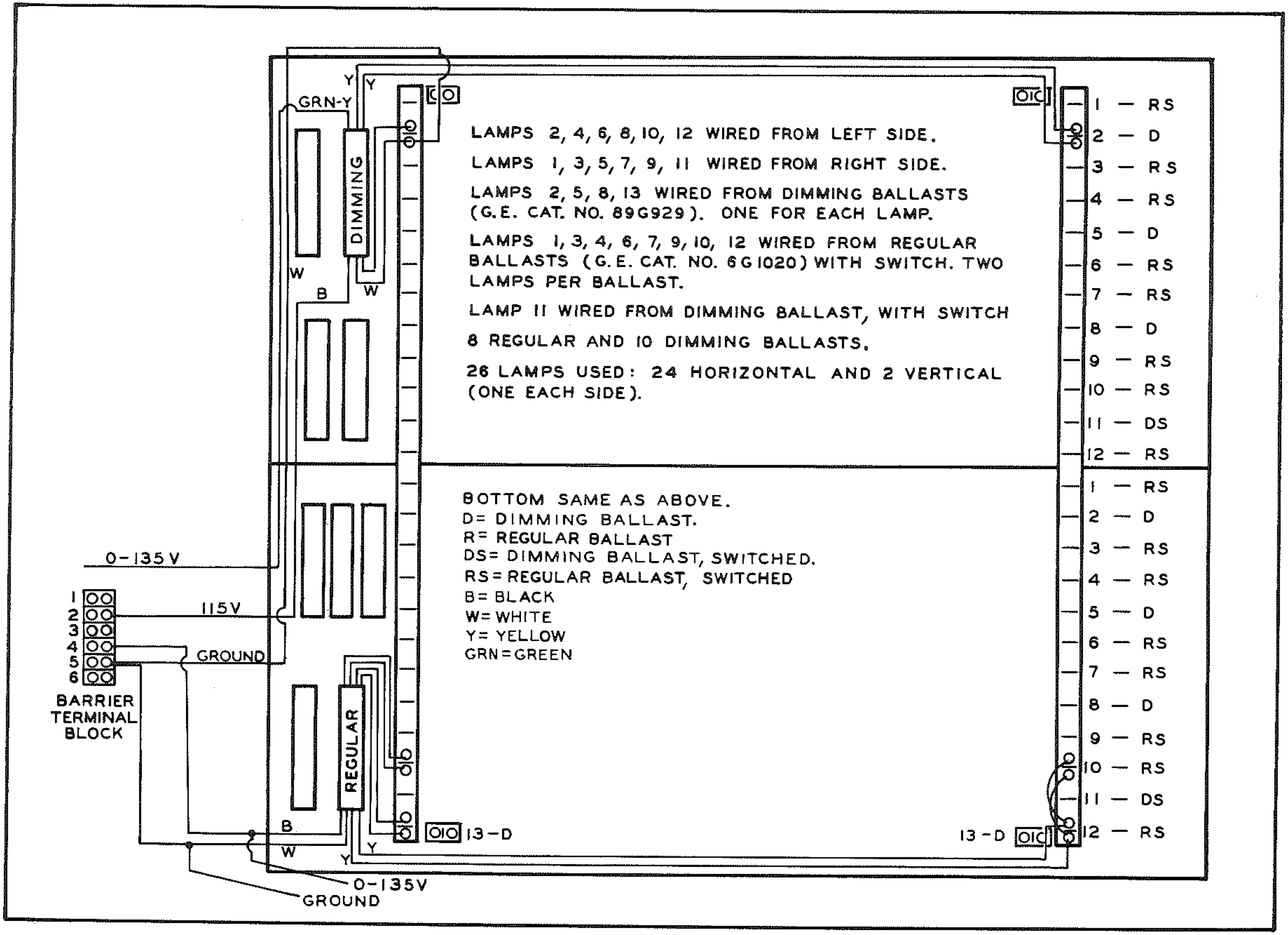


Figure 6. Test sign circuitry for ballasts and lamps.

Figure 7. Night equipment included (from left) test sign, test car (carrying observer) with fifth wheel, and brightness monitoring photometer mounted on pickup truck. Control van is behind test car.

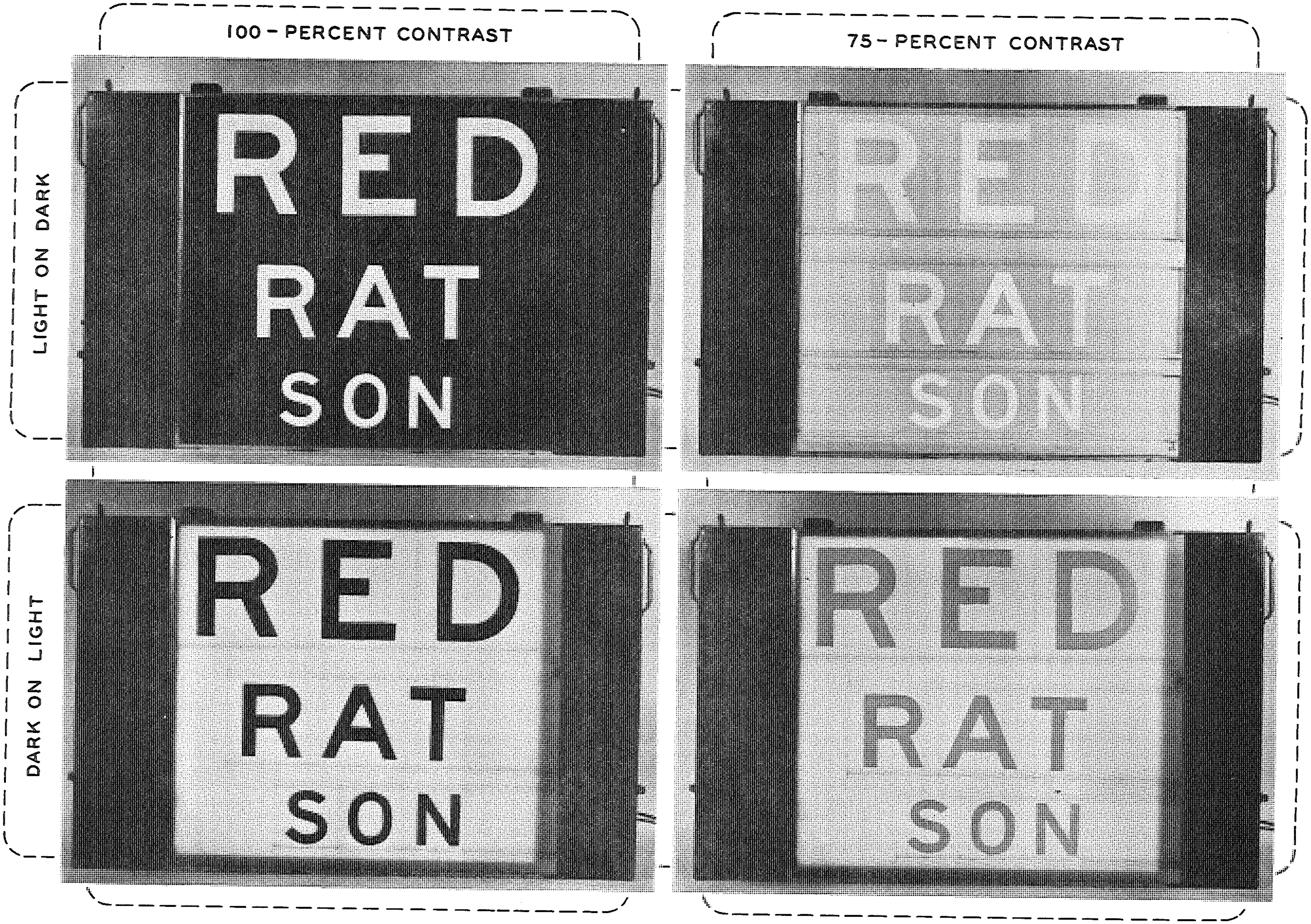


Figure 8. Typical combinations of sign face contrast level and contrast direction, photographed with internal and external illumination.

