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Division of Engineering and Industrial Research  
National Academy of Sciences—  
National Research Council  
Washington, D. C.  
1965

## *Special Committee on Night Visibility*

(As of December 31, 1963)

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## Foreword

THE ten papers that comprise Highway Research Record No. 70 are the result of the activity of the Highway Research Board's Special Committee on Night Visibility during the years 1963 and 1964. Because vision is a major factor in good driving behavior, night visibility obviously plays an important part in the driving task.

These papers study the problems involved in driving at night from many approaches. The authors discuss subjects such as visual adaptation, headlight glare effects, the influence of alcohol on the driver at night, better vision with vehicle headlights, sign requirements, sign backings and reflectorization, and problems of driving with both high and low beam headlamps.

This Record should be of special interest to those researchers concerned with aspects of vision and seeing at night. Portions of it will be important to practicing traffic and highway engineers concerned with sign reflectorization and median width design. Some of the papers will be of interest to vehicle designers and those concerned with safety aspects of drivers and vehicles.

The first seven papers are a product of the Board's 43rd Annual Meeting. "Headlight Glare and Median Widths," by Powers and Solomon, discusses several studies that explored the relationship between the median width of highways and the disabling effect of opposing motor vehicle headlight glare. The results offer valuable insight into the various factors determining these relationships.

Kinney and Connors in "Recovery of Foveal Dark Adaptation" have researched an important night driving question—what effect do brief sources of bright light have on a driver's visual sensitivity in the foveal area? Results of their research are summarized in a series of dark adaptation curves. Roper and Meese in their paper, "More Light on the Headlighting Problem," investigated five current night visibility problem areas, including improvement of seeing when using lower beam headlights, reduction of headlight lamp glare, effect of lower headlamp mounting height on cars, European quartz iodine headlamps, and the effect of alcohol in the driver on seeing distance. Brief research on these five items indicated that seeing could be improved with lower beam headlights if drivers would direct their attention to the right edge of the traveled lane and that annoyance of headlamp glare can be reduced. About sixty feet of seeing distance has been lost due to lower headlamp mounting on cars.

Dr. Oscar Richards presents his ninth annual review of literature concerning levels of night vision and illumination. Some eighty-six literature sources were investigated and evaluated for this review of 1963. Messrs. Forbes, Snyder and Pain have performed a valuable service in their paper, "Traffic Sign Requirements." This preliminary report analyzes the driving task in a simplified way using human engineering, engineering psychology, and "man-machine-systems analysis" approaches. Previous research is reviewed and summarized, and the authors suggest general areas which should be studied.

"A Study of Dew and Frost Formation on Retro-Reflectors," by Woltman, discusses his studies of extensive dew formation on typical reflective media and sign backings and offers useful performance relationships. Incidence of dew formation did not seem to be severe for the climatic conditions tested. "The Effects of Glare in Simulated Night Driving," by Mortimer, is concerned with a simulation study of illumination and glare conditions. Studies of the interactions among roadway illumination, glare illumination, glare duration, and glare frequency are discussed. Indications are that such interactions are complex and that they must be considered in simulation studies.

Three papers presented at the 44th Annual Meeting are also included in this Record. The first of these is the tenth annual literature survey by Dr. Oscar Richards for the year 1964. Similar to the 1963 literature survey, this survey is the result of an extensive canvass of 102 sources. Powers, in his paper, "Effectiveness of Sign Background Reflectorization," compares signs having different degrees of background reflectorization by analyzing their effect on the ability of drivers to follow a test route to a given destination. His study finds no evidence to support a conclusion that there is any difference in the effectiveness of the different degrees of sign background reflectorization. Schwab's paper, "Night Visibility for Opposing Drivers with High and Low Headlight Beams," is presented as an abridgment. His report is based on studies of two driving tasks using the visual task evaluator measurement techniques. His research revealed that the shifts in visibility which accompany the switching from low to high beam or vice versa are largely determined by changes in the level of adaptation to light since contrasts for this task showed little change.

# Contents

HEADLIGHT GLARE AND MEDIAN WIDTH: Three Exploratory Studies	
Lawrence D. Powers and David Solomon .....	1
MORE LIGHT ON THE HEADLIGHTING PROBLEM	
Val J. Roper and G. E. Meese .....	29 ✓
RECOVERY OF FOVEAL DARK ADAPTATION	
Jo Ann S. Kinney and Mary M. Connors .....	35
VISION AT LEVELS OF NIGHT ROAD ILLUMINATION:	
IX. Literature 1963	
Oscar W. Richards .....	41
TRAFFIC SIGN REQUIREMENTS: I. Review of Factors Involved, Previous Studies and Needed Research	
T. W. Forbes, Thomas E. Snyder and Richard F. Pain .....	48
THE EFFECT OF GLARE IN SIMULATED NIGHT DRIVING	
Rudolf G. Mortimer .....	57 ✓
A STUDY OF DEW AND FROST FORMATION ON RETRO-REFLECTORS	
H. L. Woltman .....	63
VISION AT LEVELS OF NIGHT ROAD ILLUMINATION:	
X. Literature 1964	
Oscar W. Richards .....	67 ✓
EFFECTIVENESS OF SIGN BACKGROUND REFLECTORIZATION	
Lawrence D. Powers .....	74
NIGHT VISIBILITY FOR OPPOSING DRIVERS WITH HIGH AND LOW HEADLIGHT BEAMS	
Richard N. Schwab .....	87

# Headlight Glare and Median Width

## *Three Exploratory Studies*

LAWRENCE D. POWERS and DAVID SOLOMON

Respectively, Highway Research Engineer, and Chief, Safety Research Branch,  
U. S. Bureau of Public Roads

Three study methods were explored for determining the effect of location of an opposing glare vehicle on visibility at night. Both lateral separation and longitudinal distance between glare vehicle and observer were varied. In Study 1, both glare car and target were stationary; the observer drove toward the target and indicated when he could detect it. In Study 2, both target and observer were stationary while the glare car moved toward the observer; locations of the glare car were found for which the target was just visible to the observer. Study 3 involved a self-luminous target, and, as in Study 2, both target and observer were stationary while the glare car moved toward the observer; the observer continuously adjusted the brightness of the target and attempted to keep it barely detectable. Some limited measurements of discomfort due to glare were made, but this line of investigation was abandoned due to high variability in the results and the lack of an adequate definition of discomfort.

The results showed that the effects of glare decreased with increasing lateral separation of the glare car, as expected. At any given lateral separation, the effects of the glare were present even when the glare car was at a considerable distance from the observer (3,000 feet or more); the rate of change of the effect with distance was small for a large part of this distance. Recommendations are made for the conduct of target detection studies of this type, remarks are made concerning the visual problems in night driving, and possible areas for future investigation are suggested.

•THIS REPORT summarizes several exploratory studies employing different methods of studying the relationship between median width of highways and the disabling effect of opposing motor vehicle headlight glare. The studies were performed with the intention of gaining insights into the factors which were operating and the methods which would best determine those relationships. Because insights were the main objective, the amount of data collected was small and little reliance is placed on the quantitative values. Each of the methods grew out of analysis of the limitations of the previous method. Although the studies were performed in the spring of 1961, because of recognized limitations in the data or, in some cases, a lack of understanding of what the results meant, the preliminary report was not published. Subsequent readings in the psychological and physiological literature have pointed the way to an interpretation of the results. The report is now presented for the information of others contemplating this type of research, and includes discussions of possible pitfalls and factors for which account may have to be taken. For this reason considerable detail is presented concerning field layouts, procedures, and qualification of results.

The results of these studies are based on small samples with few replications. They are more suggestive than conclusive and are of value primarily to show the types of results that may be expected and to illustrate certain effects of factors which may be

operating. The quantitative values hold only for the particular targets, subjects, surroundings (pavements, backgrounds, ambient illumination) and lamps tested. The relative values (the effect of lateral separation) may also be dependent on these variables.

It had also been proposed that the discomforting aspect of headlight glare be studied. The discomforting effect, however, was elusive of definition, and more so of measurement. An attempt to measure it was made in Study 1, but the results were too variable to be of any use. It was thereafter decided to limit the objectives to what was thought to be the more critical case of disabling glare.

Data for Studies 1 and 2 were collected in one night each and for Study 3 on two successive nights. Although different ambient illumination conditions may have existed on the different nights, it is assumed that they were fairly constant for the duration of each night; furthermore, the use of balanced experimental designs and random orders of exposure to the different conditions, e.g., lateral separations, leads to the belief that the data for each study are not biased due to serial changes in conditions. Where the data are subject to question on other accounts, qualifications to the results are given.

The existence of possible differences between nights, as well as differences in some of the other variables, reduces the comparability of the results of the different studies.

### GENERAL NOTES AND DEFINITIONS

Available as a test site was a new portland cement concrete runway, two miles long by 150 feet wide, at Dulles International Airport, prior to its being opened to air traffic. The site was 25 miles from downtown Washington, D.C., and about 12 miles from the nearest sizeable town. The area surrounding the runway was flat and grassy. Consequently, the ambient illumination was uniform and at a very low level. Few, if any, extraneous light sources were visible, depending on the direction in which the subjects were facing for the different studies. When present, these lights were distant and constant during the collection of data. For the conditions of the studies, the effects of cross-slope of the runway were assumed to be negligible so that, except where noted, all studies were performed on portions of the runway considered to be a plane surface.

The tests simulated only the meeting of a single vehicle with a single opposing glare vehicle on a constant-grade tangent section of highway where, at any cross-section, the pavements for both directions of travel are at the same elevation. The results do not necessarily hold for other geometries.

All vehicles employed in the studies had four headlamps. Before each study, the aim of the headlamps of both the glare car and the car with test subjects was adjusted according to Virginia State standards. All tests were conducted with the glare car headlights on high beam. The windshield of the car in which the test subjects were seated, the outsides of the headlamps of both the glare car and subject car, and the reflectors on the target car were maintained clean throughout the course of the studies.

Instead of median width, the more definitive concept of "lateral separation" has been used in this report. As employed here, "lateral separation" refers to the lateral distance between the driver and the near side of the opposing glare vehicle. Lateral separation can be used to convert to different combinations of median width, vehicle position, and lane width (Fig. 1). The conversion assumes that each of the two vehicles is 6.5 ft wide and centered in its lane; the driver's eyes are assumed to be 1.5 ft from the left side of his vehicle. Figure 1 may be used as follows: if conditions are median width of 20 ft, 4-lane divided highway, both vehicles in the right lane (two lanes intervening), and lanes are 12 ft wide, the resulting lateral separation is 51 ft.

The condition where no opposing vehicle was present can be thought of as corresponding to an infinite lateral separation. For convenience, this is also referred to as the "no-glare" condition, although technically any light in the field of view will produce some glare, e.g., the area of pavement illuminated by the driver's own headlights.

The term "threshold" will be found throughout this report. Psychophysical "absolute threshold," according to Stevens (1), is that level of a stimulus (e.g., brightness of an object) which marks the transition between response (detectability) and no response



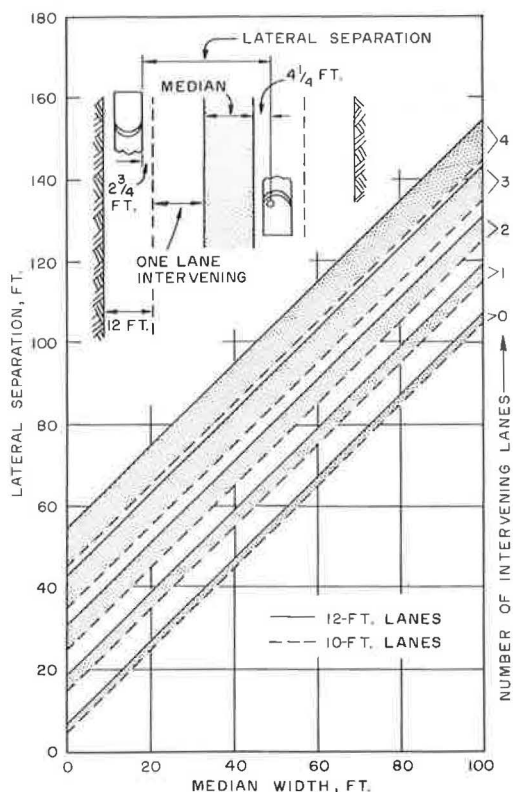


Figure 1. Relationship between lateral separation and median width for different combinations of vehicle position and lane width.

feet are fairly common. Two opposing vehicles, each traveling at 70 mph, will have a relative velocity of approximately 200 fps. If the two vehicles are initially 2,000 ft apart, they will meet in 10 sec.

## STUDY 1

The field layout for Study 1 is shown in Figure 2. (As employed in this report, "layout" refers to the plan of the site for each study; "setup" refers to the relative position of glare car and target car.) The headlights of both the glare car and the car in which the test subject drove were on high beam. The glare car and the target car were both stationary, the rear of the target car being situated 100 ft beyond the headlights of the glare car. Of the five subjects, three in their twenties and one, age 54, reported normal or corrected-to-normal visual acuity; one, age 33, reported poor acuity.

Each test subject, guiding along a pavement joint, drove toward the rear of the unlighted target car at a speed of 20 mph. His instructions were to call out to a recorder seated in the car when he felt the glare to be discomforting and again when he could discern any part of the target car (this turned out in all cases to be one or more of the six rear red reflectors). Distance markers, 40 ft apart, lined the opposite edge of the runway. The recorder would note the car's position relative to the nearest adjacent distance marker, from which the longitudinal distance could be estimated to be within

(nondetectability). This threshold level ordinarily fluctuates from moment to moment within a range separating those stimulus levels which definitely produce a response from those which definitely do not produce a response. A given stimulus value within this range will produce a response only part of the time. The probability of detection of a stimulus within this range, therefore, will vary from close to zero to almost 100 percent. Usually, the stimulus level which produces a response 50 percent of the time is called threshold (50 percent threshold). For identical conditions, the average thresholds for different subjects may be different.

The use of the term threshold in this report is much less restrictive and refers, generally, to those instances where, under the conditions present, the subject reported that he detected or lost sight of the target. Obviously, the conditions of exposure of the stimulus (e.g., time of exposure of the target, subjects' adaptation levels, and criterion for confidence of detection) could not be controlled as precisely as in a less "realistic" laboratory setup, and the individual threshold measurements reported herein could have varied considerably from the 50 percent detection level.

Although the studies were run at low speeds and for long distances (not quite long enough, it turned out), the distances (2,000 ft or more) are not as extreme as they may appear at first glance. On modern divided highways, sight distances to opposing headlights of several thousand

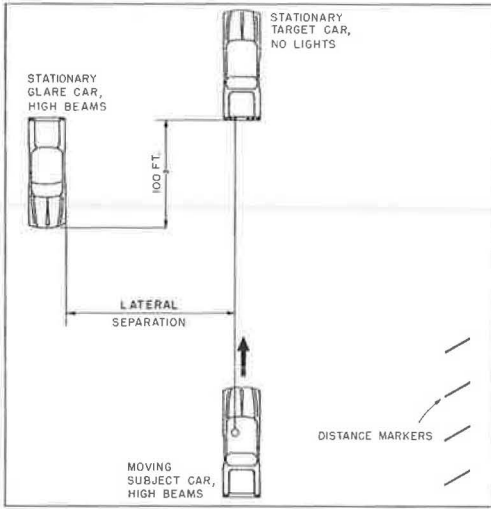


Figure 2. Field layout for Study 1.

of the car, and consequently of the headlights, was exactly parallel to the line of travel of the subject.

## Results

Study 1 is the only study for which data relative to both disability and discomfort glare were obtained. The results of the discomfort test indicated that the discomfort measurements were highly subjective and variable.

## Discomfort

Figure 3 shows, for the different lateral separations, distances from the glare vehicle at which subjects stated that they were discomforted by the opposing headlights. (Discomfort is assumed to be present for combinations of lateral and longitudinal separation from the glare car which lie under the curve.) The grid portion can be viewed as a plan of the test site. Each subject is identified by a different letter, A to E. The

points are plotted at the distances for each run at which the subject reported discomfort; where the subject reported no discomfort during a run the point is shown to the left of the zero line. For two runs at each of the two narrowest separations, subject E reported discomfort at the beginning of the run but before he was adjacent to the beginning of the series of distance markers (2,520 ft). Therefore, these distances are unknown, but greater than 2,520 ft, and have been plotted arbitrarily at 2,700 ft.

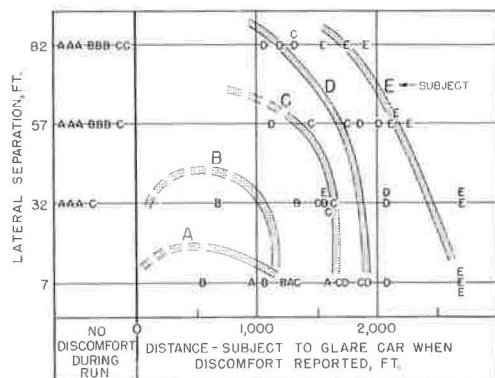


Figure 3. Effect of position of opposing high beams on reported discomfort by five subjects.

20 ft. The course markers carried reflectorized letters and were turned away from the view of the subject. The recorder viewed them by shining a flashlight out the side of the car.

Each subject made three runs at each of four different lateral separations (7, 32, 57, and 82 ft) and also for the no-glare case (corresponding to an infinite separation). Runs were made in random order, although each subject made all his runs consecutively. For each different lateral separation the target car was positioned so that it was directly ahead of the subject car. This procedure is similar to that used by the Idaho Department of Highways in a 1957 glare test (2).

The glare car was not moved at all during the conduct of Study 1 as all data were collected in one night. Therefore, the orientation of the headlight candlepower distribution was constant for all runs.

However, it is not known whether the axis

A curve has been drawn for each subject. These curves are very approximate due to the extreme range and variability of the data. Had each curve been drawn to pass through the mean discomfort distance value for each lateral separation some of them would have been S-shaped.

As expected, the distances at which the onset of discomfort was reported generally increased with decreasing lateral separation; or, to put it simply, discomfort was experienced sooner at the narrow separations. At a distance of 1,000 ft from the glare source, for example, subject A stated that he experienced discomfort only for the 7-ft lateral separation; subject B, when the separation was 25 ft or less; subject C, at separations of 50 ft or less; subjects D and E reported discomfort even with a lateral separation of 82 ft.

For any given run, as the distance between the subject and the glare car decreased and the opposing headlights got further away from his line of sight and decreased in brightness, there obviously had to be a point where discomfort began to diminish and another point where it ended, even if one or both of these are where the subject passed the glare car and the headlights were no longer visible. Therefore, the discomfort threshold curves must bend over at small longitudinal distances. Data were not collected for this end of the discomfort curves, but for illustrative purposes these parts of the curves are shown as broken-line portions for subjects A, B, and C.

The variation among subjects is no doubt due to differences both in sensitivity to glare and individual definitions of discomfort. However, it is hard to believe that the large variation for any individual subject was due to the small sample size alone. Therefore, it became apparent that discomfort glare criteria were going to be difficult to define, and subsequent research was devoted solely to the study of disability glare. Part of the variability may have been due to the fact that the subject had two tasks to perform: to report discomfort and to report detection of the target. Because detection of the target was the more emphasized task, subjects may have failed to concentrate or report on discomfort if it would have occurred at the same time that the target became detectable.

### Target Detection

Figure 4 shows the variation in target detection distance with lateral separation. The part of the target car which was detected first was always one or more of the six rear red reflectors. Each plotted point represents one run by one subject at the particular lateral separation. The data for each subject are shown with a different symbol.

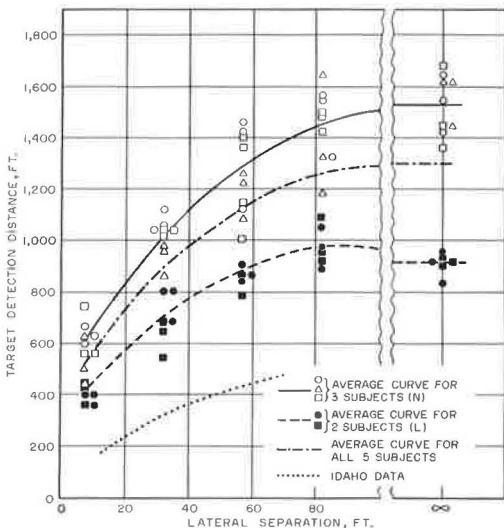


Figure 4. Variation in target detection distance with lateral separation for five subjects for conditions of Study 1 (target 100 ft beyond glare car).

The data appear to fall into two distinct groups, apparently according to the nighttime visual ability of the subjects. Consequently, they have been so grouped. The solid curve is for the three subjects in their twenties, who had reported normal acuity. The lower dashed curve is for the other two subjects, the one, 33 years old who had reported poor acuity, and the one, aged 54 who had reported normal acuity. For purposes of identification, the former group, who were judged to have normal visual ability, have been given the designation N; the latter two subjects, whose performance was judged somewhat lower, have been designated L. Within each group the variation among subjects appears small and curves drawn for individual subjects would approximate the curve for the particular group. The alternate dashed and dotted curve is an average for all five subjects.

The distances at which the target was detected increased with increasing lateral separation, as expected. Average detection distances appear to approach those of



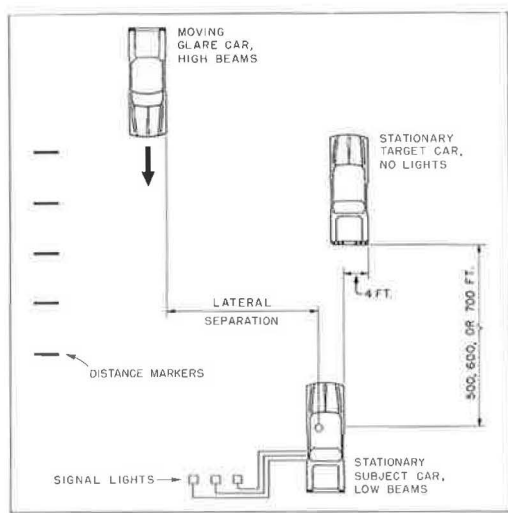


Figure 6. Field layout for Study 2.

opposing headlight beam pattern changed simultaneously with the change in apparent size of the target and the illumination on it from his own headlights. Regardless of when the subject could detect the target, the detection distance was always equal to the glare car distance plus 100 ft. This is further illustrated in Figure 5, which compares target detection distances with distance to the glare car.

All data of Study 1 fall on a line, the equation of which is  $D_t = D_g + 100$ , in which  $D_t$  is target detection distance and  $D_g$  is distance of subject to glare car. Similarly, the Idaho data fall on a line,  $D_t = D_g$ , because, in the Idaho Study, the target was adjacent to the glare car. With this study methodology, detection distances of the target cannot be determined for other relative positions of glare and target cars. For example, for a lateral separation of 7 ft, how far away could a subject have seen the target when he was 1,000 ft from the glare car? In attempting

to describe the relationship between the effects of headlight glare and lateral separation, it is necessary to know whether the detection distances derived were the most critical distances. The question remains, in regard to the results of Study 1, were these the minimum detection distances for each lateral separation?

That part of the lack of applicability of the data which was due to the study method resulted from the lack of independence of the two variables, distance to target, and distance to glare car. Therefore, this study method was abandoned in favor of one in which only one distance at a time was varied. This is the method that was utilized in Study 2.

## STUDY 2

The field layout for Study 2 is shown in Figure 6. In this case, the subject and target cars were stationary, and the glare car, with high beams, was moving. The subject car's headlights were on low beam. This is considered to be the worst condition for a two-car meeting situation.

The three test subjects reported visual acuities ranging from poor to good. Each was equipped with a pushbutton that operated a signal light of different color for each subject. The signal lights, consisting of 1-ft squares of red, yellow, or green translucent plexiglass illuminated from behind by incandescent bulbs, were situated out of the view of the subjects and sufficiently far apart to be distinguishable by the experimenters at distances up to 3,000 ft.

The three subjects, seated in the subject car (two in front, one in rear), viewed the rear of the target car as the glare car moved toward them. As long as the reflectors of the target car were visible to him, each subject kept his particular signal light on. Subjects were instructed not to communicate with each other during a run.

The same distance markers which had been used in Study 1 were situated at 100-ft intervals along the side of the test site, facing the glare car. The glare car contained three men: a driver, an observer, and a recorder. The driver's function was to stay on course, maintain a speed of 25 mph, and call off the distance markers as they were passed. The observer would call out the status of the signal lights (on or off) and the recorder would indicate this on the data sheet relative to the appropriate marker designation. Distances were estimated to the nearest 50 ft. The farthest distance from the subject which could be measured in this manner was 2,600 ft.

Three runs were made at each of six different lateral separations (4, 14, 24, 34, 45, and 59 ft) and for each of three different distances of the target car (500, 600, and 700 ft). The odd figures for the lateral separations resulted from the desire to arrange convenient tracking guides in relation to the pavement joints; separations of 4- and 14-feet were intended to bracket the zero median case, which, for lanes 12 ft wide, would provide a lateral separation of 7 ft. The target car was offset 4 ft laterally to the right of the subject car, primarily to provide clearance for, and prevent displacement by, the glare car during runs at the narrowest separation.

The order of presentation of the different target distances was arranged in sets, a set consisting of one each of the three target distances, 500, 600, and 700 ft. For each target distance within a set of three, one run was made at each lateral separation, in random order. The order of target distances within a set was random; three sets were run.

The distance at which each of the three subjects could see the reflectors on the target car without the presence of the glare vehicle was also recorded. However, only one such no-glare measurement was made for each subject.

Essentially, the objective of this study was to find those positions of the glare car for which the target detection distance was at certain specified values.

## Results

The following detailed description and discussion of the development of the data from raw to final form will be of value in pointing out many of the factors involved in visibility testing.

Figure 7 shows the positions of the glare car at which the target was visible at 700 ft to one of the subjects. Data for three replications for each lateral separation are shown. The figure can be viewed as a plan of the test site. The glare car ran from right to left, with distance measurements beginning at a longitudinal distance of 2,600 ft from the test subject. At some point the subject could no longer see the target (visibility fell below threshold). As the glare car continued its run, a point was reached where the subject could again detect the target. An average threshold curve has been roughed in. Points below the curve represent positions of the glare car (i.e., combinations of longitudinal and lateral separation) at which the target was not visible to the subject at a distance of 700 ft; i.e., the target detection distance was less than 700 ft.

For the narrow separations the target was often below threshold for the subject before distance measurements could be taken on the glare car. Consequently, the far end of the threshold curve has been drawn with a broken line to indicate the extreme uncertainty of its location. The curve has been extrapolated beyond 2,600 ft to illustrate the method. Had the glare car measurements begun at a greater distance there would have been some point at which the target would have been above threshold.

Again for the narrow separations, the targets did not rise above threshold until after the glare car had passed the subject. (Inasmuch as exact quantitative values have not been strived for, to simplify the illustrations, the threshold curves of Figures 7 and 8 have been drawn as though the target were always visible after the glare car had passed the subjects.) This could

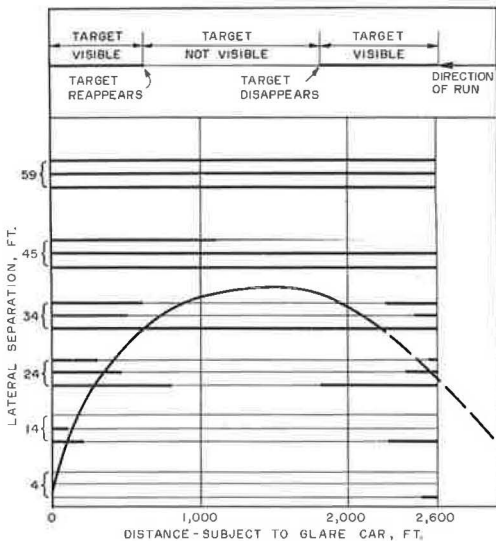


Figure 7. Target visibility data and threshold curve for one subject, Study 2.



have been due to the time lag in readapting to the no-glare condition or reaction-time lags in actuating the signal buttons and in the observing-recording process. All of the longitudinal distance data are probably too small due to time lags in the signaling-observing-recording process.

At the wider separations, the target was sometimes above threshold during the entire run of the glare car; i.e., the target detection distance was always greater than 700 ft. This was the case for one of the runs when the separation was 34 ft, for two runs at the 45-ft separation, and for all three runs at the 59-ft separation in Figure 7. Because threshold is usually defined as a 50 percent probability of detection, the threshold curve has been drawn to level out at that lateral separation where the target was always detectable 50 percent of the time, or 1.5 out of 3 runs. Therefore, the curve has been drawn to level out in the vicinity of the 1,500-ft longitudinal distance, where a maximum point would appear to be, and midway between the 34- and 45-ft separations, where the target was detectable for the entire run, respectively, once and twice out of three runs. (This assumes that 50 percent detection threshold data were being obtained. However, it is doubtful whether the points where the target appeared or disappeared represents 50 percent detection thresholds.) Many more replications would be needed to determine the exact location of the average threshold curve.

Figure 8 shows average threshold curves for the combined data of all three subjects for each of the three target distances. The parts of the curves shown with broken lines are uncertain, as explained for Figure 7. The curves can be thought of as representing contours of equal disability due to glare, in that the target detection distance is constant for all positions of the glare car which lie along each curve. The target is not visible at the distance indicated for each curve for combinations of lateral separation and longitudinal distance of the glare car which lie under the curve. Due to the difference in the horizontal and vertical scales in Figure 8 the shapes of the curves as drawn are deceptive. Inspection of the scales shows that the curves are actually very long and flat, indicating that the effect of the opposing glare on target detection is fairly constant for a large range of distances from the glare car.

These data can be shown in another way. By noting the distances of the glare car at which a horizontal line representing a chosen value of lateral separation intersects the threshold curves of Figure 8, the relationship between target detection distance and distance of the glare car for that particular lateral separation can be obtained. Points of intersection so obtained have been plotted in Figure 9 for arbitrarily chosen lateral separations of 7, 17, 27, and 37 ft. At separations wider than 37 ft, the target detection distance was always greater than 700 ft and, because target distances greater than 700 ft were not tested, no points could be obtained for these wider separations. Curves showing the variation in target detec-

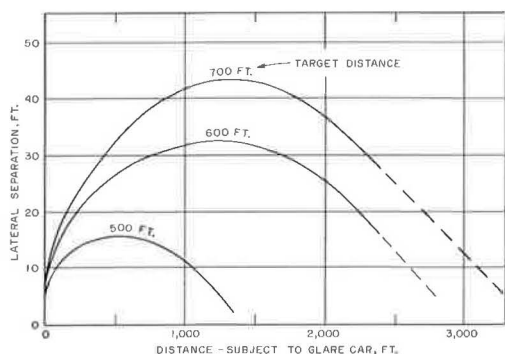


Figure 8. Combined average threshold curves for three subjects of Study 2 for each of three target distances.

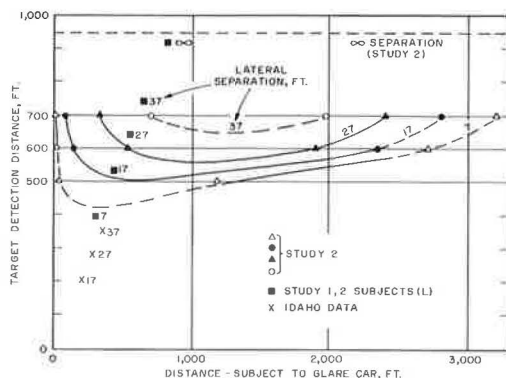


Figure 9. Variation in target detection distance with glare car distance for different lateral separations, Study 2 (partial data of Study 1 and Idaho study shown for comparison).

tion distance with position of the glare car for the chosen lateral separations have been drawn through the points. Again, the uncertain portions are shown with broken lines. The average no-glare detection distance for the three subjects was 940 ft, was derived from only one measurement per subject, and is, therefore, shown by a broken horizontal line in Figure 9.

The curves show that target detection distance is relatively high at far distances from the glare car. This is reasonable because the illumination reaching the subjects' eyes from the opposing headlamps is small. Target detection distance decreases gradually as the glare car gets closer to the subject, reaches a minimum, and then rises again as the glare car, continuing its run, moves away from the center of the visual field and the less intense portion of the opposing headlight beam is directed at the eyes of the subject. As the lateral separation increases, the minimum target detection distance that is reached is higher and appears to occur at greater distances of the glare car.

### Discussion

The extent of the curves and the low rate of decline in target detection distance with glare car distance indicate that the effect of the opposing glare on target detection distance extends for considerable distances of the opposing glare car and is fairly constant for long durations. This was previously pointed out for the threshold curves of Figure 8, from which the curves of Figure 9 were derived.

It was previously pointed out that, at lateral separations greater than 37 ft, the average target detection distance is greater than 700 ft. Similarly, the curve of target detection for the 7-ft lateral separation dips below 500 ft to an unknown value. Therefore, to have obtained data from which to draw the curves for lateral separations greater than 37 ft and to have obtained the minimum target detection distance for the 7-ft lateral separation, target distances greater than 700 ft and less than 500 ft would have had to be tested. The minimum points for the curves fall at values of target detection distance where no data exist. Intermediate target distances would have had to be tested to have obtained more accurately the minimum value of target detection distance and its location for each lateral separation.

The slope of the curves for glare car distances beyond 2,000 ft is uncertain because these parts of the curves are based on extrapolations of the threshold curves. Another cause for suspicion about the shape of the curves in this area is inherent in the study method. Because the target was at a fixed distance from the subject the threshold point of detection for far distances of the glare car was determined in a situation where the target went from an initially visible condition to an invisible one. The subject was, therefore, able to fixate on the target and could maintain detection of it for a longer time, as the glare car approached, than if the target had gone from an initially invisible condition to a visible one. It is possible, therefore, that target detection distances for the far distances of the glare car should be lower than they are shown. The shapes of the curves obtained in similar studies by the Road Research Laboratory in England (3, 4, 5) did not have as great a slope as the curves of Figure 9 at the far distances of the glare car.

The British studies utilized theoretical expansions of field data. In part, they showed, for British high and low beams and for appropriately aimed American low beams, curves for "seeing distance," for straight-ahead and curb-side test objects, that fell gradually with decreasing distance of the glare car and then rose slightly at small distances. It is significant that the curve shapes and the minimum seeing distances varied with different positions of the object across the roadway and with different headlight beam configurations (high beams facing high beam or low beam facing low beam).

The roundabout method of developing the data just demonstrated, which involved drawing the threshold curves (Figure 8) and intersecting them with chosen lines of lateral separation to obtain points with which to plot the target detection distance curves (Figure 9), was resorted to in order to illustrate some important concepts, such as the variability of threshold measurements. The average distance of the glare car for



threshold detection of the target could have been plotted for each target and lateral separation directly on Figure 9. It would not have been possible, however, to have interpolated for lateral separations other than those at which data were actually obtained.

Although this would have been a more direct method, there would still remain the problem of what to do where some, but not all, runs at a particular lateral separation do not result in threshold points, i.e., where the target is detectable for the entire run. This points up a fundamental disadvantage of this method. Because distances of the glare car are found at which the target detection distance is a given value, the data essentially fall on lines of constant target detection distance (because target detection distance is the ordinate in Figure 9). The curves of target detection distance by glare car distance that are to be derived from these data are long flat curves, indicating that the glare levels, or disability contours, which result in particular threshold detection distances, are long in extent and roughly parallel to the line of travel. If these disability glare levels can be visualized as long thin cigar-shaped contours emanating from the glare car, it can be seen that their intersection with the subject's line of travel is at a very small angle. This, combined with the variability inherent in threshold measurements, results in such a high degree of variability that the number of repetitions required for accuracy becomes impractical.

To compare the attributes of the two methods discussed so far, the data of the two subjects (L) who showed poor performance in Study 1 are shown in Figure 9. Although these data of Study 1 closely approximate the data of Study 2, it should be borne in mind that the data of the two studies are not exactly comparable due to differences in subjects, beam configurations, and methods of testing and, therefore, the fairly close apparent agreement may be mere coincidence. The data for the other three subjects (N) who took part in Study 1 were omitted from Figure 9 to conserve space on the illustration. For the same lateral separations, these subjects were able to detect the target at significantly longer distances, illustrating the wide differences that may exist between different groups of subjects.