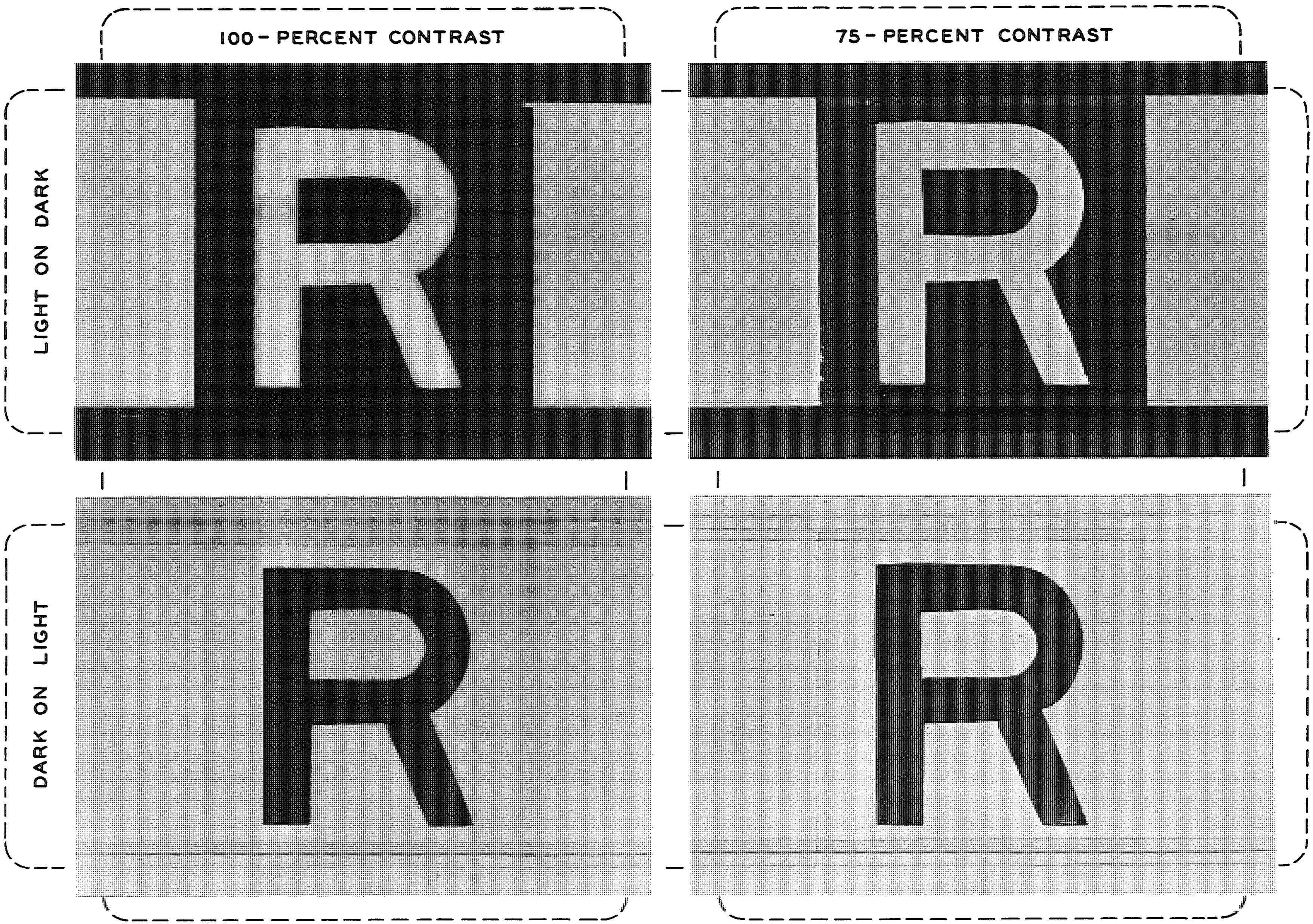


Figure 9. Typical combinations of letter contrast level and contrast direction, photographed with internal and external illumination.

acrylic letter panel. A translucent plastic sign face was covered with the 25-percent transmittance polyethylene outside of the letter panel areas to complete the background.

For dark letters on a light background with 100-percent contrast, the letters were made of black opaque polyethylene film glued on clear acrylic letter panels. A translucent plastic sign face provided the background.

For dark letters on a light background with 75-percent contrast, the letters were made of 25-percent transmittance polyethylene film glued on clear acrylic letter panels. The same translucent plastic face was used for the background.

Sign Variables. Sign luminance, contrast level, contrast direction, and letter height were manipulated at the sign itself. Each level of each of these variables was observed by each observer.

Five levels of sign luminance were used: 0.2, 2, 20, 200, and 2000 ft-L. A sixth level (0.02 ft-L) was originally included in the study, but it was difficult to obtain such a low level reliably, particularly in brightly lighted areas. This range of luminance was considerably greater than encountered in highway or advertising signs, either illuminated or reflectorized, and was selected to investigate the effects of a sign's being too bright as well as not bright enough.

As described previously, the sign face permitted presenting dark letters on a light background and light letters on a dark background, each with contrast near 100 percent (actually 93 to 97 percent) and near 75 percent (actually between 72 and 78 percent). Each presentation of the sign included three words, one each in heights of 13.3, 10, and 7 in.

Ambient Illumination. Illumination and glare measurements, using the Pritchard photometer, were made at numerous locations. Three were chosen to provide the lowest and highest levels that a driver was likely to encounter, and also medium ambient illumination typical of lighted freeways. In addition, at the low and medium ambient locations, the lighting level was increased by headlamps simulating opposing traffic. This provided a total of five levels of ambient illumination. Each observer viewed the full range of sign variables under one of these five ambient lighting conditions.

A rural road paved with bituminous aggregate was used for low ambient illumination. A distant house provided the only illumination at the eye other than that of the sign and the test car's headlamps on low beam reflecting from the roadway. Illumination at the eyes of the observer was as low as possible (less than 0.01 ft-c) for a person in the front seat of an automobile with the headlamps on.

The medium ambient location was the eastbound three lanes of a six-lane boulevard (Michigan Ave. between Lansing and East Lansing), as shown in Figure 10. The observer was shielded from headlights of opposing traffic by trees and shrubs in the 60-ft median. Illumination was provided by 400-watt mercury-vapor streetlight luminaires at a 31-ft mounting height, spaced along the right side at 150-ft intervals. There were no luminaires in the median. A small amount of advertising lighting, not near the roadway, was located along the route, adding only insignificantly to illumination and glare readings. Horizontal illumination ranged from 3 ft-c beneath the luminaires to 1 ft-c between luminaires. Average illumination in a vertical plane at the observer's eyes was 0.2 ft-c.