Because the Study 1 method utilized a fixed relationship between the glare car and the target, all data of Study 1 fell on a straight line, as was illustrated in Figure 5. In Figure 9, this line intersects each lateral separation curve at one point only. Furthermore, these points are not necessarily the minimum detection distances for each lateral separation.

It should be pointed out that the retroreflectors which constituted the target in these studies were a relatively high-contrast task. These reflectors have a reflection factor in the order of 1,000, whereas all objects which reflect diffusely have reflection factors smaller than unity. The data of the Idaho study, for a target with a reflection factor smaller than unity, are also shown in Figure 9 to illustrate the differences in the magnitude of the detection distance that will result from the use of different targets. Because targets of different initial difficulty will be detected at different distances from the glare car, the driver will be oriented differently to the opposing headlight beam pattern (i.e., he will be exposed to different levels of glare), and the curves for other targets may have different shapes than those derived from Study 2.

## INTERIM SUMMARY AND RECOMMENDATIONS

The two studies discussed so far utilized target detection distance as the measure of visibility. Because the third study did not, it would be well to summarize the results of Studies 1 and 2 at this point.

### Interim Summary

One surprising result of these experiments was the extent, in terms of distances between the subject and the opposing vehicle, to which the opposing glare had an effect and the relative constancy of the effect over a large range of these distances. Just how far a substantial glare effect extends is not known, but the results of Study 2 indicate that visibility will be affected to a considerable extent by opposing headlights at distances in excess of 3,000 ft.

That human beings differ in visual ability and sensitivity to glare was known, but what was not realized was the effect this variability might have on the relationship between target detection distances and lateral separation, as indicated by the differences in the curves in Figure 4 for the three subjects (N) compared to the two subjects (L). It was surmised that the reason for this difference in the relative effect of glare was that the two groups of subjects, differing in initial visual ability, were at different distances from the glare car when the target was at threshold for them individually and they were, therefore, subjected to different levels of glare when detection occurred. It was further suggested that the use of targets of different initial (no-glare) difficulty would also result in different relationships between detection distance and lateral separation.

### Evaluation of Study Methods

Assuming that the effects on target detection distance are the criteria chosen for evaluating the effects of glare, interim recommendations can be made on the basis of the two studies considered so far, both of which utilized target detection distance as the parameter.

Figure 10 illustrates the qualitative theoretical relationships between target detection distance and distance of the glare car for several different methods of study. The broken-line curves represent hypothetical typically shaped curves of target detection distance by glare-car distance for constant lateral separations. The two curves in each graph might represent data for different lateral separations for different targets, or for subjects with different sensitivities to glare. The light solid lines are intended to illustrate the manner in which the data are derived.

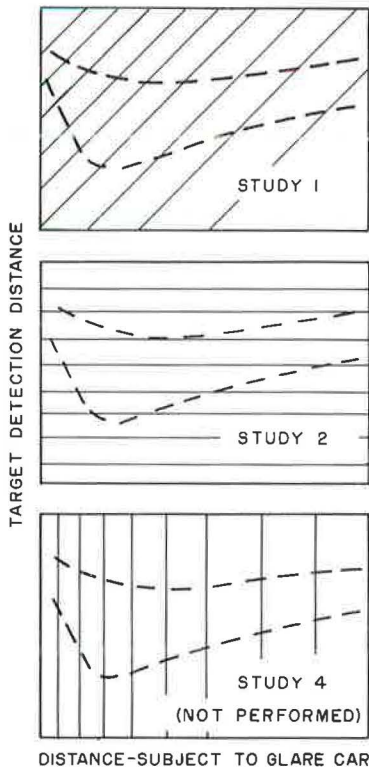


Figure 10. Theoretical relationships between target detection distance and glare car distance for different study method.

The top part of Figure 10 illustrates these relationships for Study 1, in which the opposing glare car and the target were stationary and the subject drove toward the target. This fixed relationship between glare car and target resulted in a fixed relationship between distance of the glare car and target detection distance. Figure 5 showed that the data for the different lateral separations all fell on a diagonal line which intersected the ordinate at a distance equal to the longitudinal separation between the glare car and the target, and with a slope of unity. This demonstrated that, for any one setup (i.e., relative positions of glare and target cars), there is a direct relationship between the distance of the glare car and the distance at which the target was detected. Thus, all data for Study 1 fell along one of the diagonal lines in the top part of Figure 10 and severely limited the general value of the study. However, this limitation can be overcome by collecting data for several setups, each of which would involve a different distance between glare car and target. The data for each setup would fall on one of the diagonal lines in the top graph of Figure 10. A curve can then be drawn through the appropriate values for each lateral separation.

In Study 2, subject and target were both

stationary and the glare car moved. With this method, distances of the glare car were found for constant target detection distances. The data, therefore, fell along lines of constant target detection distance (indicated by the horizontal lines in the middle graph of Figure 10). The threshold points which resulted from the intersection of the subject's line of travel with the threshold curves (Fig. 8) were used to generate the curves of target detection distances by glare car distance (Fig. 9). Because the threshold curves extend for such long distances and are nearly parallel to the line of travel, the locations of these points of intersection are subject to a great deal of variability. The fact that these curves are nearly parallel to the line of travel indicates that the glare effect is apparently fairly constant for a large range of longitudinal distances between subject and glare car. The Study 2 method would be more suitable for those portions of the target detection distance curves that have considerable slope, i.e., where target detection distance changes rapidly with glare car distance. However, Figure 9 shows that these conditions apply to only a small portion of the curves.

A third possible variation of this type of study, which was not performed, would be to have the subject and the glare car stationary while the target is moved toward the subject. This method is shown as Study 4 in Figure 10 because a study which was performed and is described in the following section is known as Study 3. With the glare car and subject stationary, the glare condition would be constant and the distance at which the target could be detected at different lateral separations would be found for this condition of glare. Several different distances between the glare car and the subject would be used. The data, in this case, would fall along lines of constant distance between subject and glare car and would be represented by the vertical lines in the bottom part of Figure 10. This would probably be the best method for obtaining those parts of the target detection distance curves which have a low slope. For the large-slope portions of the curve, the points of intersection would be subject to error. The main objections to this study method are the difficulty of moving the target toward the subject and the consequent changes in the environment of the target.

#### Recommended Method

Although the greatest initial objections were made to the method of Study 1, the use of several relative distances between target car and glare car disposes of these very objections. Therefore, this method, with some modifications as described subsequently, is recommended for visibility tests based on target detection distance.

In addition to using several relative distances between glare car and target, a number of subjects should be used, preferably representing a cross-section of ages and degrees of visual ability. There is evidence which indicates that older drivers have poorer night vision (6) and are affected by glare to a greater degree than those with normal vision (7, 8). It should be pointed out that vision scores under daylight levels of illumination are not an assurance of the degree of night visual ability (9).

The use of one particular target for these tests will give relationships between lateral and longitudinal separations and detection distance which hold for that target only. These relationships may be different for different targets depending on the magnitudes of the distances at which the targets are detectable and at which the different subjects are able to detect them. Therefore, it is recommended that several critical targets of interest and of varying difficulty be used.

Because threshold is related to the probability of detection, target detection will be affected by the degree of attention devoted to the task and the degree of expectation associated with the target's presence and location. (According to Roper (10), objects were detectable at twice the distance when subjects were actively looking for them as when they were unexpected.) It is, therefore, important that all subjects receive the same instructions and utilize a constant criterion (e.g., "I definitely see it," "I think I see it") for all tests so that the results can be compared. To reduce guessing and anticipation, it is suggested that during the course of the experiment the target not be present at times and that the targets be changed at random between runs.

Varying the position of the target transversely across the subject's line of travel is not recommended because this will change the illumination on the target from the sub-



ject's own headlights and will change his line of sight with respect to the opposing headlights. It will be shown in the discussion of Study 3 that the background against which the target is viewed has a critical bearing on the detectability of the target. Also to be described will be a possible effect due to light from the opposing headlights which is reflected from the pavement in the vicinity of the target. Light from the opposing headlights may be reflected from the target itself. The results of a study by Schwab (11) indicate that light from opposing headlights affects the visibility of targets in ways aside from the glare effect. Changes of target position, therefore, may be equivalent to using different targets and, if done, a complete set of data should be taken for each position and analyzed separately. It may be that minor variations in position across the subject's lane may not be critical where the target is one which can be detected at great distances (500 ft or more). Still, any variation in position will tend to increase the variability of the data.

Because it is difficult to determine beforehand where the critical points in the curves will occur (e.g., breaks in the curves, minimum detection distances for each lateral separation), particularly where several targets differing in difficulty are used, preliminary estimates of the relative distances between glare car and target and the lateral separations to be studied should be based on pilot studies utilizing the targets and the subjects that will take part in the experiment.

Greater efficiency may be obtained in executing the field studies if several subjects are employed simultaneously. Allowance should be made for any differences in their lateral positions. One possibility would be to have them alternate positions. No subjects should be seated in the back seat of the subject car because this will result in the opposing headlights sometimes being blocked by those in the front or by parts of the car itself. One possible disadvantage to this procedure would be that differences in the degree of concentration of the subjects would result if one drove while the others were able to devote their full attention to looking for targets. Again the subjects could alternate driving and riding in a carefully balanced and randomized fashion.

To reduce reaction-time lags and promote greater accuracy and convenience in the distance measurements, some method of instrumenting the distance measurement and recording of responses should be utilized, e.g., a fifth wheel device for distance measurement with a pushbutton for response by the subject actuating a print-out or pen recorder. Whatever method is used, it is important that, where more than one subject is run at a time, subjects be prevented from influencing each other.

The exploratory studies reported here and studies reported elsewhere have dealt solely with the case where a single opposing vehicle is met. Although this is not an unusual situation, it is perhaps more common for a driver to be faced with several opposing vehicles at a time at frequent intervals along the highway. It is, therefore, suggested that the more critical case of a continuous line of opposing vehicles be tested. The spacing of these vehicles and the number of lanes of opposing vehicles could be varied to simulate different volume conditions and lane configurations. In this case, the variable, distance of the opposing glare car, would be replaced by the level of glare (in terms of density of opposing vehicles or veiling brightness). Inasmuch as these exploratory studies have shown that the glare effects extend for long distances of the opposing glare car, the line of opposing vehicles would have to extend for considerable distances. Should this not be feasible, shorter lines of opposing vehicles could be utilized, but another variable would be present, i.e., distance to the first (or last) opposing vehicle. It is possible that the difference in glare effect between that due to a continuous line of opposing vehicles and that due to some critical segment of the line may be negligible. To determine the critical segment, if there is one, might itself require an extensive study.

At the risk of appearing facetious, one further suggestion is made. Studies of headlight glare utilizing clean windshields do not achieve the realism typical of that of actual windshields in use. Perhaps the most critical case should include a dusty windshield. However, problems can be foreseen in maintaining the windshield condition constant. Perhaps some method can be found to simulate the light-scattering properties of a dusty windshield.

### Detection Distance as a Parameter

The values of target detection distance given here are the maximum possible because they represent measurements at the lowest possible limit of performance, i.e., bare detection under conditions where the subject is concentrating on detecting something, usually knows what he is looking for, and knows approximately when and where to look for it. In the actual driving situation this is not the case and, compared to the test situation, the driver will be closer to the target when he detects it. At detection, the angular dimensions of the target (visual angles subtended by the visible dimensions) will be greater and the illumination on it will be greater by the square of the ratio of the respective distances (inverse square law of illuminations). For example, if the driver needs to be half as close to detect the target in an actual driving situation as in the test situation, the angular dimensions of the target have had to be doubled while the illumination on the target has had to be increased four times. By the same token, relative detection distances do not represent the same relative degrees of visibility. It cannot be said that visibility is twice as good under one set of conditions as under another but only that the detection distance of a particular target is twice as great. Because, however, in a test situation one cannot simulate the degree of attention and expectation existing in the actual driving situation and still expect to elicit usable responses from subjects, one must make some concessions to practicality.

It should be realized that the detection distance obtained by taking the average of a number of detection distance observations represents the distance at which the target is barely detected with maximum concentration 50 percent of the time. This would be acceptable because relative values are useful if one could count on actual driving detection distances being directly proportional to those obtained in the test situation. This appears doubtful, however, in view of all the other changes that take place as distance to the target changes.

To adjust partially for realism, it is suggested that some higher probability level of detection be shown, such as those distances at which the target is detectable 95 percent of the time. Practical limitations, in terms of the amount of data that would have to be collected, would prevent the achievement of any higher probability of detection. Where it is possible to obtain approximately 100 replications for each condition (one lateral separation, one target, for one setup of glare car and target), that detection distance which is exceeded 95 percent of the time may be taken from a cumulative frequency plot. This procedure is unreliable where the sample size is much smaller; for instance, with a sample size of 20 observations, the lowest 5th percentile would have to be based on only one observation. Where the sample is smaller than 100, a normal distribution may be assumed or tested for, the mean and standard deviation calculated, and the 5th percentile computed. The higher the variability in the data, the larger the sample size needed for reliability.

These problems arise from the use of detection distance as the parameter for ascertaining the effects of opposing glare on visual performance because the only data which can be obtained are at locations where the target is at threshold. The level of visual performance at other locations cannot be measured. That is, if, under a given set of conditions, a target of interest can be seen (i.e., it is above threshold), there is no way of knowing how well it can be seen.

Discussion of some of the other controls and factors of importance in visibility tests, such as measures of glare levels and the effects of the areas against which the target is viewed, must be postponed until after the discussion of Study 3.

It was stated at the beginning of this section that the recommendations would be based on the assumption that the effects on target detection distance were to be the criteria for evaluating the effects of headlight glare. The recommendations for this type of study hold only for this assumption. This is another way of saying that studies of target detection distance should be performed only if effects on target detection distance are meaningful.

## STUDY 3

The analyses and interpretation of the results of Studies 1 and 2 were plagued by the problems of the dependency of the results on a particular practical target, of possible variations due to different headlight aims and different positions of the target, and by the simultaneous changes in both the illumination on, and the angular size of, the target as the subject approached it. To obtain a general picture of the extent of the glare effect, a different approach from the previous methods was attempted in Study 3.

The aim was to have a constant-size fixed target, the visibility of which could be varied by varying its brightness. It was thought that the relative brightnesses necessary to maintain a constant level of visibility of the target would give indications of the relative effects of different lateral separations and of longitudinal distance of the opposing vehicle. The only measure of the level of constant visibility that could be obtained was the threshold level.

The field layout for Study 3 is shown in Figure 11. The target consisted of a 21- by 26-in. white translucent plexiglass screen illuminated from behind by an incandescent lamp. A variable transformer was used to vary the voltage across the lamp and thereby vary the brightness of the target. The voltage induced in a photocell mounted next to the lamp was recorded. A range of brightness readings on the target was obtained using a Spectra Brightness Spot Meter (12) reading directly in footlamberts (lumens/square foot); this calibration was used to transform the recorded photocell output into brightness values.

The subject was seated in a stationary car and viewed the self-illuminated target at a distance of 900 ft. The target was situated directly ahead of the subject with its center approximately 3 ft above the pavement. The subject's eye height was 4 ft. The subject's line of sight was, therefore, essentially parallel to both the path of the glare car and to the pavement. The 21- by 26-in. rectangular target, at 900 ft, subtended visual angles of approximately 7 by 8 min of arc. The subject car's headlights were on low beam to establish a constant brightness on the pavement and adjacent area typical of that found in the normal driving situation.

As the glare car, with high beams on, came down the track at a speed of 10 mph, the subject used the variable transformer to vary the brightness of the target so that it remained approximately at the threshold of visibility. He did this by increasing the target brightness until he could just detect the target, then decreasing the brightness until the target disappeared, etc. After some practice these oscillations were capable of being performed rapidly (approximately one cycle per second) and with low amplitude. The middle of the range was taken as threshold.

After the glare car had passed him, the subject continued to keep the target at an approximation of threshold while his eyes readapted to the no-glare condition. This was assumed to have occurred when the record of the photocell output reached a constant level. The average of these values over all runs was taken as the no-glare threshold for the subject.

The longitudinal distance between the subject and the glare car was obtained by road tube actuations which were recorded simultaneously with the photocell output.

Runs were made in random order with the glare car at lateral separations of 7, 20, 32, 57, and 107 ft. The first road tube was situated 3,000 ft from the subject, but because it apparently took some time for the subject to find his threshold level, the data are not considered entirely reliable before 1,800 ft.

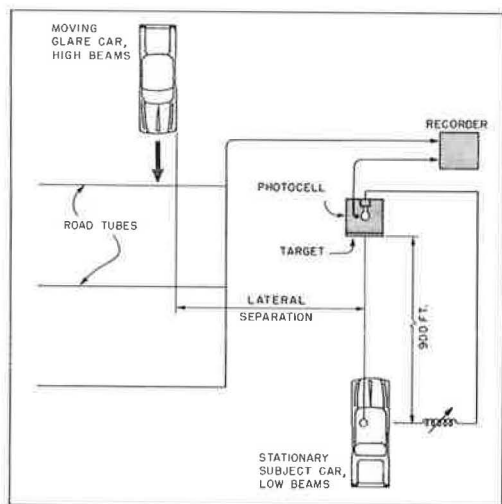


Figure 11. Field layout for Study 3.

## Results

It was expected that the results of Study 3 would be more clearly interpretable than those of Studies 1 and 2 because it was believed that the variables were more exactly controlled and were more exactly subject to measurement. That this was partially true, at least in a qualitative sense, can be seen from Figure 12. A set of curves is shown for each of two subjects, A and B. That part of the abscissa to the right of the zero-distance point is the longitudinal distance between the subject and the glare vehicle. That part to the left is the time after the glare car passed the subject. (The time scale is equivalent to the distance scale for the 10 mph running speed of the glare car; i.e., 10 mph is 15 fps, and the time and distance scales have been so drawn that a 1-sec interval on the former is the same length as a 15-ft interval on the latter.) The ordinate is the target brightness in footlamberts, such that the target was at the threshold of visibility for the subject. Each curve is for a different lateral separation and represents the smoothed average of at least three and sometimes four replications.

The interpretation of Figure 12 can best be visualized as follows: the subject is considered to have been situated at distance zero, facing the glare vehicle as it approached from the right of the figure. As the distance between subject and glare source decreased, the decline in the curves indicated that the brightness necessary to maintain threshold visibility also decreased; i.e., the disabling effect of the glare source was apparently decreasing. This was contrary to what had been expected.

For example, in Figure 12a, for a lateral separation of 7 ft, when the glare vehicle was 1,800 ft away the subject required a target brightness of 4 footlamberts for threshold visibility. When the glare vehicle was 600 ft away, only 2 footlamberts were required. When the glare vehicle was not present, only 0.018 footlamberts were required.

All curves do not approach the no-glare level at zero distance; this is no doubt due to the fact that the subject's eyes had not readapted to the no-glare condition. The time to readapt is shown to the left of the zero-distance point.

These readaptation times are possibly longer than would be the case in the normal driving situation because of the long duration of exposure. On the other hand, the readaptation times obtained may be shorter than those found in the normal driving situation due to the slowness of the simulated meeting. The subject must obviously be readapting during the time the glare level is dropping as the opposing vehicle is about to pass him. This time period between the exposure to the higher glare levels and the disappearance of the glare source would be much shorter at normal speeds; readaptation in the normal driving situation would begin closer in time before the zero-distance point and might, therefore, continue for a longer time after the glare car had passed the driver. The net effect on the observed adaptation times of these two compensating operations cannot be determined for the test situation.

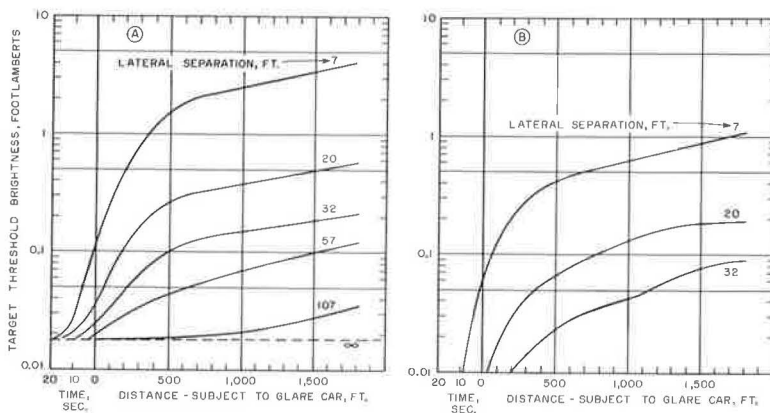


Figure 12. Threshold brightness of 8-min target—variation with distance of glare car for different lateral separations for two subjects, (Study 3), (a) subject A, and (b) subject B.



Because the curves represent the smoothed averages of a few replications, there may have been significant changes in slope at various distances of the glare car which could not have been determined because of the limited sample size. As an indication of the variability between runs, or of the range of values which approximate threshold, subject A's no-glare thresholds varied from 0.013 to 0.026 footlamberts, or one-third of a log unit. This is comparable to the variation in thresholds normally found in this type of research. Because this was a steady condition, the no-glare threshold measurements showed the least variation between runs.

Both subjects had taken part in Study 1. Subject A was one of those who showed relatively poor nighttime visual performance (L) and subject B was one of those who were classed as normal (N). It can be seen from Figure 12 that subject A required more than half a log unit more brightness to detect the target than subject B. To bring the target down to threshold when the glare car was at the wider lateral separations, subject B required brightnesses lower than those which could be obtained with the apparatus available. Furthermore, for the no-glare condition he was able to detect the target by the light from his own headlights without its being internally illuminated at all. Before a continuation of the discussion of these results can be presented, a digression is necessary.

### Psychophysiology of Vision

An explanation of the results requires examination of the phenomena which are operating, based on a background of the psychophysiology of vision (13, 14).

When one looks directly at an object, light from the object forms an image at the central part of the retina, called the fovea, where the most distinct vision results. Light entering the eye from a bright source away from the line of sight should form an image on the retina away from the fovea. However, because the media of the eye (cornea, lens, etc.) are not perfectly transparent, this light is partly scattered within the eyeball and some of it falls on the fovea, raising the adaptation level. The effect is similar to the interposition of a veil of light between the object and the eye and has, therefore, been termed "veiling brightness." An equation for the veiling brightness,  $B_v$ , produced by a point source (e.g., a headlight) is given by Fry (15):

$$B_v = \frac{k E \cos \theta}{\theta (\theta + 1.5)} \quad (1)$$

$$E = \frac{I}{d^2} \quad (2)$$

in which  $B_v$  is veiling brightness (footlamberts),  $E$  is illumination at the eye (foot-candles),  $I$  is intensity of the source directed at the eye (candles),  $d$  is distance of the source from the eye (feet),  $\theta$  is angle between the source and the line of sight (degrees), and  $k$  is proportionality factor (28.9 when these units are used). This equation was derived from experiments involving male college subjects. Older subjects may be expected to experience greater amounts of scattering due to increased opacity of the media of the eye with age (8, 16).

An object is detectable because of the contrast of its brightness,  $B_o$ , to the brightness of the background,  $B_b$ , against which it is viewed (more correctly, to the level of brightness to which the area of the retina adjacent to the image is adapted). Contrast is expressed by Blackwell (17) as

$$C = \frac{B_o - B_b}{B_b} \quad (3)$$

Because the veiling brightness exists in the eye, its effect is to appear to add to the brightness of the target and the background. However, it decreases the effective contrast,  $C_e$ , because the brightness difference between the object and its background remains unchanged while the adaptation level (the original  $B_b$  plus the superimposed  $B_v$ ) is raised.



$$C_e = \frac{(B_o + B_v) - (B_b + B_v)}{B_b + B_v} = \frac{B_o - B_b}{B_b + B_v} \quad (4)$$

Therefore, the extent to which a given magnitude of veiling brightness will reduce visual ability will depend on the magnitudes of the existing brightnesses. (To complicate matters further, lest it be thought that the contrast required to detect a given size target is constant, threshold contrast varies with adaptation brightness.)

### Discussion

Utilizing Eqs. 1 and 2 and a candlepower diagram for the configuration of headlamps (four-lamp high beams) used in this experiment, values for veiling brightness due to the opposing headlights were calculated for each of the lateral separations for the geometric conditions of the experiment. Veiling brightness may be measured directly by the Fry-Pritchard glare lens used in conjunction with a Pritchard Telephotometer. This lens, attached to the photometer, measures the veiling brightness due to all light sources in the field of view by integrating them according to Eq. 1. Both this lens and the Pritchard photometer are briefly described by the American Standards Association (12). Fry (18) gives a detailed description of the lens. Figure 13 shows the variation in veiling brightness with longitudinal distance of the glare car. The calculations, for a horizontal line of sight, are based on the assumption that the glare car is traveling in a path parallel to the subject's line of sight on a horizontal plane. The magnitude of the veiling brightness and the shapes of the curves will be different if any of the following are changed: orientation of the line of sight, highway geometry (affecting the orientation of the opposing headlamps), and number of glare sources or headlight beam (high to low). In addition, the degree of opacity of the media of the eye will differ between individuals. The peculiar shapes of the curves are caused by the way in which the factors affecting veiling brightness vary with lateral and longitudinal separation.

The curves are drawn in the same format as those of Figure 12; i. e., the subject is assumed to be situated at distance zero facing the glare car as it approaches from the right of the illustration. Veiling brightness at the 7-ft lateral separation rises

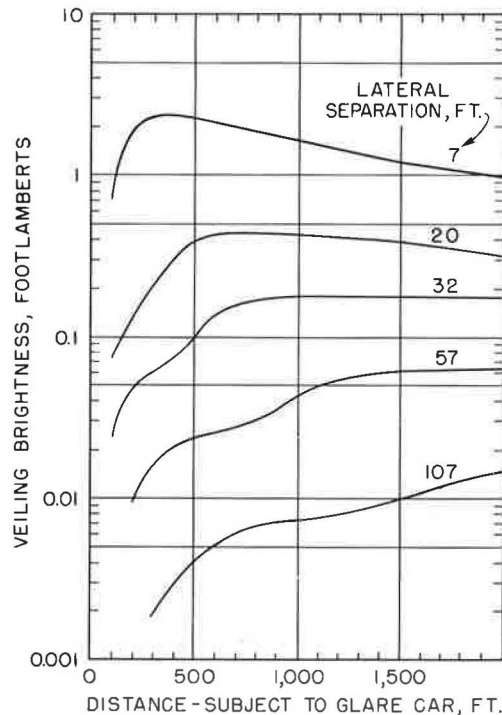


Figure 13. Veiling brightness for opposing high beams, Study 3 (Eq. 1).

gradually to a peak as the glare car approaches from 2,000 ft away to within 400 to 300 ft, and then drops sharply. Veiling brightnesses at the 20- and 32-ft lateral separations are fairly constant for long distances, beginning to drop off at about 600 and 700 ft, respectively. Veiling brightnesses for the 57- and 107-ft lateral separations are already decreasing as the glare car approaches to within 2,000 ft of the subject.

Values for veiling brightness are not shown at small longitudinal distances because the candlepower diagram does not give values for very large angles. At these distances, candlepower is very low and the glare angle ( $\theta$ ) is getting so large that veiling brightness becomes very small. Veiling brightness due to the headlights must obviously be zero at zero longitudinal distance from the subject; therefore, the curves must approach the zero distance line asymptotically on the log scale.

Target threshold brightness is related to veiling brightness through the brightness-contrast function (Eq. 4). Unfortunately, the equipment available at the time this experiment was performed was inadequate to measure the low levels of background brightness which were present at the site, so that target contrast could not be calculated. However, all other things being constant, target threshold brightness should vary directly with veiling brightness; e.g., where veiling brightness is high, target brightness should be correspondingly high.

Comparison of the threshold brightness curves of Figure 12 with the veiling brightness curves of Figure 13 shows this, generally, to be the case. However, there is some inconsistency. For the 7-ft lateral separation, between 1,800 and 300 ft, target brightness is falling while veiling brightness is rising. At lateral separations of 20 and 32 ft, target brightness is falling even while veiling brightness remains fairly constant. Only for the 57- and 107-ft separations do target brightness and veiling brightness decrease concurrently.

A comparison of the Study 2 target detection distance curves of Figure 9 with the veiling brightness curves of Figure 13 shows them to be generally consistent (to visualize this, imagine that Figure 9 is turned upside down). For the narrow separations, at glare car distances where veiling brightness is increasing, target detection distance is decreasing, and vice versa. Therefore, the Study 2 target detection distance curves seem to show a different relationship between the effects of headlight glare and position of the glare car than do the target threshold brightness curves of Study 3. Based on the target detection distance, the disabling effect of glare was shown in Study 2 to increase as the glare car approached from far distances, to reach a maximum and then to decline. On the other hand, the Study 3 data on target threshold brightness show the disabling effect of glare to be worst at far distances of the glare car (up to 1,800 ft) and to decline as the glare car approached. Is this difference in results due to the differences in the targets and the study methods? Perhaps a different way of looking at the data of Study 3 will be helpful.

It was postulated previously that if all other things remain constant for different locations of the glare car, then changes in veiling brightness alone should determine changes in the contrast conditions and, consequently, in target threshold brightness. It should follow, therefore, that where the same value of veiling brightness occurs for different locations of the glare car, the corresponding target threshold brightnesses should also be equal.

To check this, the data of Figures 12 and 13 have been combined in Figure 14 to show target threshold brightness for the associated veiling brightness for each subject, lateral separation, and distance of the glare car. Two sets of curves are shown, one for each subject. The small numerals on the curves are the distances, in hundreds of feet, of the glare car at which the data were derived. The boxed-in numerals are the lateral separations for each curve. If the target threshold brightness is wholly dependent only on the level of veiling brightness (and if the calculated values of veiling brightness are correct), all curves for each subject should overlap. Considering the limitations of the target threshold determinations and the fact that veiling brightness has been calculated rather than measured, the coincidence of the curves for the different lateral separations for each subject is quite good. An arbitrary trend line has been drawn for each subject. The curves for each lateral separation have been drawn as far as the veiling brightness values available would permit. Were very low veiling

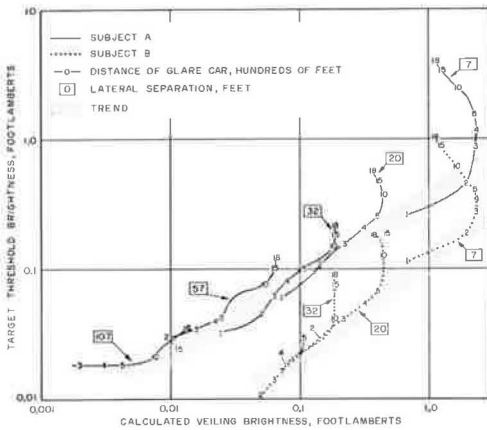


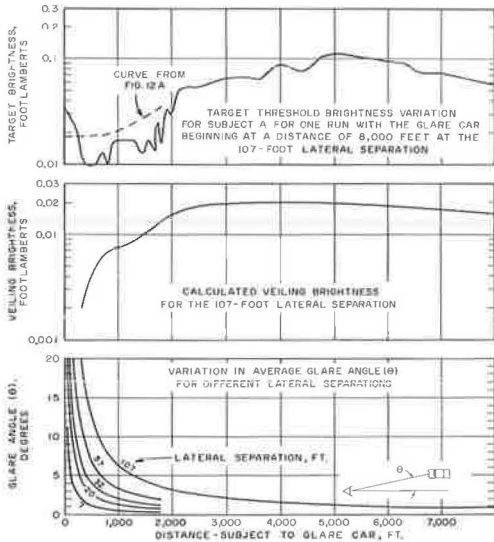
Figure 14. Target threshold brightness vs calculated veiling brightness for two subjects.

brightness values available for the small distances, all the curves theoretically would follow the trend lines to the no-glare level, were it not for the lag in adaptation. This may be why most of the curves show a decreasing slope at the small distances.

Although, for the most part, the curves show a high degree of coincidence, there are discrepancies where the curves do not follow the trend lines or the trend slopes. The inconsistencies noted when the target brightness curves of Figure 12 and the veiling brightness curves of Figure 13 were compared stand out clearly. Closer examination shows that these departures from the trend lines occur most pronouncedly at the narrow separations and at the far distances of the glare car. Here a visualization of the target and its background, as viewed by the subject, may aid the interpretation. Part of the target,

being somewhat closer to the pavement than the subject's eyes, is viewed against a background of pavement. The opposing headlights not only introduced veiling brightness into the eye but also lighted up the pavement near the glare car. In addition, at long distances there is some specular reflection from the pavement between the glare car and the subject. Furthermore, for far distances and, particularly, at narrow lateral separations, the opposing vehicle is very close in angular distance to the target. Therefore, for these long distances and narrow separations, a lighted area of pavement existed close to the target. This would have decreased the contrast of the target, requiring a higher target brightness to bring it up to threshold. Furthermore, the veiling brightness calculations have been based on the assumption of a fixed unwavering line of sight. Because, presumably, the target was approximately at threshold, it should not have been visible approximately half the time, and so could not be fixated upon constantly. (Even if the threshold brightnesses derived are not for 50 percent detection, the oscillations in target brightness brought about by the subject required that the target be nondetectable approximately half the time.) Small eye movements undoubtedly brought the line of sight closer to the opposing headlights, thereby increasing the veiling brightness over that which had been calculated. It is possible that the subject may have occasionally glanced directly at the headlights. A third possibility, suggested by Schwab (11), is that forward scattering in the atmosphere of the light from the opposing headlights is appreciable at small angles. This scatter light would be similar in nature, and in effect, to the scattered light in the eye, which results in veiling brightness. It would reduce the effective contrast of the target, requiring a higher brightness to bring it to threshold. It is also possible that the extremely bright headlights, being the only prominent objects in the field of view, tended to distract the subjects' attention partially from concentrating on the target so that the target had to be brighter to overcome the competition. All of these effects would be present to some extent in the actual highway driving situation. The effect of the spillover light from the opposing headlights onto the pavement of the driver's own roadway would be mediated by the characteristics of the median and the geometries of the two roadways.

The questions raised previously as to why the Study 2 target detection distance curves showed a somewhat different relationship of the effects of headlight glare to location of the glare car than do the target threshold brightness curves of Study 3, therefore, cannot be answered exactly. It is possible that the answers may lie in some of the differences between the studies. The differences between the shapes of the curves for calculated veiling brightness and target threshold brightness of Study 3 were attributed to several possible factors. Among these were the reduction in target contrast due to the area of pavement lighted by the opposing vehicle, and the proximity of





## SUMMARY

The studies reported herein were undertaken with the intention of exploring alternative methods of studying the relationship between headlight glare and median width. Inasmuch as insight into the magnitude and extent of the glare effect and the factors involved was desired, the amounts of data collected were small; therefore, little reliance should be placed on the absolute quantitative values. Furthermore, the quantitative values hold only for the particular conditions studied, such as the geometry of the test situation, target, subjects, and surroundings. The qualitative relationships between target detection distance and position of the glare car will also be affected by the values of these variables. The tests simulated only a meeting with a single opposing vehicle with high beams on.

The results of the discomfort test in Study 1, the only study which dealt with both discomfort and visibility, showed that measurements of discomfort due to glare were too variable, and discomfort, itself, was too difficult to define, for a limited study to have much value. No apparent relationship was found between visual and discomfort sensitivities to glare.

Studies 1 and 2 utilized the rear of a black unlighted car as the target. In all cases, the rear red reflectors were the part first detected. Study 3 utilized a self-luminous target the brightness of which could be varied. The results of all three studies showed that the effects of glare on visibility (i.e., target detection) decreased with increasing lateral separation and were substantial even when the opposing glare car was at a longitudinal distance of several thousand feet from the observer. Very limited data from Study 3 indicate that effects of the opposing headlights on visibility may be present even when they are at distances of as much as 8,000 ft from the subject. For any individual lateral separation, the rate of change of visibility with distance of the glare car was small. Large differences in night visual ability and glare sensitivity may exist between subjects; other research has correlated these differences with age.

It was concluded from an analysis of the results of Studies 1 and 2 that different relationships between position of the glare car and target detection distance may result for different targets or different subjects because of the interaction between distance at which detection occurs and level of glare existing at that distance. This comes about because of differences in orientation with respect to the opposing headlight beams at different distances from the glare car.

The method of Study 1, where the glare car and target were stationary and the subject moved toward the target, was shown to yield incomplete results if a fixed relationship between the target and glare car were maintained. This would impose an arbitrary relationship between distance of the glare car and detection distance. To overcome this disadvantage, it was suggested that several different relative distances between glare car and target be used, with the target both in advance of and beyond the glare car.