Washington Ave., the main street in downtown Lansing (Fig. 10), was used for high ambient illumination. This six-lane asphalt street is among the most brightly lighted in Michigan. Twin 1000-watt luminaires at a mounting height of 35 ft are spaced opposite one another at 118-ft intervals on each side of the 75-ft wide street. Pavement illumination ranged from 11 ft-c beneath the luminaires to 5 ft-c between them. Advertising lighting lines both sides of the street. Normal headlight glare from cars constantly traveling the opposite direction contributed very little to the total illumination at the eye, and no attempt was made to conduct legibility tests with and without headlight glare. Average illumination in a vertical plane at the observer's eyes was 3 ft-c.

For glare conditions at the low and medium ambient illumination locations, cars were parked at the left side of the roadway with low beams on and engines running to provide nearly normal voltage to the headlamps. Twelve cars were spaced at 100-ft intervals from a point near the beginning of the legibility run, along its length to a point 200 ft beyond the sign. Glare cars were placed about 17 ft laterally from the observer at the low ambient location, and 15 ft laterally at the medium location. Although a single car with high beams might provide worse glare conditions than these, glare conditions similar to those in this study would be commonly encountered in heavy traffic conditions.

At each location, the bottom of the sign was 14 ft above the pavement. The nearest edge of the sign was placed about 2 ft laterally from the traffic lane curb. At the low and high ambient illumination locations, test

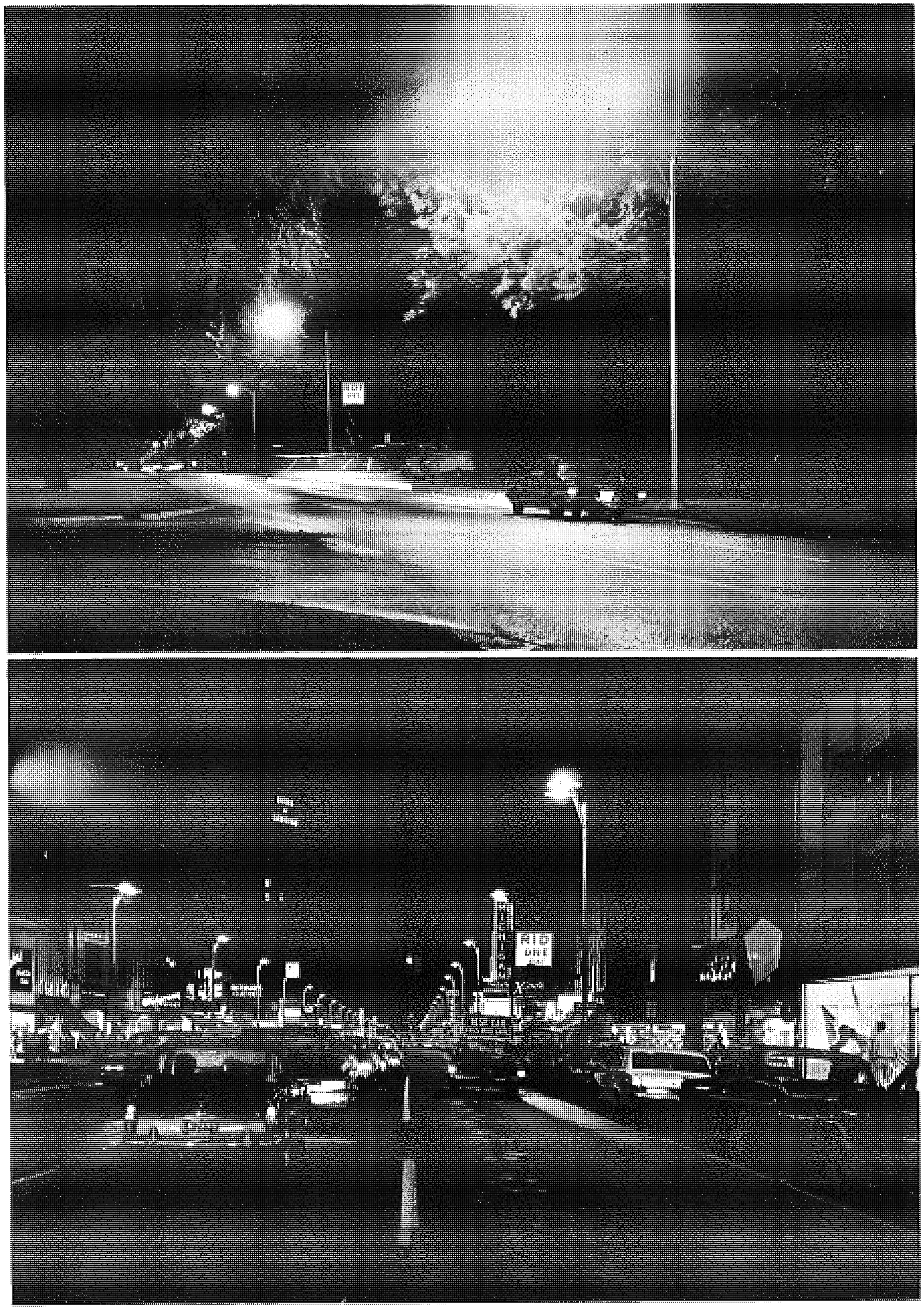


Figure 10. Night test areas for medium ambient illumination (top) and high ambient illumination (bottom).

cars traveled in the right lane, giving a lateral distance from the observer to the sign of 6 or 7 ft. At the medium illuminated location, travel in the inner lane was necessary for safety in left turns to return to the starting point. This gave a lateral distance of 25 ft from the observer to sign. While placement of an illuminated sign is not critically important, as for reflectorized signs dependent on headlamp beams, the glare from streetlight luminaires is dependent on sign position. While most sign placements would have glare from luminaires similar to that at these locations, if a luminaire were very near the line of sight of a driver reading a sign, legibility might be markedly reduced.

Experimental Procedure. Observations were made during hours of complete darkness in late summer and fall of 1964. Observers seated in the front seat with the driver were instructed to read the sign messages as soon as possible, and to continue reading until told their response was correct. An experimenter in the back seat compared observer response with a prepared data sheet. He recorded fifth wheel odometer readings at the instant of correct response, and also when the test car passed the sign. Test runs were coordinated by radio from the test sign and began at least 2000 ft ahead of the sign. Vehicle speed was maintained at approximately 15 mph.

Three observers were tested each evening, in separate cars, usually requiring at least 2-1/2 hr to complete all observations. At the low ambient location, cars maintained at least 300-ft headway so that headlamp beams or tail lights of one car would not affect the adaptation level of the eyes of the observer in another car. At the other locations, closer distances were permitted since automobiles contributed only a small fraction of the total illumination.

Each observer made 20 runs past the sign, in order to view all combinations of luminance, contrast direction, and contrast level. Since a sign face change was required for each contrast-level contrast-direction combination, each of the five luminance levels was viewed before making this time-consuming change. With this restriction, all experimental conditions and messages were assigned in random sequence.

In scheduling the night tests, it was recognized that a revised target date for completion of testing and autumn weather conditions made it inadvisable to attempt to include all 150 observers used in daylight testing. Further, because of illness, resignations, transfers, and other factors, the full total was no longer available. Owing to these considerations, a sample of 60 observers was selected (20 from each of the three age groups), with alternates designated from the remainder.