The method of Study 2, where target and subject were stationary and the glare car moved toward the subject, was shown to be inaccurate because the cigar-shaped actual glare disability contours cut the subject's theoretical line of travel at such small angles that numerous repetitions are required for any accuracy. In addition, the threshold probability levels are unknown, so that it is impossible to determine where to draw the contours in the vicinity of those lateral separations where, for some runs, the target is always detectable for the entire run.

Other recommendations were made for the performance of detection distance studies, such as the use of several different types of targets, random orders of presentation, representative observers, and a constant criterion for reporting detection (in terms of the observers' confidence of detection); it was also suggested that one of the most critical realistic conditions would be that where a driver is faced by a large number of opposing vehicles on low beam. To render the situation even more critical and realistic, a dusty windshield could be used.

The difficulty of interpreting relative detection distances for the purpose of assessing visibility was discussed, particularly in view of the probable lack of proportionality between detection distances under the conditions of attention and expectation existing

in the test situation as compared to the normal driving situation. To approach more closely values of detection distance which would be representative of detection distances in actual driving, it was recommended that the values shown be the 5th-percentile detection distances, rather than the average detection distances. The use of the 5th-percentile rather than the average would give distances at which the target was detectable 95 percent of the time rather than 50 percent.

In Study 3, subject and target were stationary and the subject attempted to keep the self-luminous target approximately at the limit of visibility while the glare car moved toward him. As expected, target visibility increased with increasing lateral separation. At the narrow separations, readaptation times to the no-glare condition were on the order of 5 to 10 sec. Surprisingly, it was found that target visibility appeared to increase as the glare car approached the subject, at least for the distances which were analyzed (1,800 to 0 ft). This result was found to be consistent with the variation of calculated veiling brightness for the wide separations, but not for the narrow separations. Comparison of veiling brightness and target brightness indicated either that the veiling brightnesses as calculated were not the same as those present in the experiment, or that other factors were affecting the visibility of the target. It was conjectured that these other factors, which may have affected both the subject's adaptation brightness and the contrast of the target, were due to fluctuations in the line of sight, changes in brightness of the pavement against which the target was viewed due to light from the glare car headlights, or forward scatter in the atmosphere of light from the glare car headlights. Other possibilities are that the subject occasionally glanced directly at the headlights or that the headlights, being the only prominent objects in the field of view, had an attention-distracting influence.

It appears, therefore, that a report of the location of the opposing vehicle is not sufficient alone to define the visibility conditions. The independent variable should be some measure of adaptation, rather than the number or position of opposing vehicles or horizontal footcandles. In night visibility research, therefore, account should be taken of all factors which would affect the visual adaptation level so that results may be tied to a common denominator.

#### REMARKS

To explain some of the results of Study 3, some aspects of the physiological basis of vision were reviewed. They are repeated here to form a basis for the ensuing remarks.

Visual receptors are sensitive to a wide range of luminances. They adapt to the particular levels available, although there is a time lag, particularly when going from higher to lower levels of illumination. Objects are discriminable by contrast, defined as the difference in brightness between the object and the adjacent background against which it is viewed, divided by the latter (Eq. 3).

Because the media of the eye are not perfectly transparent, all light entering the eye is somewhat scattered or diffused. Where the field of view is dark, this scattered light from high-intensity sources can be of appreciable magnitude in comparison to the brightnesses of objects. This scattered light within the eye has the effect of a veil of light, superimposed over the field of view and varying in brightness with angular distance from the source. It is, therefore, called veiling brightness. An equation for the veiling brightness,  $B_v$ , equivalent to that due to a point source (e.g., a headlamp) situated at a distance,  $d$ , from the eye, and at an angle,  $\theta$ , from the line of sight, directing an intensity,  $I$ , at the eye, is

$$B_v \propto \frac{I}{d^2 \theta (\theta + 1.5)} \quad (5)$$

$I/d^2$  will be recognized as the illumination,  $E$ , from a point source, in footcandles if  $I$  is in candelas and  $d$  is in feet.

The disability glare effect is largely due to this veiling brightness which lowers the

effective contrast by raising the adaptation brightness while leaving unchanged the difference in brightness between the object and its background (Eq. 4).

The brightness of the object itself, as viewed by the driver, will depend on the light it emits, if any, and the light it reflects from the environment, from the driver's own headlights, from other sources such as other vehicles moving in the same direction as the driver, and from opposing headlights. The brightness of the background against which the object is viewed may also derive from any of these sources.

Light on the pavement from the opposing headlights may help delineate the roadway alignment ahead of the driver by increasing the contrast between the pavement and the shoulder. This is especially true where the pavement surface has different specular reflection characteristics from the shoulder. This is usually the case because roadway shoulders ordinarily are unpaved. In addition, this effect will enhance the visibility of objects seen in silhouette but will reduce the visibility of objects seen in direct light, such as pavement markings.

The factors which determine visibility, such as veiling brightness or background brightness, will themselves be affected by various median features. One of these features is median width. At any given longitudinal distance separating an opposing vehicle from an observer, a greater horizontal separation will result in the opposing headlights being at a greater angle from the line of sight; lower intensities of light and, consequently, less illumination will be directed at the eye of the observer. Both the increased angle and the lowered intensity will result in lower veiling brightness. Background brightness will be reduced because less of the forward-scattered component of the light will be present along the line of sight and less light from the opposing headlights will fall on the driver's own roadway.

On divided highways in rolling or hilly terrain, independent roadway design frequently is employed for all or substantial portions of the highways. With this type of design, usually combined with curvilinear alignment (continuous flat curves), the two roadways are designed as separate cross-sections with variable widths of median and independent grade lines. In general, this design tends to reduce glare by providing sections of wide medians, frequently with natural growth or dense plantings between the roadways. Sections of earth or rock may be left in the median area. The independent grades also may reduce the glare from oncoming cars. However, in certain locations, where the centerlines of the two roadways tend to converge or where the difference in adjacent grades is slight, glare problems may be accentuated. In good design, these potential problems are located during design and, if possible, avoided. If they cannot be eliminated, screen planting is usually specified.

Those types of median features which mediate the effects of opposing headlights by interposition can be classed as light-obstructors. Full screenage of the opposing headlights from view can be achieved by earth mounds, solid plantings of vegetation, solid fences, or fences which block the view of opposing headlights at almost all angles at which they would be visible, such as a venetian blind-type slat fence or expanded-metal antiglare screen. Partial blockage can be achieved by means of chain link fence, which completely blocks the view of opposing headlights at small angles only. Plantings of vegetation in the median can block the view of opposing headlights, if very thick and continuous. Less dense planting may tend to result in intermittent flashes. Deciduous plantings may lose much of their effectiveness when their foliage is gone, but evergreen types eliminate this difficulty. Some limited use has been made of translucent screens which reduce the intensity of the light from opposing headlights by reflecting some, absorbing some, and diffusing the rest.

Other median features may produce undesirable shadows where light from opposing vehicles falls on the driver's own roadway. A high curb may put the left edge of the pavement in shadow. A curb may also diminish the contrast between pavement and median. A low solid barrier may accentuate the shadowing effect. Guardrail posts and vegetation in the median may introduce irregular, moving shadow patterns on the roadway ahead of the driver.

Other solutions or aids to the night visibility problem have been proposed or are in use. Foremost among these has been the increase in visibility by increasing the am-



bient illumination and roadway brightness by highway lighting. It should be pointed out that the luminaires, themselves, may constitute important glare sources.

Additional illumination in the driver's field of view could be provided easily by increasing the intensity and angular spread of the headlights. This would, of course, greatly intensify the glare problem. The headlight glare problem results from the need to provide light directed along the roadway while the condition exists that drivers traveling in opposite directions on the same road face each other's light sources. Polarization of headlights has been proposed as a means of drastically diminishing the apparent brightness of opposing headlights while maintaining or increasing the efficiency of the light output of the driver's own headlights (19). This solution has heretofore foundered on the problems associated with the period of transition between partial and complete conversion to polarized headlights. Changes in conditions since the time this system was last considered may yet enable this solution to be realized (20).

A partial remedy has been to increase the reflectivity or luminance of some significant objects of interest to make better use of or to overcome the limitations of existing headlight illumination. Reflectorization of signs and pavement markings and the provision of taillights and rear reflectors on vehicles are examples of this.

Perhaps it would be of value, before considering solutions, to attempt to achieve a more definitive formulation of the problem.

Opposing headlight glare is a problem because it reduces visibility at night. But visibility at night, even without glare, is not considered good. Therefore, the visibility-reducing aspects of headlight glare are a part of, and not different from, except in degree of severity, the entire night visibility problem. The night visibility problem can be defined, superficially, as a lack of sufficient light. The next step would seem to be to consider what it is for which there is a lack of sufficient light and what the results are of the lack of visibility thereof. This line of argument leads to a consideration of what needs to be seen. What needs to be seen would depend on what visual information is utilized by the driver in the performance of the driving task. Unfortunately, knowledge as to these information needs is limited, as is appropriate definition of the major aspects of the driving task itself. As additional definition of the driving task is obtained, it is envisioned that more light (figuratively) will be shed on the driver's requirements for light (literally). In the meantime one can speculate, in the hope of opening up lines of approach which may prove fruitful.

One can begin by observing that there is apparently sufficient light being presently provided for the visual task to enable the night driving task to be accomplished. This can be stated with some degree of confidence because of the fact that, for the most part, drivers do succeed in accomplishing the task. However, all this may prove is that human beings are highly adaptable. It is not to say that the task could not be accomplished with more of a margin of safety and comfort. What appears to be lacking at this point is a reliable quantitative measure of the degree of adequacy of visibility for the night driving task because of a lack of understanding of what constitutes the task.

The primary area of concentration thus far has been on detection or visibility of targets, perhaps because this is the easiest thing to measure and appears to have the most direct bearing on the visibility problem. The problem of interpreting detection distances has been discussed previously as has the limited applicability of absolute threshold data to the actual driving situation.

Several instruments have been developed which attempt to assess the visibility of objects at suprathreshold levels. Among these may be mentioned the Visual Task Evaluator (12, 21, 22) and the Finch Visibility Meter (12, 23). However, even the visibility data obtained with these instruments must be evaluated by arbitrary criteria. In addition to enabling suprathreshold measurements, these instruments offer the advantage that a wider range of types of targets, such as selected portions of a continuous target (e.g., a pavement edge), may be studied than is the case where observations are made of detection distances for test subjects, where targets are limited to discrete objects. However, the presence of objects (i. e., objects which may be struck, as differentiated from objects of interest such as pavement lines) in the roadway is rare. The following hypothetical set of conditions may be considered: (a) the



driver can be confident that there are no objects in his path of travel except for other vehicles, and (b) all vehicles are sufficiently well lighted and marked as to be detectable even under severe conditions of opposing glare. Given these conditions, would there then be no night visibility problems? Hardly! The driver would still have to be able to see the roadway to obtain information for steering and lateral position control and for judging the location of other vehicles relative to his path of travel.

There are indications that drivers' judgments for steering and position in lane, as well as judgments of relative speed and position with respect to objects and vehicles, are determined by judgments of angular velocities, and that the distance ahead at which these cues are detected is proportional to speed (24). If it is therefore necessary for the driver to detect these cues at some distance ahead of him, he would be required to reduce his speed under conditions of lower visibility. Should he desire to maintain the same speed as under good visibility conditions, some compensation probably must take place and he may have to devote more concentration and attention to the task of retrieving information, resulting in increased tension and fatigue but little or no measurable effect on gross driving performance. It is also possible that the ability to determine the course of the roadway even further ahead than is necessary to detect steering cues facilitates the driving task by relieving the driver of part of the vigilance task.

On the basis of subjective experience it seems that, even where the glare effect on visibility is small, such as where a wide median exists, the presence of opposing headlights is annoying. Allied to the problem of the increased vigilance required when visibility is poor is the possibility that the awareness of a deficiency in visibility, and the ensuing uncertainty of detecting cues, may themselves induce tension. Because man is by nature a daytime animal, the mere presence of darkness may be psychologically depressing.

Because opposing headlights (or other high-intensity sources such as luminaires, advertising displays, or lights associated with roadside business establishments) tend to be by far the brightest and most prominent objects in the field of view, they may tend to distract the driver's attention from the primary visual task in addition to and because of their effect on contrast. This distraction (visual "noise") effect could result in visibility reduction from the psychological effect in addition to the physiological effects. As an additional aspect of the problem of the intensified vigilance required, it would add to tension and fatigue. In addition to the psychological stress and discomfort engendered, continued exposure to bright headlights may be physically discomforting.

It may well be that the major benefits of eliminating high-intensity glare sources from the driver's field of view will be in the area of driver comfort; perhaps increased emphasis on investigations of glare and visibility vs comfort and fatigue is warranted.

#### ACKNOWLEDGMENTS

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# More Light on the Headlighting Problem

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•IS there any practical way that seeing can be improved with the lower beam? Can the annoyance of headlamp glare be reduced? What is the effect of the headlamp mounting height on today's cars? How about the new quartz iodine headlamps that are being promoted in Europe? How much does alcohol—in the driver—affect seeing distances?

Answers to these questions were sought in a recent series of seeing-distance tests using opposing cars with observer-drivers and observer-passengers. The procedure was similar to that described in "Seeing Against Headlamp Glare." (1)

Two opposing cars, radio equipped and with the test headlamps, were started some 4,000 ft apart on a 2-lane highway, accelerated uniformly to 40 mph with this speed maintained throughout the test run. Test obstacles 16 in. square and with 7 percent reflectance (dark gray) were placed at the right edge of the traveled roadway. There were a total of 10 obstacles, 5 ahead and 5 behind the meeting point. The observer-driver and observer-passenger ignored the obstacles on the left side of the road. They watched for the obstacles on the right side of the road only and indicated the moment of detection by pushing a button. The button actuated a pen which marked a tape recorder geared to the transmission.

A sufficient number of repeat runs were made to get a fair average of the seeing distance values as the two cars approached, passed at the meeting point and proceeded beyond. The data were plotted in curves with the seeing distances as ordinates and the distance between cars as abscissae up to the point of meeting, and the distance behind the meeting point after the point of meeting.

Referring to the question on lower beams of sealed beam headlamps, present lower beams are now manufactured to meet specifications established by the Society of Automotive Engineers. These specifications are intended to cover a beam pattern which represents the best compromise between the requirements of seeing and glare relief. Minimum candlepower values are prescribed for those parts of the beam which are important from the standpoint of seeing ahead, and maximum candlepower values are provided for those parts of the beam which are apt to be directed at the opposing driver's eyes. A very important seeing distance point in the lower beam is the so-called  $\frac{1}{2}^\circ$  down,  $2^\circ$  right point, which is  $\frac{1}{2}^\circ$  below the level of the headlamp centers and  $2^\circ$  to the right of straight ahead of each headlamp.

Present SAE specifications call for a minimum of 6,000 candlepower at this point from each headlamp and a maximum of 10,000 candlepower at this point from each headlamp.

Figure 1 shows the average seeing distance values on a straight level roadway obtained in these tests for 6,000, 10,000 and 20,000 candlepower (lower beam) at this  $\frac{1}{2}^\circ$  down,  $2^\circ$  right point when approaching, meeting and proceeding beyond an opposing car with exactly the same beam candlepower values. Lamps were properly aimed and at 31-in. mounting height. A considerable gain in seeing distances is obtained with the beam providing 20,000 candlepower at the point  $\frac{1}{2}^\circ$  down,  $2^\circ$  right.

In reference to the alleviation of headlamp glare, anyone who has the opportunity to take part in tests of this kind soon learns that if the driver when meeting other vehicles at night will always direct his attention along the right edge of the lane of travel (and particularly avoid looking at the opposing headlamps) the annoyance of glare is greatly reduced and the seeing distances considerably increased. Under this condition, one need not focus the attention exactly straight ahead, nor to the left side of the road.

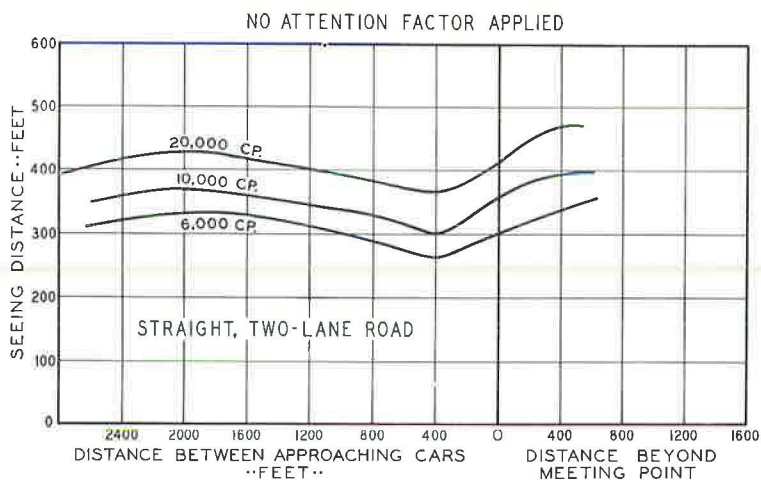


Figure 1. Average seeing distances.

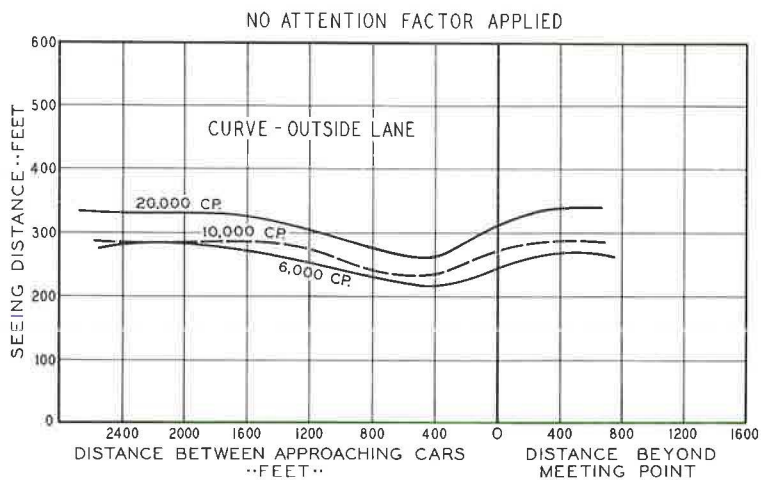


Figure 2. Seeing distances (12,000-ft curve radius).