Since each of the 60 observers viewed the sign variables in only one of the five ambient conditions, there were 15 age-by-ambient condition groups of four observers each. To make groups as equal in ability as possible, the 20 observers in each age group were ranked by their daytime legibility scores, and divided into four blocks of five. The five observers in each block were then randomly assigned to the five ambient conditions. However, scheduling of observers was hampered by repeated cancellation of runs due to bad weather (rain or slight fog). When an observer could not be scheduled with the others in his group, an alternate was chosen having daytime legibility distance values as similar as possible. In order to complete the experiment before snow was on the ground, observers with acuities not closely matched were used. Possible effects of such imperfect matching will be discussed later in connection with test results.

RESULTS

Presentation of results of an experiment involving so many variables must be somewhat lengthy. After the data analysis has been described, each experimental variable will be taken up separately, and the results presented graphically to show the effect of sign luminance on legibility for each experimental condition. Interpretation of results in terms of their practical application will be deferred to the "Discussion" section of this paper.

Analysis

Mean log legibility distances, in feet per inch of letter height, were computed for each combination of experimental conditions, and an analysis of variance was carried out. The logarithmic transformation was used to make the linear model more congruent with the data. Since effects of variables are expected to be proportional--i.e., if an observer reads a sign twice as far as another observer under one experimental condition, he would be expected to read a sign twice as far under another condition--their logarithms are expected to be additive. An analysis without this transformation was also carried out, with almost identical results.

As mentioned in the description of procedure, observers were less well matched in daytime legibility than the experimental design had anticipated. In order to make comparisons of ambient night illumination conditions more accurate, each observer's scores were adjusted to equate them in terms of daylight legibility distances. For example, if an observer's daylight legibility distance were 10 percent greater than the average of all observers, his night legibility distances were reduced proportionately so that differences in daylight acuity were controlled. Such an adjustment had no effect on the assessment of experimental conditions viewed by all observers. Except for the variables of age and ambient illumination, the analysis of variance and differences between experimental conditions were identical with and without this adjustment.

The analysis of variance is summarized in Table 1. Because the full tabulation was so lengthy, it is given in an abbreviated form. Besides the degrees of freedom and mean square for each main effect or interaction, the appropriate degrees of freedom and mean square for error are also listed. In each case, the error mean square is the interaction variance with blocks of observers. (For example, the error mean square for A is the mean square A x G; the error mean square for A x B is the mean square A x B x G.)

The analysis of variance provides a guide in interpreting results. Effects or interactions that are statistically significant are assumed to reflect real differences worthy of interpretation, while those that are not significant may reflect differences that would not hold up in replication of the experiment.

Age

In spite of theoretical reasons for expecting deterioration of night vision with age, differences between age groups were not significant when averaged over all experimental conditions--whether analyzed with or without the adjustment for daylight legibility previously described. To explain this, it should be noted that there were only 15 observers in each age group (18 to 37, 38 to 57, 58 and over). To make precise comparisons among age groups more observers would be needed per group. Also, observers in this experiment were personnel from highway research and design agencies, including a few who had retired from them. Such persons are more likely to have glasses with a proper optometric correction than the average driver. Also, older persons in such an organization tend to be of higher rank, and it is possible that such a person would be less cooperative in finding time to be an observer in this experiment if his night vision were poor. Therefore, the failure to find overall differences between age groups should not be considered evidence that such differences do not exist in the population of drivers.

However, the large interaction of age with sign luminance should be noted. As is shown in Figure 11, there is little difference in legibility at

TABLE 1
ANALYSIS OF VARIANCE FOR NIGHT TEST RESULTS

	Source of Variatiou	Degrees of Freedom for Source	Mean Square for Source	Degrees of Freedom for Error	Mean Square for Error (Source of Variation x G)	F-Ratio
		df	MS	df	MSE	F
Between Observers	A (Ambient Illumination)	4	0.6638	12	0.3757	1.77
	B (Age Group)	2	0.5411	6	0.2912	1.86
	A x B	8	0.1397	24	0.3158	0.44
	G (Blocks of Observers)	3	0.7344			
Within Observers	C (Contrast Direction)	1	1.8696	3	0.0497	37.62**
	A x C	4	0.0353	12	0.0606	
	B x C	2	0.1577	6	0.0585	26.96**
	A x B x C	8	0.0571	24	0.0473	1.21
	D (Contrast Level)	1	2.4917	3	0.0148	168.36**
	A x D	4	0.0165	12	0.0315	
	B x D	2	0.0474	6	0.0328	1.45
	C x D	1	0.0014	3	0.0765	
	A x B x D	8	0.0240	24	0.0177	1.36
	A x C x D	4	0.0327	12	0.0375	
	B x C x D	2	0.0125	6	0.0198	
	A x B x C x D	8	0.0166	24	0.0348	
	E (Luminance)	4	25.4841	12	0.0692	368.27**
	A x E	16	0.9128	48	0.1113	8.20**
	B x E	8	0.1501	24	0.0406	3.70**
	C x E	4	0.1300	12	0.0108	12.04**
	D x E	4	0.0290	12	0.0224	
	A x B x E	32	0.0258	96	0.0705	
	A x C x E	16	0.0323	48	0.0181	1.78
	A x D x E	16	0.0126	48	0.0172	
	B x C x E	8	0.0284	24	0.0195	1.46
	B x D x E	8	0.0060	24	0.0181	
	C x D x E	4	0.0234	12	0.0174	
	A x B x C x E	32	0.0155	96	0.0190	
	A x B x D x E	32	0.0161	96	0.0146	
	A x C x D x E	16	0.0203	48	0.0151	1.34
	B x C x D x E	8	0.0198	24	0.0101	1.96
	A x B x C x D x E	32	0.0130	96	0.0150	
	F (Letter Size)	2	0.1305	6	0.0107	12.20**
	A x F	8	0.0048	24	0.0201	
	B x F	4	0.0118	12	0.0193	
	C x F	2	0.1259	6	0.0042	29.98**
	D x F	2	0.0390	6	0.0034	11.82**
	E x F	8	0.0381	24	0.0050	7.62**
	A x B x F	16	0.0139	48	0.0151	
	A x C x F	8	0.0079	24	0.0020	3.95**
	A x D x F	8	0.0053	24	0.0050	
	A x E x F	32	0.0085	96	0.0049	1.73*
	B x C x F	4	0.0085	12	0.0030	2.83**
	B x D x F	4	0.0034	12	0.0033	
	B x E x F	16	0.0037	48	0.0056	
	C x D x F	2	0.0109	6	0.0028	3.89
	C x E x F	8	0.0099	24	0.0022	4.50**
	D x E x F	8	0.0059	24	0.0027	2.19
	A x B x C x F	16	0.0048	48	0.0050	
	A x B x D x F	16	0.0029	48	0.0022	
	A x B x E x F	64	0.0035	192	0.0043	
	A x C x D x F	8	0.0061	24	0.0031	1.97
	A x C x E x F	32	0.0033	96	0.0034	
	A x D x E x F	32	0.0056	96	0.0032	1.75*
	B x C x D x F	4	0.0014	12	0.0055	
	B x C x E x F	16	0.0075	48	0.0040	1.88*
	B x D x E x F	16	0.0021	48	0.0026	
	C x D x E x F	8	0.0064	24	0.0040	1.60
	A x B x C x D x F	16	0.0046	48	0.0026	1.77
	A x B x C x E x F	64	0.0030	192	0.0038	
	A x B x D x E x F	64	0.0035	192	0.0033	
	A x C x D x E x F	32	0.0049	96	0.0027	1.81*
	B x C x D x E x F	16	0.0037	48	0.0024	1.54
	A x B x C x D x E x F	64	0.0029	192	0.0032	

**Significant at 0.01 level.
*Significant at 0.05 level.

the high sign luminance, but at low sign luminances the curves are farther apart. Unexpectedly, in this sample of observers one finds the middle age group having the highest legibility values at low luminances, rather than the younger age group. When individual curves were examined it was clear that this result was due to the fact that two of the observers in the younger age group had quite poor vision, both day and night. Another sample of observers would be expected to show the younger observers with highest legibility values at low luminance. Although differences are not clear, the data suggest a deficiency of older drivers toward low luminance signs that is greater at lower ambient illuminations.