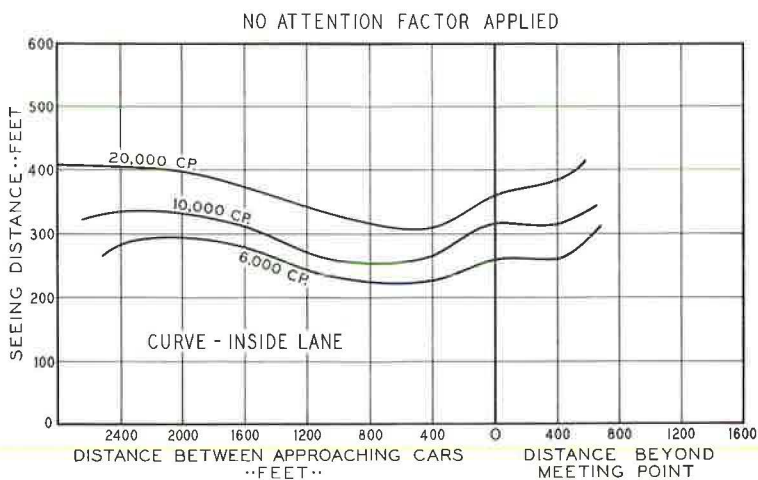


Figure 3. Seeing distances (12,000-ft curve radius).

Peripheral vision is sufficient to detect anything which crosses the road from left to right between the two cars. Fortunately, silhouette seeing (2) also serves to disclose such obstacles.

Although greater seeing distances would result from increasing the candlepower at the specified point to 20,000 on a straight road, what is the effect when negotiating a curve against oncoming traffic? To answer this question, tests were repeated in a similar manner, but while negotiating a curve having a radius of 12,000 ft. During the period of approaching the other vehicle, one of the two cars had its headlamps pointed almost directly toward the opposing vehicle, and the other of the two cars had its headlamps pointed away from the opposing vehicle (Figs. 2 and 3). Figure 2 covers the situation of the driver and observer having the opposing headlamps pointed directly at them; Figure 3 covers the situation wherein the opposing headlamps are pointed away from the driver and observer.

Again, the observers were purposely directing their attention along the right side of the traveled lane, and definitely avoided staring at the opposing lamps. If drivers can be educated to do this, a lower beam providing higher candlepower values near the center of the road or the center of the traveled lane can definitely provide added safety in terms of seeing distances versus stopping distances.

In these tests, the opposing vehicles were in adjacent lanes, with no separation between lanes other than a white line.

On turnpikes or freeways where there is separation between the opposing lanes, the effect of glare is reduced, the more the separation between lanes, the greater the reduction in glare. Therefore on freeway or turnpike driving, the seeing distance capability can be expected to be considerably greater than the values shown in Figures 1, 2, and 3 (1).

In the previous cases, the headlamps on both test cars were properly aimed. Misaim of the lower beam either reduces the seeing distance or increases glare to the approaching drivers. If the candlepower is increased near the top of the lower beam and near the center of the road, there is of course a likelihood of increased glare if the lamps are misaimed high, and/or to the left. To determine the effect of misaim with candlepower at the  $\frac{1}{2}^\circ$  down and  $2^\circ$  right point, another series of tests was run with 20,000 candlepower from the headlamps on one car and 8,000 candlepower from the headlamps on the other car. The latter candlepower was selected because it is midway between the minimum and maximum candlepower specified by the SAE for this point. Figure 4 shows the results of 20,000 candlepower misaimed up and to the left facing 8,000 aimed correctly and 8,000 candlepower facing 20,000 (misaimed) compared with 8,000 candle-

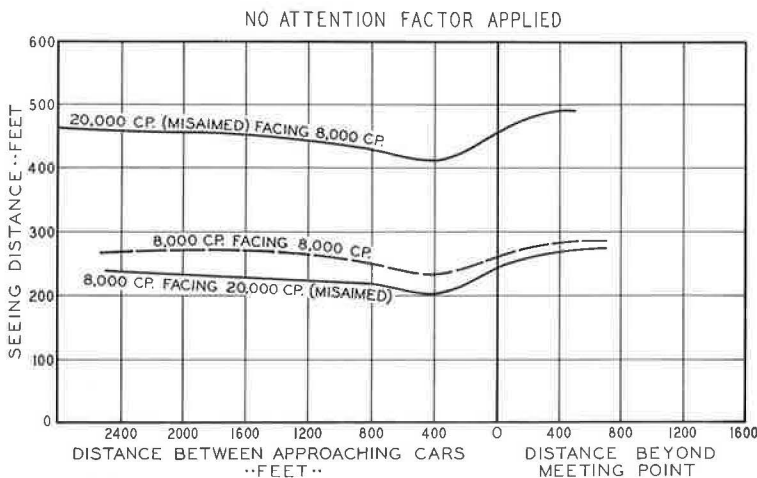


Figure 4. Seeing distances on a straight 2-lane road (for reference the dashed curve shows two cars using production lamps properly aimed).



power facing 8,000. If the lower beam candlepower is increased, the drivers of old cars will suffer some loss in seeing distance when facing new cars if the new car headlamps are misaimed high and to the left, but practically no loss in seeing distance if the new headlamps are correctly aimed.

The effect of headlamp mounting height on seeing distance, in the case of the upper beam which provides high beam candlepower values at the level of the headlamp centers and above, is negligible. Should the upper beam headlamps be mounted much lower than at present (for example, 12 or 18 inches above the ground) shadows would be cast by rough spots in the road which could be annoying; however, this is not a serious factor at the present minimum mounting height of 24 inches from the ground to the center of the lamps.

In the interest of a low silhouette which seems to have popular public approval, the headlamps have been lowered from an average of 30 to 32 inches several years ago to 24 or 25 inches from ground to center of lamps at present. This definitely reduces the seeing distances available with the lower beam because the high candlepower values in the lower beam must be directed below the level of the headlamp centers.

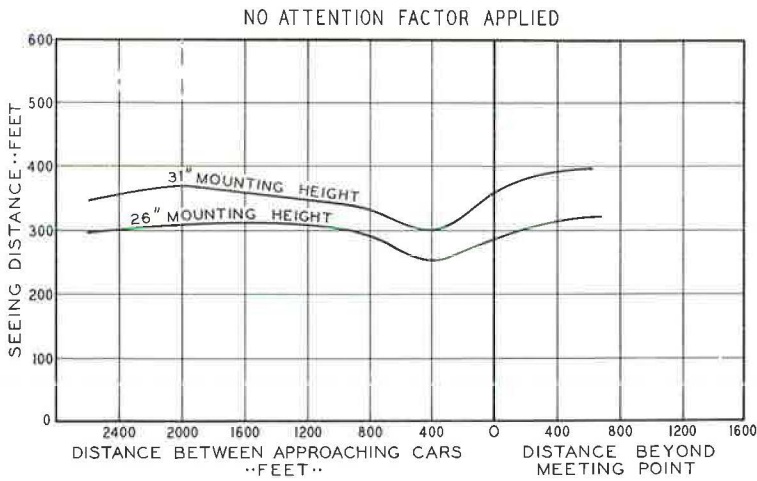


Figure 5. Effect of lamp mounting height.

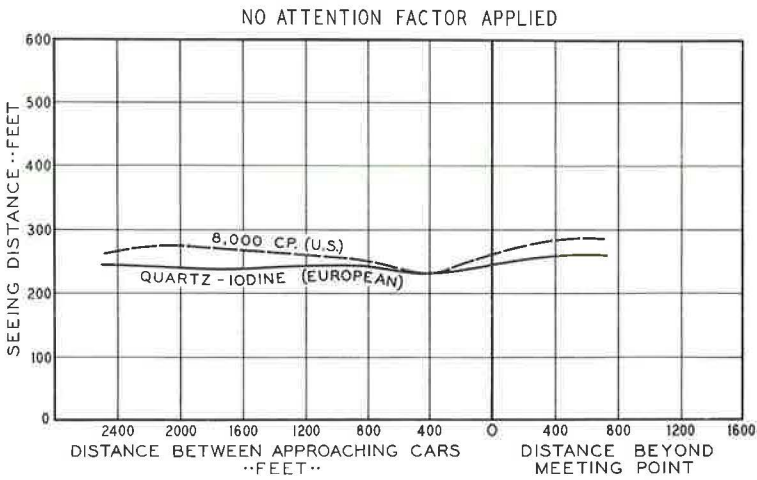


Figure 6. Comparison of production American and European (Form E) lower beams with 62-w quartz-iodine bulbs.



Theoretically, the geometry of the situation indicates that, considering the important seeing distance point  $\frac{1}{2}^\circ$  down and  $2^\circ$  right, 10 feet in seeing distance should be lost for every inch the headlamp height is lowered. Therefore, when the headlamp height is lowered from the 31 inches of several years ago to 25 inches now, 60 feet in seeing distance is lost.

As a check, the test of the 10,000 candlepower curve (Fig. 1) was repeated but with the headlamps mounted at 26 inches above the ground instead of the 31-in. mounting height. Figure 5 shows that the average seeing distance loss checks very well with the theoretical calculation.

Although the stylists and the public would probably not accept car designs that would place the tops of the headlamps above the fender or hood line, it should be feasible to raise them a few inches above the present 24-in. minimum value (ground to headlamp centers) with a substantial gain in seeing distances.

In this country, the maximum beam candlepower allowed from the upper beam of headlamps is 75,000. The Uniform Vehicle Code and the laws of the states do not in-

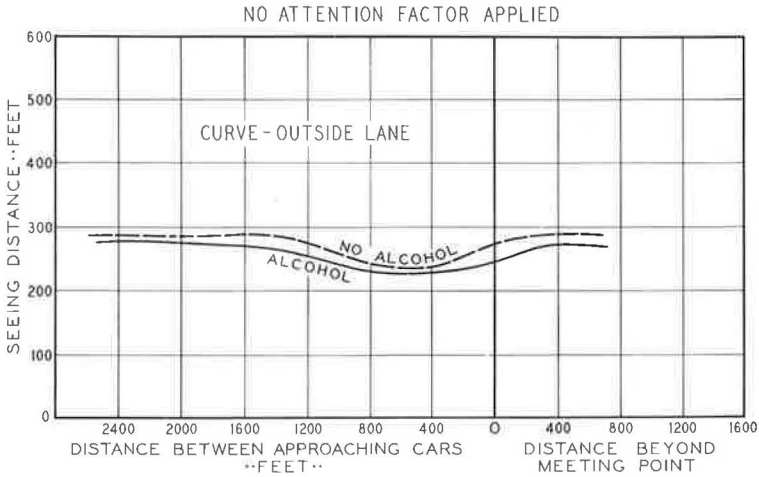


Figure 7. Effect of two "short" drinks on seeing distance.

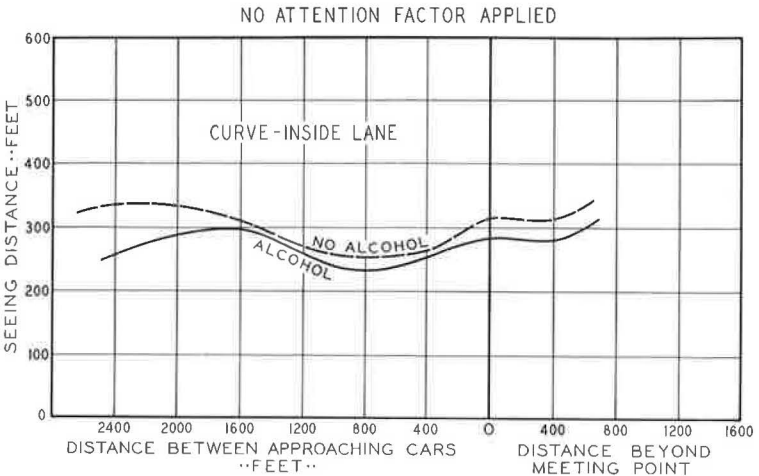


Figure 8. Effect of two "short" drinks on seeing distance.

clude this value. However, it is part of the SAE specifications which most states use as a criterion to determine whether the headlamps justify their approval. The European and international maximum is 300,000 beam candlepower. American engineers and lighting experts feel that any values much above the present SAE maximum of 75,000 would make it virtually impossible to use an upper beam, in view of traffic conditions in the United States. However, for many areas in Europe outside of towns, there is very little traffic, hence their upper beam of considerably higher candlepower gives very pleasing results.

The European lower beam (not including the English lower beam) features a very sharp edge at the top. The filament in the usual parabolic reflector is placed considerably ahead of the focal point, with a shield underneath which shadows the entire lower half of the reflector. This in effect throws away half of the possible light output in the beam, but it provides above horizontal candlepower values which are a fraction of ours.

Comparative tests of the type described in this paper have shown that the typical European lower beam provides less seeing distance along the right side of the road, but more seeing distance along the left side of the road. The reason has been that our sealed beam lower beams have provided more candlepower near the top of the beam on the right-hand side, but the depression on the left-hand side has been an average of about a degree more than that in the case of the European lower beam.

One of the major advantages of the sealed beam headlamp is the elimination of the effect of "bulb blackening." In the case of the quartz iodine lamp, there is very little bulb blackening. Instead of depositing on the bulb surface, the evaporated tungsten re-deposits upon the filament. This permits the use of a tungsten filament of higher efficiency and therefore higher brightness.

Through the courtesy of Carello of Turin, Italy, two pairs of European headlamps using quartz iodine bulbs were obtained. These headlamps provided a lower beam only. They were part of a 4-lamp system, the upper beam provided by a separate pair of lamps. Figure 6 shows the comparison of results on the straight level 2-lane road of the Carello lower beam powered by a 62-w quartz iodine bulb and a typical average sealed-beam lower beam of 8,000 candlepower at the specified point. The authors feel that the European design does not take full advantage of the possibilities with the quartz iodine lamps.

Inasmuch as the test road (an as yet unused section of a new freeway) had no traffic other than our own, we decided to measure the effect of "two drinks" after dinner. Therefore, immediately after the test covered by the 10,000 candlepower curves of Figures 2 and 3, in the course of about one-half hour, the drivers and observers had two drinks totaling a little less than three 86 proof ounces and repeated the test. The results are shown in Figures 7 and 8. Incidentally, none of the participants felt that they were at all under the influence of alcohol, yet their seeing distance was reduced.

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# Recovery of Foveal Dark Adaptation

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•A continuing problem in night driving is the effect of glare sources, as oncoming headlights, on the visual sensitivity of the driver. The literature contains considerable information on the effect of brief, bright lights on peripheral, scotopic vision, and the amount of time necessary to recover sensitivity after such exposures can be estimated from these data (4, 5, 8, 11).

Although good scotopic vision is undoubtedly of use to the night driver, its importance should not be overemphasized. Peripheral acuity, even at best, is not adequate for most seeing tasks; in the purely scotopic range of illumination levels, where the fovea is blind, acuity is exceedingly poor. At these levels targets must be 10 to 25 times as big as a foveal target at a normal light level to be seen. Furthermore, in the mesopic range of illumination levels, where most night driving situations fall, foveal vision can be used and foveal or central acuity is better than peripheral (9). These facts, coupled with the normal tendency to direct one's gaze at an object that one wishes to see, make foveal vision of major importance in night driving situations.

The literature on the effect of brief glare sources on foveal sensitivity in this range is rather sparse. There are, of course, numerous studies on foveal dark adaptation (6, 7) and a few on the effects of brief exposures on recovery of this dark adapted foveal sensitivity (3, 10). From these studies we know that foveal sensitivity to dim lights improves with dark adaptation, that this increased sensitivity takes place very rapidly (the major portion in the first 30 sec or 1 min), and that there is no further increase after about 5 min in the dark. The recovery of foveal dark adaptation after exposures to light depends on the intensity and duration of the adapting source, the longer or brighter the source the more recovery time needed.

Investigations have also been made of visual acuity during dark adaptation (1, 2). After complete light adaptation to a given level, the luminance required for resolution of a target decreases with time in the dark. The curves are very similar to those of simple foveal dark adaptation except that the final acuity threshold is higher than the light threshold and depends on the size of the target to be resolved.

There are, to our knowledge, no data specifically concerning an important night driving question: What is the effect on dark adapted foveal acuity of brief, bright sources of light? This study was undertaken to answer the question.

The sources investigated varied between 0.3 and 3,000 ft-L, a range which includes most of the brightnesses of oncoming headlights. Durations between 1 and 45 seconds were studied. Since the amount of light required for an acuity threshold varies with the size of the target to be resolved, an acuity target was chosen of a size which gave a final threshold in the low photopic range of illumination and within the range of intensity levels typical of the night driving situation.

All measures were made with a Hecht-Shlaer adaptometer. The glare stimuli were produced by the mechanism for an adaptation source provided in the Hecht-Shlaer; this source subtended  $35^\circ$  in diameter and was set at six different luminance levels between 0.36 and 3,000 ft-L. A source subtending  $4^\circ$  was also investigated to be sure that size was not a variable in this study. The test stimulus was an acuity grid,  $1^\circ$  in diameter, whose luminance could be varied by a neutral density wedge and neutral filters. The bars of the grid, alternately opaque and transparent, subtended 6 min of visual angle. Two fixation points were provided, one on either side of the acuity grid, and the subject was instructed to look in the middle of them.

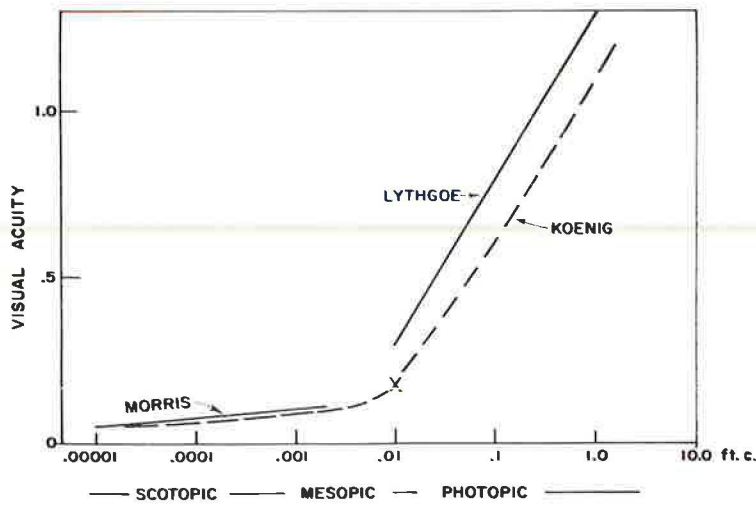


Figure 1.