Ambient Illumination

Overall legibility averages for the three ambient illumination conditions were not significantly different, but the large interaction with sign luminance was of major importance in this study--a sign of low luminance is seen better in low ambient illumination, while a bright sign is seen better in high ambient illumination. This interaction is illustrated in Figure 12. Each point on these graphs represents the average over age groups, contrast directions, contrast levels, and letter sizes. While details differ depending on these variables, the main relation between ambient illumination and sign luminance is illustrated. It should be noted that for comparison purposes the Figure 12 curve for high ambient illumination with headlight glare is duplicated on the graph for results without headlight glare. As previously noted, night testing without headlight glare was impractical on the downtown street, and headlight glare was a small proportion of the total glare at that location.

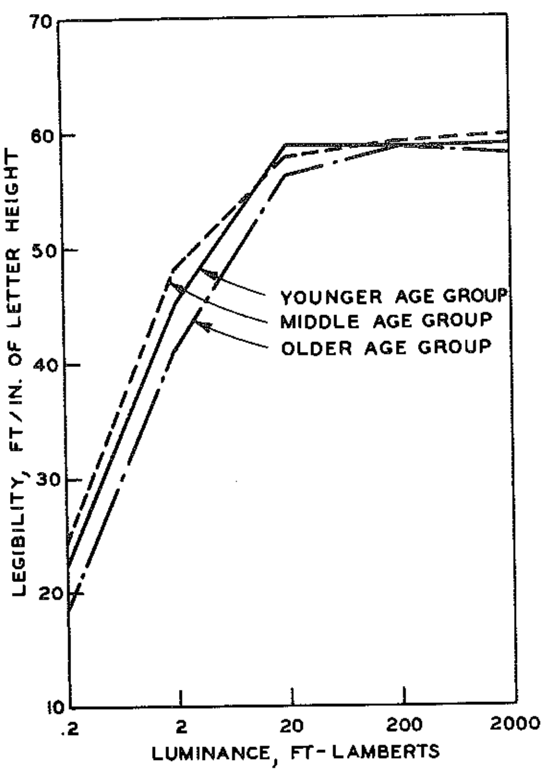


Figure 11. Effect of sign luminance on legibility by age groups.

In Figure 12, results are shown for the three locations with and without low-beam headlight glare. Legibility of low-luminance signs at the rural low-ambient illumination was considerably affected by glare, reducing legibility distance to almost that of the medium-ambient condition without glare. The effect of headlamp glare at the medium level was not marked.

Without headlight glare, the sign at 0.2 ft-L was read at over twice the distance in the lowest ambient illumination (dark open road) than in the high ambient illumination (downtown). The reverse was true for the sign at 2000 ft-L; it was read about 10-percent farther away at the high

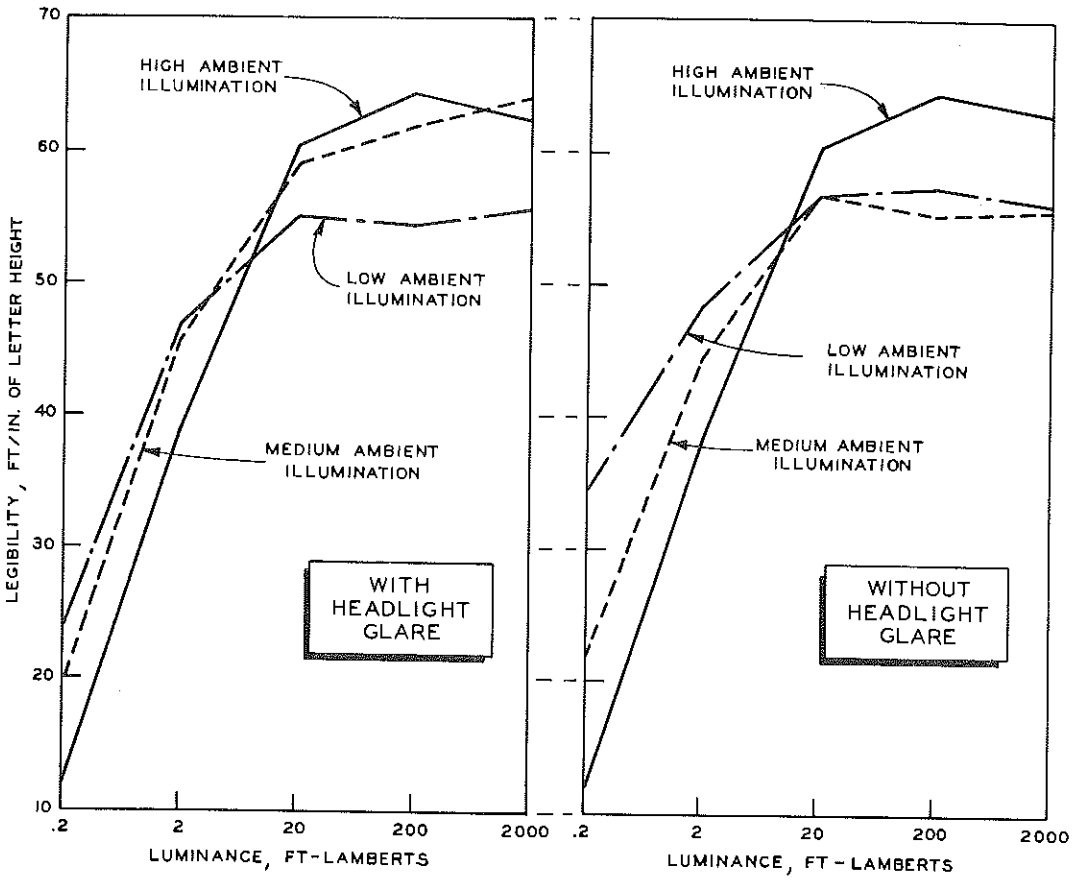


Figure 12. Effect of sign luminance on legibility, for the three ambient illumination conditions with and without headlight glare.

ambient illumination. Legibility distances for the medium ambient illumination (typical luminaires) were intermediate between those for the extremes.

Although one might be tempted to recommend minimum luminances from these average results, such recommendations should be deferred until further results are considered.

Contrast Direction

The superiority of light letters on a dark background over dark letters on a light background was highly significant; averaged over all conditions, the difference was 11 percent. But this superiority was not uniform--the significant interaction with sign luminance is shown in Figure 13. At

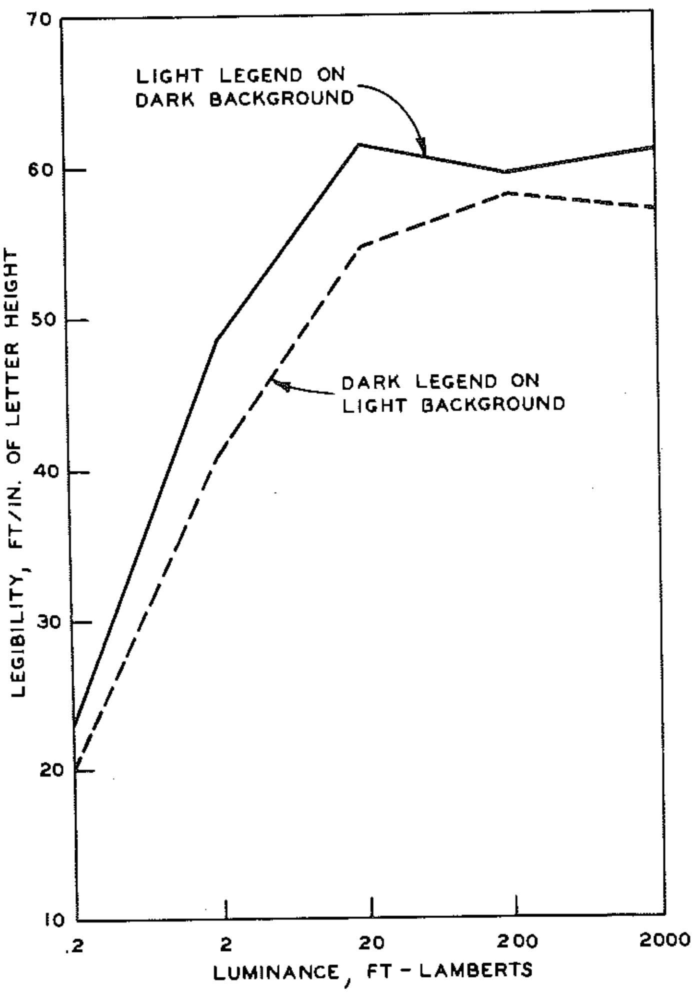


Figure 13. Effect of sign luminance on legibility, for the two contrast directions.

low and at high luminances, the differences are small and not significant, but at intermediate luminances the differences are larger. It is also noted that the curve for black on white rises more slowly with increasing luminance, requiring higher minimum luminances for optimum legibility.

These same differences in curve shape were found earlier in the laboratory study by Allen and Straub (5). Figure 14 shows the results when plotted separately for each ambient illumination condition. Although the interaction of contrast direction by luminance by ambient illumination barely fails to be statistically significant, the data shown in Figure 14 suggest that the difference between contrast directions decreases to a negligible amount in high ambient illumination, which corresponds to a previous finding of little or no difference between contrast directions in daylight conditions (15).

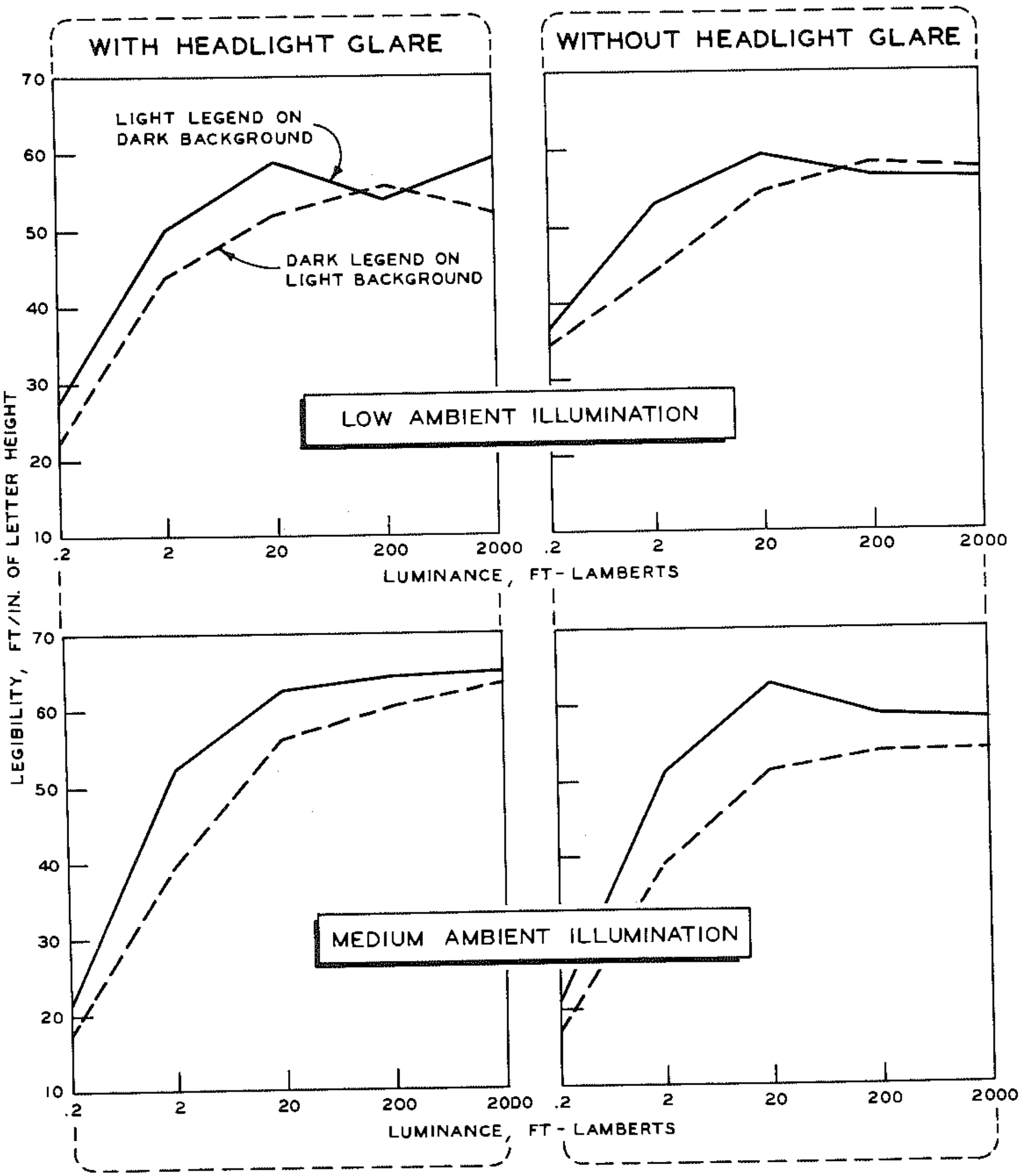
Contrast Level

On the average, the high-contrast legends (near 100-percent contrast) were read about 12 percent farther away than the lower contrast legends (about 75-percent contrast). This amount of loss of acuity with contrast reduction checks closely with that found in laboratory studies of Cobb (16) and Blackwell (17). Although one might expect to find interactions with glare, age, and luminance, no large interactions were found. The only significant interactions involved letter size. These interactions were not large, and will be discussed later in terms of an artifact of the experiment by which the adaptation of the eye was affected by the sign itself.

The fact that the effect of reduced contrast was about the same under all conditions suggests that separate luminance requirements are not necessary for signs with colored backgrounds. The loss of legibility due to contrast reduction also suggests, of course, that if the luminance of the dark portion of the sign is more than one-fourth the luminance of the bright portion, losses larger than 12 percent are to be expected. Since it is possible that color contrast effects might affect legibility to a small extent, the exact amount of loss due to the contrast reduction caused by use of a colored background might not be the same as was found in this experiment.

Letter Size

Previous research, such as that of Forbes, Moscowitz, and Morgan (10) and Allen (1), has shown that when sign luminance is held constant, legibility distance is very nearly proportional to letter size. If legibility is calculated, as it is here, in feet per inch of letter height, it is almost the same for any letter height. Of course, this is not true in general for reflectorized signs, since their luminance changes markedly with distance, depending upon the light reaching them from headlamps and the optical characteristics of the material (18).