The subject first dark adapted for 5 minutes; then measures were made of his acuity threshold by a method of constant stimuli. The adaptation source was then presented for a given interval and the course of readaptation to the previously determined threshold was measured. Since foveal adaptation often proceeds very quickly, a single curve could not be determined all at once; therefore the following procedure was adopted. The acuity grid was set at a predetermined level of luminance above threshold and was presented repeatedly for 1 sec at 5-sec intervals until the subject reported seeing it. If the first level was considerably above threshold, a second lower luminance level was then set and the procedure repeated. In order to fill in other points in the curve, the adaptation source was presented again and the test stimulus set at different lu-

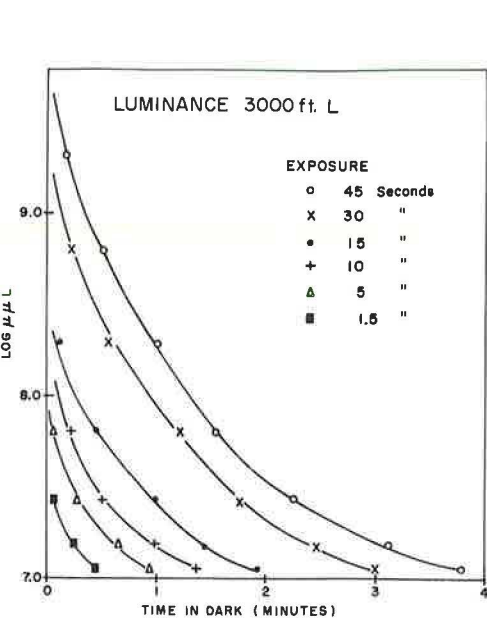


Figure 2.

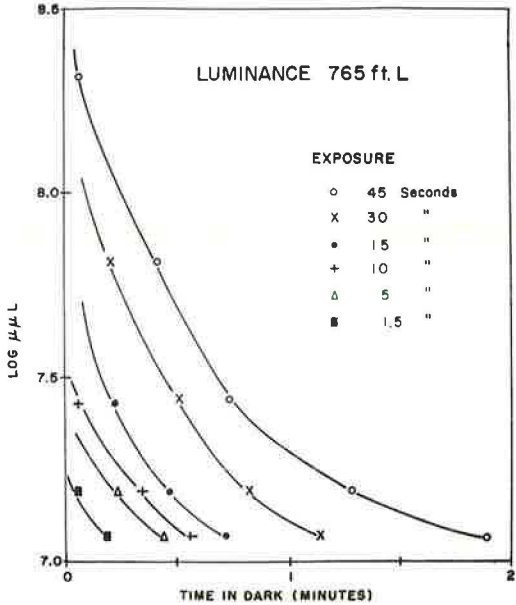


Figure 3.

minance values. All the durations for a given adapting luminance were measured in one session with the order of presentation of both durations and repetitions of the same duration randomized within the session. At least three sessions were run for each adaptation level.

Figure 1 gives the position of our acuity measures in the total picture of acuity and illumination. General levels are given at the bottom of the graph: peripheral scotopic vision at the left below  $1/1,000$  ft-L; foveal, photopic at the right, above  $1/100$  ft-L; with the mesopic range in the middle. Luminance levels for night driving, reported to this group in the past, almost all lie in the mesopic and low photopic range (12).

At the right (Fig. 1), the straight lines show the typical relation of increased acuity with increased illumination for foveal vision. The comparable function found for scotopic, peripheral vision is at the left. The target yields a visual acuity value of about 0.2; this is the reciprocal of the detail size in minutes. After complete foveal dark adaptation, the threshold in ft-L for this target is 0.01 ft-L (indicated by large X). The conditions of this study thus lie close to the limit of foveal vision and are typical of the range of values found in night driving.

The main results of the experiment are shown as a series of dark adaptation curves. Figure 2 shows the data given for the 3,000 ft-L source. On the ordinate are the luminances required for the target to be seen; on the abscissa the time in the dark. Thus, after 45 sec of 3,000 ft-L, the initial threshold is considerably above  $9.0 \log \mu\mu\text{L}$  or above 1 ft-L, and it required about 4 min in the dark for the final threshold value of 0.01 ft-L to be regained. After 5 sec of the same source, the initial threshold is about 0.1 ft-L, and 1 min in the dark is required for the acuity grid to be seen at threshold. After only 1.5 sec, it still takes about 30 sec to regain the original acuity level. Similar families of curves are found for each adaptation source. Figure 3 shows the curves for the 765 ft-L source, and Figure 4 shows the data for the 450 ft-L and the 36 ft-L sources. The obvious differences between these families of curves are that the initial threshold is lower and the total time to readapt is less for the dimmer sources.

This point can be made more explicit by plotting the same data with intensity the parameter rather than time. Figure 5 is an example of this treatment, showing the effects of different luminances at a constant exposure time. With an exposure of 15 sec,

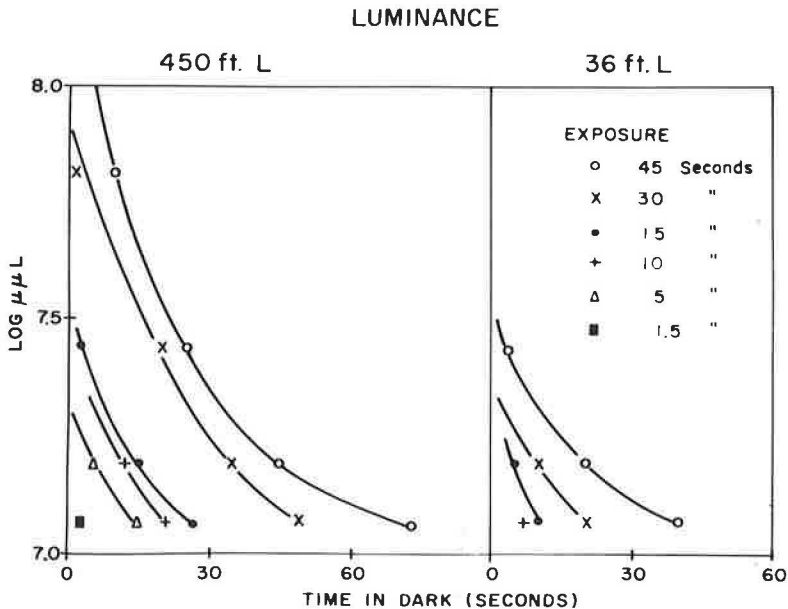


Figure 4.

for example, the total time to readapt varies from 2 min for the 3,000 ft-L source to 10 sec for the 36 ft-L source. With lower luminances of these exposure times, there was no measurable effect on the acuity threshold.

The data presented thus far have been the averages of the three subjects and there are, of course, individual differences. However, regular families of curves were

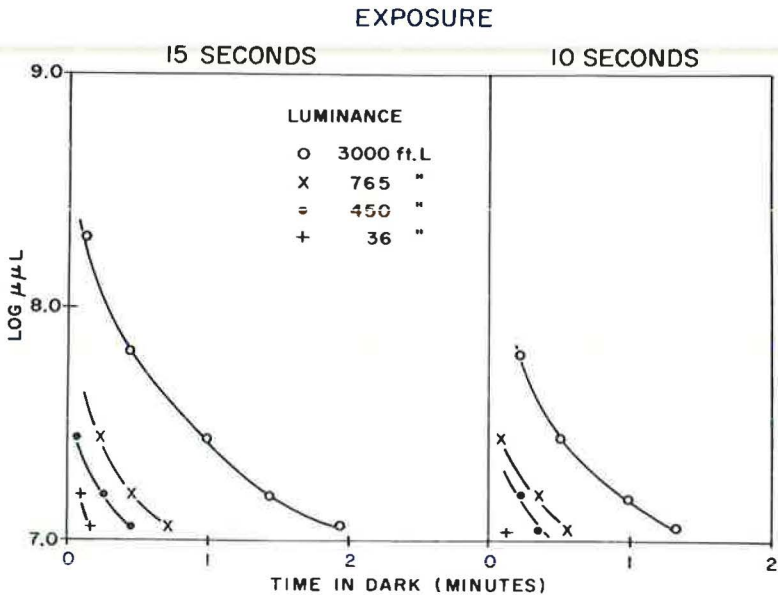


Figure 5.

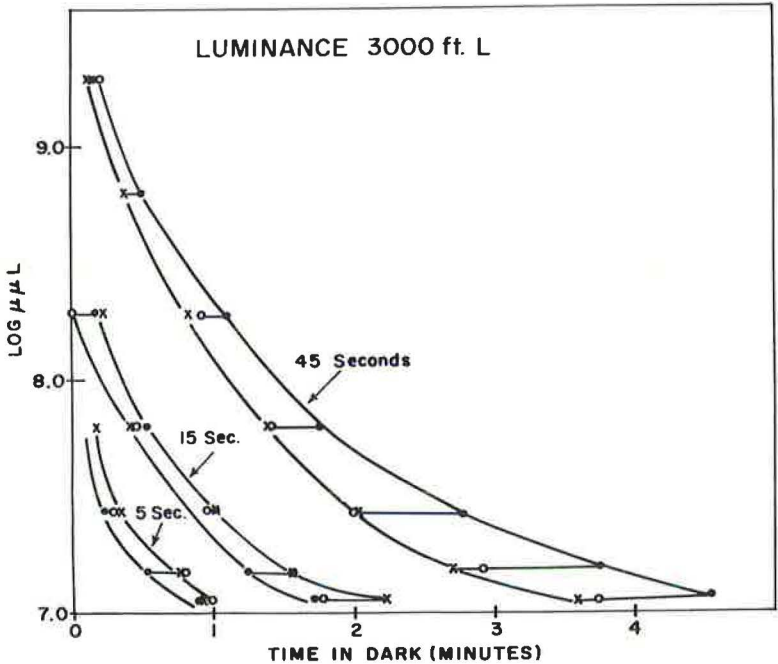


Figure 6.



found for each subject; the initial threshold and the total time to readapt varied systematically with the intensity and duration of the adaptation source in the same way as was shown in the average curves.

Figure 6 is an example of the individual variations. The luminance of the adaptation source is 3,000 ft-L and the exposure times of 45, 15 and 5 sec are given. The horizontal lines indicate the range of individual differences. Thus after 45 sec the extreme values for the final threshold were 3.5 to 4.5 min and after 5 sec exposure, 50 to 60 sec. Individual differences thus are minor compared to the effects of the glare sources.

There are two other questions that were investigated during the course of the experiment. First is the size of the adapting field. Since this field stimulates the fovea and we are measuring foveal readaptation, there is no theoretical reason why its size should be a factor. Nevertheless, an empirical check was made on this and sample readaptation curves following stimulation by a  $4^\circ$  glare source produced the same curves as did the larger field.

Second, we determined for each subject the length of exposure time beyond which no further effects were found; or in other words, the exposure time which completely light adapted the fovea at each level. For one subject, the curves for 30 sec and 45 sec were very similar; for the other two subjects, a time of 1 min produced the same curves as 45 sec. Thus with exposures beyond approximately 45 sec any further increases in dark adaptation times are not expected.

Considering some of the relationships between these data and the night driving situation, the effects of glare sources are many. There is, of course, the discomfort and even pain when the intensity of the glare is well above the adaptation level. There may be losses of visual sensitivity even if the source is located on a different retinal area than that being tested; such losses are usually attributed to reduced contrast and to stray light within the eye itself (13). These effects were not the subject of this study; instead, what is the effect when the glare source is directed at the retinal area to be subsequently used? This effect may be considerable or it may be so small as to be unmeasurable, depending on the intensity and the duration of the source.

To summarize the data, various products of intensity and time of the glare sources

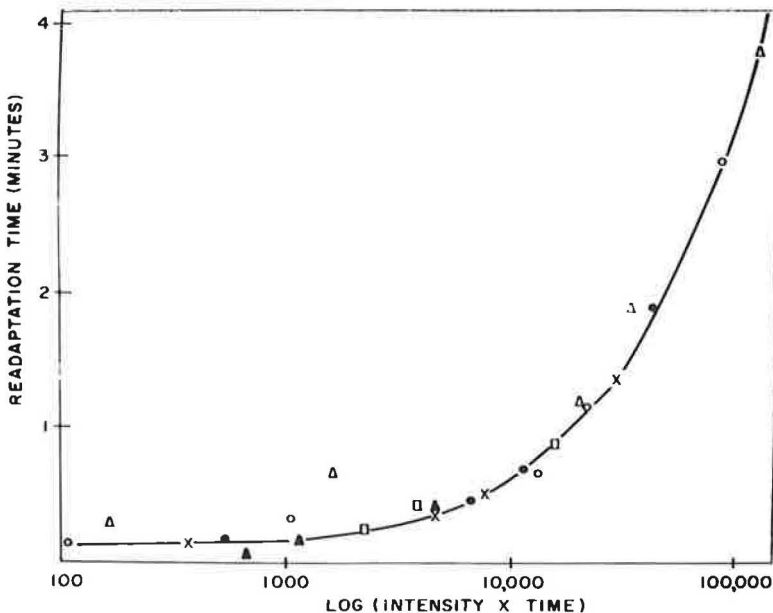


Figure 7.

have been compared. Figure 7 shows the results of this comparison. The total time necessary for the fovea to readapt to threshold is plotted as a function of the log of the product of intensity and duration of the source, and a single line has been drawn through the data points. Thus 3 sec of 3,000 ft-L is plotted at the same point as 30 sec of 300 ft-L; both require about 40 sec of readaptation time. The curve starts at a level of very little effect, 10 sec or less of readaptation time, and rises sharply to an asymptote of 4 to 5 min with large values of intensity  $\times$  time.

There is an obvious temporal limit beyond which the function will not apply. Since the fovea is completely light adapted within, say a minute, longer intervals will produce no additional effect and longer temporal values cannot reasonably be used in the calculations. It does not matter whether the eye is exposed to a given level for 1 min or 5 min; the subsequent dark adaptation curve will be the same. One other precaution—not all the data points fit perfectly; there seem to be, for example, a few systematic differences but these are more interesting from a theoretical than a practical point of view. In general, however, the curve holds very well and it holds over a remarkable range of values, in time from 1 to 30 sec, and in luminance for 4 log units. Thus, certainly, to a first approximation, the effect of any combination of intensity and time of glare source can be predicted.

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# Vision at Levels of Night Road Illumination

## IX. Literature 1963

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•TWELVE years ago the first of these reports (66) was written to make pertinent information on vision available to the members of the Night Visibility Committee. At that time there was a general opinion that accidents were mainly the result of seeing failure and that proper testing for visual efficiency would ameliorate the situation. Endeavors to relate specific seeing attributes to accidents had little success and some voices were raised to discount the role of seeing in accidents. Now there is a more balanced viewpoint that vision is the major port of entry into the individual of information necessary for good driving, but that other factors are concerned with the use of the information and also with triggering an accident.

Walton (75) recognizes two visual tasks in driving: "First, the driver must be able to see to control his vehicle; second, he must see and react to what is happening around him." He believes the problems of depth and distance need investigation with regard to driving at night. Byrnes (19) discusses the visual task of driving in terms of space and time and gives recommendations to the ophthalmologists as to what vision tests should be made on drivers. He proposes a basic license for daylight driving requiring 20/40 acuity, 140° fields and no diplopia. Night driving privileges should be given or withheld as deemed desirable. The greatest need is for a good test for night seeing. Seeing against glare should be tested after 50 years age.

The ophthalmological problems facing the physician concerned with certifying the ability to drive are also under active consideration in Germany. Hager (40) reports that drivers with impaired vision are involved in more accidents, and Piper (58) presents clinical cases in his discussion of the doctor's problem.

The equipment used for screening vision at Staten Island is described by Smith (71). Ungar (79, 80) is surveying the motorist's vision requirements in Great Britain. Attempts to evaluate the Smith-Cummings-Sherman training system for drivers reveal clearly the difficulties of the task and the problems are of interest even though the work of Payne and Barmack (56) could not unequivocally demonstrate this system to be effective.

Rashevsky (62a) has applied mathematical methods to the analysis of the driving problem. While night driving has not yet entered the equations, the approach is novel and promising. Of special interest is the use of information from the Greenshield's Drivometer (59) in the mathematical analysis (62b). Platt's (59) investigation should be extended to night driving.

Some general items on vision are: the new edition of Judd's (46) "Color, etc.", Blackwell's (13) and Boynton's (15) summaries, and the Armed Forces-Optical Society symposium (57). The Lewis (52) review has little on night driving seeing.

Connolly (21, 22) has criticized Buick and Plymouth automobiles from the human engineering and seeing viewpoints. Other items in his series of papers (20, 23-26) give information and opinions from his experience and files. Allen (2) shows how various parts of the car produce glare and make seeing difficult for daytime driving; some of which are also handicaps for night driving. Another paper (6) considers seeing from a Volkswagen.

The new roadway lighting standard is described by Edman (32). Rex (64) summarizes and rates many of the problems of good road lighting. An improved luminance



meter is described (8). Eastman and McNelis (31) report finding no significant differences in threshold contrasts using filament, mercury and sodium lighting and suggest that the increase in acuity associated with monochromatic light may account for de Boer's better seeing with sodium lighting. Performance tests by Smith and Wendell (72) at illuminances of 0.25 to 1 fc as compared with 45 fc are of interest. At the lowest level of lighting, depth perception was markedly reduced and newspaper reading difficult.

Bergsjö (10) proposes adding an inertia switch to turn on a red stop light whenever the vehicle slows down, to help reduce rear-end collisions. A parking red light would be used to distinguish a stopped from a slowing car. He also suggests prohibiting all red lights along a highway that could be confused with traffic signals. Johansson (45) found that dipped asymmetrical headlights give longer visibility distances than symmetrical ones, but that speed had to be reduced to keep braking distances within seeing distances. As dipped headlights are said to be unnecessarily glaring, Jehu (44) suggests reducing their intensity to about one-tenth by a switch which would add a resistance into the lamp circuit when less light is desirable. Dipped lights could show a moving vehicle by contrast with the side lights of a parked vehicle.