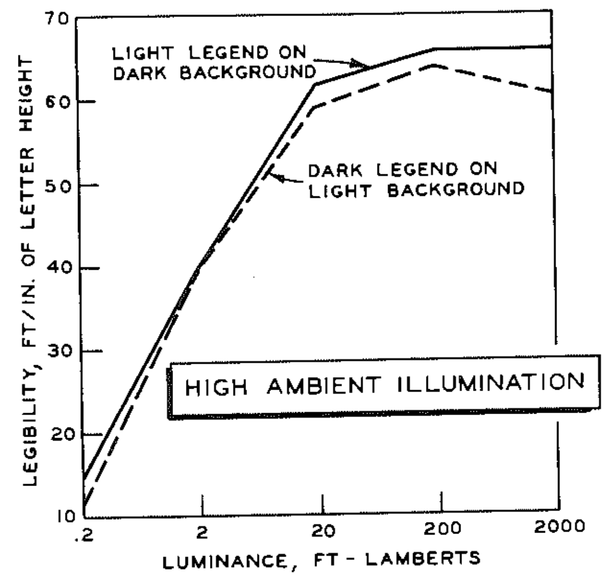


Figure 14. Effect of sign luminance on legibility, for the two contrast directions in separate ambient illumination conditions.

In the present study, however, highly significant differences were associated with the overall average legibility of the three letter sizes, with the smaller letters seen proportionately farther. This is not uniformly true, however. Letter size interacts significantly with most other variables, and with combinations of some of them. Although one might suspect that the relatively smaller border of the large letters could be producing these effects, the data are not consistent with this interpretation. Figure 15 illustrates that under all conditions, legibility of the

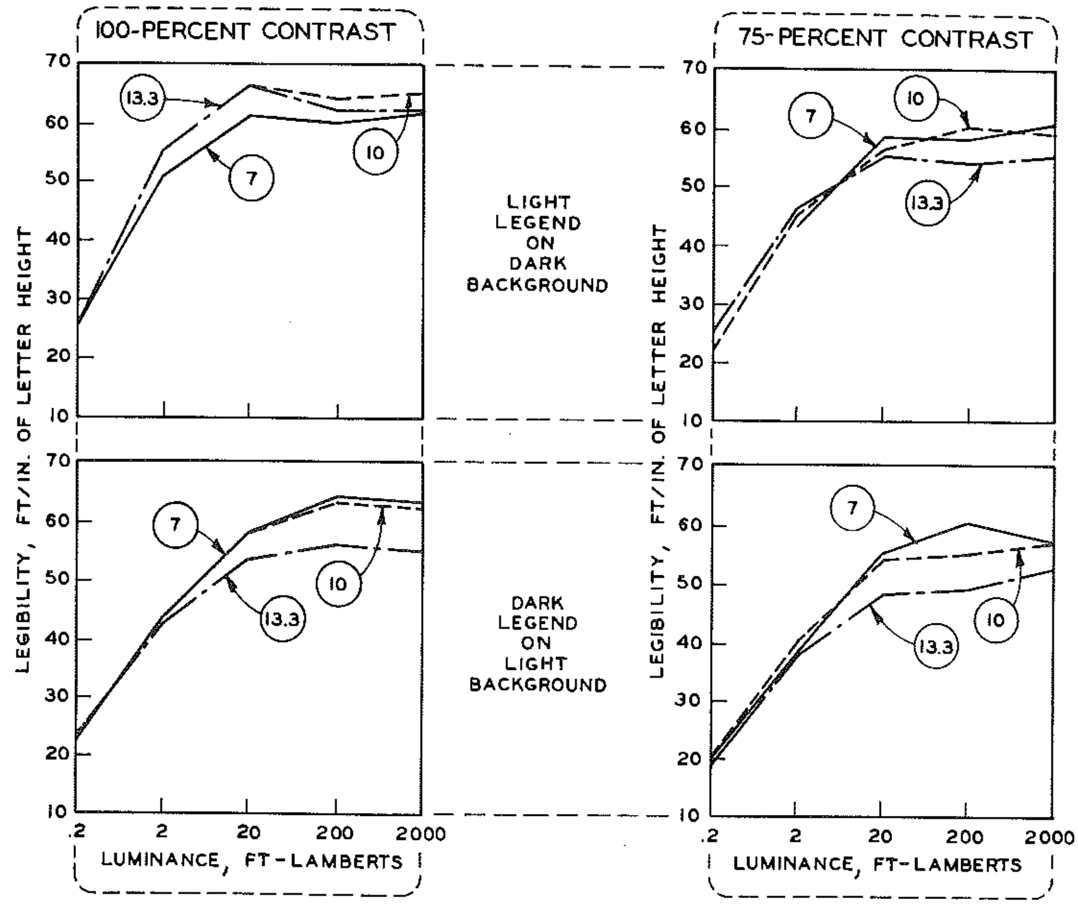


Figure 15. Effect of sign luminance on legibility, for the three letter heights.

three letter sizes is equal at low sign luminances, while the smaller letters are more legible at high sign luminances. Note that the differences are larger for dark letters on a light background than for the other contrast direction, and also for 75-percent contrast. These effects were found at each ambient illumination level, and were more marked at the low ambient levels than the high.

The only interpretation that fits the data seems to be that the bright sign itself was changing the adaptation level of the eye. Whether the retinal adaptation was changed, or pupil size, or both, is not clear. The observers in this experiment kept their eyes on the sign continuously, trying to read each message as soon as possible. Apparently, the high brightness signs, particularly if most of the face was bright (black letters on white) or if the face was not dark (white letters with low contrast) gave sufficient light to the eye long enough to change the adaptation level (or pupil size), increasing acuity for the bright sign. Although again the number of observers was not large enough for age differences to emerge clearly, the data suggest that this effect is larger for the young observers. Apparently, older eyes do not change adaptation (or pupil size) as readily. While it is impossible to be certain that this effect was taking place without measurements of adaptation level and pupil size, these findings certainly suggest that this factor be taken into account when interpreting results.

A driver ordinarily would not keep his eyes on the sign for such extended periods, and would not have such a facilitating effect of adaptation change to help him read such a bright sign. This would suggest that the data slightly overestimate the legibility distance of black letters on a white background at high luminance levels. For these signs at low luminance levels, and for white letters on a dark background at all luminances, this factor would have negligible effect on the results. However, the fact that a bright sign may raise the adaptation level of the eye has other implications. Use of large, high-luminance, black-on-white signs may raise the adaptation level sufficiently to impair the driver's ability to see dark objects on the road ahead.

Individual Differences

When data for individual observers were compared, large individual differences were observed in effects of the variables. These large individual differences contributed to the lack of clear differences between age groups. Although differences in the effects of low luminances showed substantial individual variation, the differences were larger in responses to the very high luminances. The 2000 ft-L level appeared too bright to most observers, but when instructed to read as soon as possible, most could read at about the same distance as they read the 20 ft-L sign, and some at a greater distance. Others seemed not to be able to see such a bright sign clearly, but perhaps they were influended by their belief that they could not read such a bright sign. Similar effects were observed for contrast reduction. Some observers consistently read the low contrast sign as well as the high contrast one, while others consistently read it at shorter distances. The extent to which the eye's adaptation was affected by the sign itself also appeared to show substantial individual differences and probably age differences. Glare readings on a Pritchard photometer and calculations of contrast reduction were made which theoretically should have resulted in correspondence between high and low contrast signs. However, individual responses to both glare and contrast were so different that efforts in this direction were abandoned. Research in which visual variables can be more precisely controlled is needed in order to characterize these individual differences and their changes with age.

DISCUSSION AND CONCLUSIONS

Recommended Minimum Luminances

The immediate practical question to be answered from this study is this--what sign luminance is required for adequate legibility under various ambient illumination conditions? For a dark rural road without glare from headlights of opposing traffic, this investigation verified findings of the earlier study (1). Maximum legibility is achieved at about 10 ft-L for white Series E letters such as are used on large signs on Interstate routes. If a 10-percent loss in legibility can be tolerated, luminance as low as about 1 ft-L may be used. If luminances as low as 0.1 ft-L were permitted, legibility distances would be cut down seriously--to about 50 percent for the average driver, and perhaps 60 percent for the older driver. An absolute minimum cannot be specified, since one has to decide how much loss of legibility is permissible. Recommendations given here are intended to provide only a negligible loss.

To specify a minimum luminance one must consider the methods and materials available for sign fabrication and the economics and practicality of obtaining desired performance characteristics. Variations in luminance across the face of the sign become an immediate consideration and such variations can be great. The Institute of Traffic Engineers has recommended in a report on externally illuminated signs that variations of 5 to 1 can be considered acceptable and 3 to 1 desirable (19). However, well constructed illuminated signs have been encountered with variations of 10 to 1, even excluding the dark edges. Such variations are not apparent to the naked eye, unless the dark portions are sufficiently low in luminance to make a perceptible reduction in legibility (say, below 1 ft-L in a dark rural area). Although specifications for signs should be set only after full investigation of the problems of meeting them in practice, minimums of 10 ft-L for the main portion of the sign and 1 ft-L in the darkest portion would be desirable for optimum legibility. Of course, all recommendations should apply to signs as maintained in the field, rather than to new, clean ones.

Unless the driver is protected from the glare of opposing traffic, higher luminances are needed. In this study, glare cars with low beams were were placed at 100-ft intervals, and were separated laterally about 17 ft from the observer (this separation corresponded to a 10-ft median without shoulders, with both vehicles in the lanes next to the median). For this condition, optimum luminance appears to be between 20 and 100 ft-L. Legibility distances would be cut to about 80 or 85 percent for 2 ft-L, about 70 percent for 1 ft-L, and about 45 percent for 0.2 ft-L. For such conditions, a desirable minimum would be 20 ft-L for the main portion of the sign, with a minimum of 2 ft-L at the darkest portion.

For the location chosen to be typical of the ambient illumination of lighted freeways (400-watt mercury-vapor luminaires with 150-ft spacing) without glare from opposing traffic, luminances for adequate legibility were only slightly higher. With glare from opposing traffic using lanes next to an 8-ft median, the results were nearly the same. It would appear higher adaptation level made the effect of glare less serious, and the glare from headlamps was not great compared to that from streetlight luminaires. The desirable minimum luminances for these conditions would be similar to those for the rural condition with glare from opposing traffic.

For the highest ambient illumination (about the highest a driver is likely to encounter in a downtown area), about 200 ft-L appears optimum, and serious loss of legibility occurs below 20 ft-L. A minimum luminance of 100 ft-L in the main portion of the sign, with a minimum of 10 ft-L in the darkest portion, would seem desirable.

One might question whether separate requirements are needed for the different ambient illumination conditions. Clearly, if all signs were illuminated uniformly at 20 ft-L, legibility would be very good at all locations, even if luminances as low as 10 ft-L were allowed at the darkest portions of the sign. But the difficulty and expense of achieving such a close tolerance in uniformity of luminance over the sign must be considered, which brings up the question of maximum allowable luminances at each location.

Recommended Maximum Luminances

The results of this study do not give a good basis for determining the maximum allowable luminances. The observers in this study had no task other than reading the test sign, and looked at it constantly until they had read the message in the smallest letter size. At the dark rural location without headlight glare, some observers remarked that the 200 ft-L sign was too bright, and the 2000 ft-L sign was considered much too bright to be read. They were instructed to read it as soon as possible anyway, and succeeded in doing so at about the same distances as for the 20 ft-L level. Ordinarily, however, a driver does not look constantly at the sign, and is not highly motivated to read it as soon as possible. The fact that he could read it at such a distance if he tried very hard does not imply that he would.

Also, the data suggested that high-luminance signs can change the adaptation level of the eye (or the pupil size, or both). This finding suggests that the driver's vision would be impaired for other tasks requiring dark adaptation. It seems unwise to install unnecessarily bright signs which are unpleasant to the driver and may impair his vision. In the authors' opinion, an upper limit of 30 ft-L would seem desirable for rural locations, and luminances above 100 ft-L would definitely be too bright. For illuminated highways, luminances as high as 100 ft-L would seem permissible. In brightly lit urban areas, luminances as high as 500, or perhaps even higher, might be satisfactory.

Other Sign Types

The preceding discussion of minimum and maximum luminances applies properly only to white Interstate Series E letters, with the stroke width and spacing used with them, against a dark background. The data for the 75-percent contrast letters give no evidence that different luminance requirements would be needed for such white letters against colored backgrounds. If the background were more than one-fourth as bright as the legend, however, luminance requirements might be different, in addition to the loss of legibility associated with low-contrast signs. Maximum luminances would probably need to be reduced.

Although laboratory data (2) have indicated some interaction between luminance and letter series, the interaction was not large. Luminance requirements should be similar for other letter series, especially the similar ones (Series D and F). If a substantially narrower spacing between letters were used, the effect of luminance might be different. If letters of substantially narrower stroke width were used, luminance requirements (both maximum and minimum) should probably be higher.

For dark letters on a white background, the need for higher luminances for optimum legibility was noted in the "Results" section, as well as the lower legibility distances in the intermediate range of luminances. All of the recommended minimum luminances would need to be increased (except at the highest ambient illumination condition), as can be seen by referring back to Figure 12. In rural locations, it would appear that the maximum luminances should be decreased, at least for large signs.

A large sign with most of its face very bright might have a serious effect on the driver's dark-adaptation and therefore, as stated earlier, impair the driver's ability to see low-brightness objects. A sign with a very bright face would also appear to be an unnecessary and undesirable source of veiling glare. Although the generally superior legibility of light letters on a dark background would probably not hold up if a narrower spacing were used between letters (20), it would appear that current practice, making little use of large white signs, is well founded.

Further Research Needed

The extent of the effect of the sign itself on the observer's adaptation level was not anticipated when the study began, and it was expected that 2000 ft-L would be sufficiently bright to cause a reduction in legibility as a result of the bright portions of the legend fusing together. However, similar results were obtained in an unpublished laboratory study by the senior author using the method described by Allen and Straub (5). While complaining that 1000 ft-L was too bright to be seen clearly, observers in that study were able to read messages very well, with either long or short exposure times. Further research, in which adaptation level, pupil size, and characteristics of the visual task are varied systematically, would be needed to determine the nature of the acuity-luminance relation at high luminances. Since the data suggest substantial individual differences, an adequate sampling of observers at all age levels should be used.

On the practical side, further research is needed to tie the results of this study to the legibility of reflectorized signs, so that data will be available for a choice between reflectorized and illuminated signs for various signs and ambient illumination conditions.

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