Incandescent, fluorescent, mercury and sodium lamps have the same dazzling influence on contrast sensitivity according to Jainski (43), but for equal surrounding luminances and intensity of glare illumination, readaptation time was longest after glare from incandescent and shorter from sodium light. Flamant (33) also reports longer recovery time from white than from yellow light and still greater from blue light.

Pabst (55) reviewed the dazzle problem of night driving, and points out the greater susceptibility of the fatigued driver. Glare resistance should be measured on drivers having difficulty in seeing at night. He indicates that increasing the road lighting is the only effective solution of the glare problem and that this is an economic and engineering rather than an ophthalmological problem. The letters to the editor following Pabst's article showed no uniformity of British opinion on the glare problem. In a study (17) of stress in the use of driving simulators, glare produced the greatest effect on vehicle following and no effect on time to coincidence judgments.

Blackwell (11, 12) and Fry (35) give methods for evaluating glare and prescribing illumination levels. Severin et al. (70) measured recovery using an intense source for flash exposures of 0.15 sec. Estimating from their curves a bright headlight glare of 3,500 fL would require about 0.14 min to recover to an adaptation level of 0.06 fL and 0.4 min to a level of 0.013 fL; for 500 fL exposure about 0.1 and 0.2 sec, respectively. Auto drivers are exposed to glare for longer times, so while the data are of interest they cannot be applied directly to night driving seeing.

According to Stevens and Stevens (73) brightness in Brills,  $\psi = k(L - L_0)^\beta$ , where  $L$  is the luminance and  $L_0$  the absolute threshold. The values  $k$ ,  $L_0$  and  $\beta$  change with the adaptation level;  $\beta$  being 0.33 for the dark adapted eye and 0.44 for the eye adapted to 1 L. The perceived brightness increases as a power function of the photometric brightness (luminance). There may thus be increased gain from better road lighting and illumination engineering should also consider brightness. Reaction times are longer for a light imaged on the retina at increasing distance from the fovea, or when the light is less intense and Rains' (61) data would be more useful if they were replotted in the form of a retinal map.

Boynton and Miller's (16) work on the effect of sudden changes in illumination on seeing are now available and should be useful in graduating changes in lighting, as at tunnels. Hazel (39) shows that tone and texture can be used to aid transitional lighting and states that one-tenth the lighting could then be used within the tunnel.

Kostka (50) favors using reflective materials to improve the seeing of signs at night and discusses the need for better signs. Experience with signal lights in aviation is discussed by Projector et al. (60) with respect to night road traffic. Lights are judged farther away at near distances and nearer than they actually are at distances greater than about 80 ft, in their experience.

Allen and Lyle (4, 5) describe their night vision test which also gives information on retinal luminance and for determining the light needed for seeing low contrast ob-

jects. Guth (38) is measuring size, contrast, time and luminance with a new apparatus to determine what can be seen, in another approach to the night driving seeing problems. Richards (65) showed interrelations between luminance, acuity, contrast and age and described improved equipment being used to measure seeing at night driving luminances.

Flom et al. (34) found that bars arranged to be adjacent to a Landolt C presented to one eye, impaired detection of the C presented to the other eye; presumably a supra-retinal effect. Such a loss from contour interaction could decrease the information obtainable from signs, maps and topography.

The California project program on dynamic visual acuity is outlined by Ball (9). Cutler and Ley (28) using an improved method, found an initial fall in kinetic visual acuity (even at very low speeds) to a level which remains fairly constant or improves to a critical rate of about  $60^\circ/\text{sec}$  when rapid deterioration of vision occurs. Below  $60^\circ/\text{sec}$  with monocular vision much variation was found between individuals. Binocular is markedly better than monocular dynamic visual acuity. Larbus (84) reports that for satisfactory perception the velocity of the moving object should not exceed 100 -  $150^\circ/\text{second}$ .

Eye movements used in examining a picture are examined by Webb et al. (77) and a similar technique should provide useful information about the task of seeing when driving at night.

Objects along the road stimulate a tendency to steer away from them. Michaels and Cozan (54) show that this depends on the ability of the eye to detect the rate of change of the visual angle subtended at the eye between the object and the road axis. A small object can generate a greater relative visual velocity than a larger one. An example cited is that a vehicle seen only by the reflection from an unlighted taillight is placed as outside the path of travel, but inside the path when it is seen fully lighted by a street light. These effects should be added to the mathematical analysis of driving by Rashevsky (62) and others.

The illuminated dashboard panel area may not be large enough to stimulate accommodation and avoid the empty field lack of stimulation (29). Three aged subjects did not accommodate. Younger subjects accommodated to a small degree (0.25 - 1.75D). The same amount of accommodation was found by Doesschate (29) at 1.2 and 500 lux (0.1 - 47 fc).

The Pulfrich effect resulting from less light reaching one eye than the other eye can lead to a miscalculation of relative distance and an accident. The dialation of one eye by an ophthalmologist resulted in the case reported by Gramberg-Danielsen (36). This points out also danger from unequally matched sunglasses or tinted contact lenses. Night vision sensitivity did not increase from its seasonal peak during the three months cruise of the Triton from the prolonged restriction from sunlight (Kinney, 49).

Weale (76) believes that senile reduction of accommodation is due to a progressive change in the balance of the elastic forces in the capsule and lens matrix, to a reduction of zonular tension due to the continuing growth of the lens and to a similar reduction in growth of the ciliary body.

Vibration from larger road vehicles, according to Hornick (42), of 1 to 7 cps does not decrease vision. Higher frequencies of 10 and 40-70 cps do decrease seeing. Lange and Coermann (51) report a decrement in seeing for 10 of 12 subjects at 5 cps, another at 7cps, and a constant decrement from vibrations over 12 cps. They give resonance frequencies for the human body. Rathbone (63) discusses sensitivity to vibration. Definite information on the effects of vibration on the seeing ability of the auto driver seem yet unavailable for either day or night time.

Able (1) calls attention to the small fields of view and lack of binocular vision often resulting from the corrective glass worn after a cataract operation and advises instead correction with a contact lens before driving is resumed. This applies also to pedestrians. Richards (67) warns against wearing tinted contact lenses at night when there is sufficient absorption to decrease seeing, which prohibits all but the palest tints. Fletcher and Nisted (81) also advise against wearing tinted contact lenses at night and state: "Spectacle correction may well be superior to contact lens correction at night," because edges or surface transitions tend to disturb vision when the pupil is large.



Allen (3) emphasizes that wearing sunglasses cannot be permitted at night, even in yellow tints. He also states: "No known sunglass can possibly improve the ratio of useful to glare light at night" and "... tinted windshields offer a real handicap at night with no visual benefit in daytime." D'Orsay's (30) letter to the editor agrees with Allen and notes another hazard from spectacles which continually slip down the wearer's nose. It would seem to the reviewer that driving glasses should have temples that fit properly around the ears. Safety glasses, possible increased minus for the near sighted and a spare pair of glasses are advised in a good editorial (7). Threshold measurements of intensity show higher thresholds for detection when wearing sunglasses both with and without glare than without sunglasses (86).

Color sensitivity for red-green mixtures were measured by Connors and Kinney (27) for various positions on the retina and the earlier conflict between information from changing size of stimulus and retinal location is resolved by the finding that the green sensitivity passes through a maximum and then decreases. MacAdam (53) concludes that psychometric scale values are nonlinearly related to chromatic differences, even when adjustments are made for the anisotropy of the chromaticity diagram.

Prolonged treatments of arthritis with chloroquine can result in changes of the cornea, in the color sense, and pigment degeneration in the retina of the eye (48, 68, 82). Amphetamine activates and barbiturates depress accommodation in moderate therapeutic doses and the latter changes distance heterophoria towards esophoria, near heterophoria toward exophoria, narrows the fusional range, and causes a recession of the near point according to Westheimer (78). George (37) found blurring of vision in a 53-year-old man within two days after taking chlorpropamide (Diabinese). Scott (69) states that retinal pigmentation can occur from thiridazine therapy beyond a safe dosage. General summaries of drug effects on vision have appeared (18, 41, 47, 74, 83). It is time for the medical profession to give consideration to the dangers from medication and possible excessive usage of tranquilizers and stimulants that may effect driving ability. A small decrease in seeing and the ability to respond can be a factor in the increased accidents at nighttime. Bohné (14) found that cigarette smoking slightly improved dark adaptation, caused questionable dilation of the retinal blood vessels and had no significant effect on visual fields. Fatigue problems in aviation (85) may also be of concern in auto driving.

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# Traffic Sign Requirements

## *I. Review of Factors Involved, Previous Studies and Needed Research*

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Published research reports for 10 years were systematically searched for studies of factors affecting highway sign effectiveness. Attention gaining characteristics proved to have been relatively little studied compared to legibility, but were indicated to be of equal importance.

Analysis of the driving task indicates the importance of multiple response tasks in measuring attention gaining characteristics. Further research on the latter is planned.

•MANY studies have been done on characteristics of street and highway signs to improve their effectiveness. Many of the results of these studies over the last 30 years have been put into practice by traffic engineers and sign designers to achieve a great improvement in traffic sign effectiveness. In some early studies both attention value and legibility factors were given some study. Since that time, however, the greatest amount of research has been on sign legibility and much less on attention value and what the message should be.

The present study, therefore, was undertaken to review previous research and to carry out further research with a special emphasis on attention factor problems.

This preliminary report analyzes the driving task in a simplified way using the "human engineering," "engineering psychology," or "man-machine-systems analysis" approach. It then summarizes briefly previous research reviewed. It also indicates briefly types of studies known to be under way. Finally, it suggests general areas which should be studied and those it is proposed to attack first as next steps in this study.

### MAN-MACHINE ANALYSIS OF THE DRIVING TASK

To analyze the variables and interrelationships playing a part in traffic sign effectiveness, it is first desirable to analyze briefly (in very much over-simplified form) the factors in the automobile driving task. Most people are so familiar with driving that it is assumed to be a simple human performance. On the contrary, when analyzed into the number of tasks which are carried on simultaneously and the functions which the human is performing, automobile driving proves to be a most complex human performance.

The driver's task was descriptively analyzed very briefly by Forbes (1) and in great detail by Miller (2). Both of these analyses as well as others which have been made showed the essential complexity of the automobile driving task.

However, a highly simplified man-machine-environment analysis of the block diagram type has become fashionable and has the great advantage of stimulating greater consideration of factors involved by diagrammatic visual presentation. Rather extreme simplification of most human performances is required to apply this approach. Figure 1 presents such an oversimplified schematic analysis.



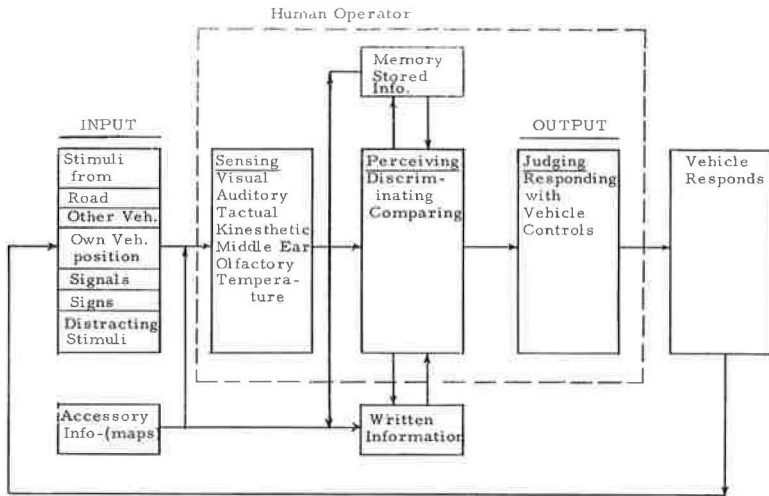


Figure 1. Man-machine-environment analysis.

A careful analysis of human operator performance in a man-machine-environment system shows that the operator represents several functions in the control loop (3). This type of analysis has been very helpful in analyzing man-machine problems in other areas and is equally applicable to automobile driving.

The driver can be viewed as a sensing, discriminating, evaluating, and responding series of units (Fig. 1). The resulting responses act through the controls of the vehicle, changing the vehicle's behavior which then feeds back and modifies the input to the sensing mechanism again. The input to the sensing mechanism includes the various road characteristics and stimuli from other vehicles on the road. It includes stimuli from his own vehicle, visual impressions for signs, signals and markings of all types. Finally it includes distracting stimuli from other objects and people who are not a part of his driving task, but which may attract his attention away from this task.

The sensing mechanism of the human involves visual, auditory, and other sensory types of stimulation.

The perceiving and discriminating function includes interpreting the various pattern of stimuli. It may involve comparing them with stored information from memory and possibly with accessory information from road maps and other previous instructions, visual or auditory.

As a result of the discriminating and comparing function, evaluations and judgments are made by the driver in determining his own responses with the controls of the automobile. These control responses affect the vehicle's behavior, and this in turn feeds back and affects the sensory input from his own vehicle's speed and position on the street or highway.

### Complexity of the Driving Response

Even this simplified analysis points out the basically complex nature of the task of the driver. Although the skilled driver carries on many of these tasks almost automatically, it can be shown that the number of sensing, discriminating and judging procedures continually carried on is large because of the number of different characteristics of the road, of the behavior of other vehicles, of the behavior of one's own vehicle, and of the various instructions from signs and signals and markings. In addition, distracting stimuli may range all the way from listening to a football or baseball game on the radio or noticing activities at the roadside picnic to trying to quell a minor riot in the backseat by two or three small members of the family.



## Multiple Task Required for Measuring Sign Effectiveness

It has been shown conclusively that increasing the number of stimuli and responses of any task increases its difficulty and the time required for an adequate perception, judgment and response (4). Therefore, although a driver may not always realize that his driving responses are affected by these multiple input stimuli, it is certain that they will be. For this reason, valid measurement of the effectiveness of street and highway signs requires a procedure which includes multiple input and output tasks of some sort. This is especially important for visibility and attention value studies, since they include much more than the simple question of whether the sign lettering can be read at given distances. Pure legibility measurements can be made without requiring multiple tasks. But the question of whether a given sign is actually read on the highway under the actual conditions of driving will depend on the effect of multiple inputs and outputs to the human responding mechanism.

A review of previous work by many investigators indicated that some of the previous studies have (and some have not) attempted to take account of the effect of the complexity of the driving task.

## PREVIOUS RESEARCH LEGIBILITY STUDIES

A brief summary of some 40 of the most pertinent out of 210 reports follows.<sup>1</sup>

### Measurement of Legibility

Among the earliest highway sign legibility studies, Forbes (5) distinguished between "pure legibility" and "glance legibility." The former was the distance at which highway signs could be read with the subject taking his own time and the latter was the distance for reading test signs under short glance conditions using a shutter to limit to approximately 1.0 second the time during which the sign was visible. To measure either type of legibility, control of previous knowledge and other psychological variables is vital. The observers must not know ahead of time what letter recommendations are going to be seen. A large number of observers representative of the driving public should be used, their visual acuity should be known, and a number of observations per person should be made. Many studies of sign legibility have been made, some with observers walking and recording signs read (6, 7) and some with either signs or observers moving and indicating signs read in other ways (8, 9, 15).

For wide design capital letters of the Series E or Series D type, legibility distances have been shown to be approximately  $Y = 50X$ , where Y is legibility distance in feet and X is letter height in inches. These values were such that 85 percent of the drivers would be included, (6, 7).

### Words Read at a Glance

One of these studies (5) showed that only three or four short, familiar words could be read at a single glance. Signs were exposed with a shutter arrangement for approximately 1 second. The findings were essentially confirmed for the rounded capital letter standard alphabet (10).

### Letter Size and Sign Location

At least two studies (11, 12) have calculated a basis for determining letter size and sign placement in relation to the point of required maneuver. Legibility distances, and a minimum time for maneuver and for rate of deceleration were used. Mitchell and Forbes used 1.0 second as minimum glance time for a 3 word sign and doubled it to allow for a second chance. Odescalchi et al. used a longer time as a result of Road Research Laboratory studies which measured time for a subject to find a destination name among 3, 6, or 9 destination names on the test signs. The subjects also were

<sup>1</sup>Total titles considered as possibly pertinent—397; total titles considered pertinent and checked—211; selected as most pertinent, read and abstracted—110.

required to give the proper direction after returning to a continuing alternate task (responding to a signal device inside the car).

Both United States (13) and British (14) standards recommend letter heights of 4 to 12 inches (height of wide capital letter or lower case letter "loop" height) for different road and speed conditions.

### Letter Width and Spacing

Many other studies of various factors affecting legibility have been reported. Reported as optimum are a height, stroke-width ratio from 4 to 1 through 6 to 1 (15, 16, 17). With wide design letters a spacing of one-half the average letter width (18), a spacing adjusted for area between letters (7), and even wider spacing (19) have been found desirable. With a higher letter brightness, a narrower stroke width increases legibility by reducing merging of strokes from retinal irradiation (20).

### Color and Contrast

Early studies (21) showed black on white and black on yellow to be of greatest contrast and legibility. More recently legibility has been shown to be as good or better under some conditions with white letters on a black background (22). Also, a careful study of sign brightness and legibility by Allen and Straub (23) indicated that the effect of illumination, letter design and contrast direction for best legibility is dependent on the brightness level of letters and background. For a given letter design, very high brightness may reduce legibility in a dark surround but may be required in illuminated surroundings (23). This confirms an observation in an earlier study (7).

### Summary

It is not within the scope of this paper to go further into legibility studies. However, it can be seen that considerable information on the various characteristics affecting highway sign legibility has been obtained by experimental research. Further systematic studies of such factors as brightness, stroke width, and spacing are desirable in order to measure more carefully their interaction. However, for practical purposes the legibility distances of the standard alphabet letters recommended by the National Joint Committee on Uniform Traffic Control Devices are well known.

## PREVIOUS RESEARCH--VISIBILITY AND ATTENTION FACTORS

Assuming that the lettering or the symbols on a sign have been designed to achieve a sufficiently long legibility distance for the conditions, there remains the important question whether the sign is actually "seen" by the driver. That is, does he actually respond to the visual stimulus represented by the sign. There are at least two questions involved here; that is, (a) visual detectability of the sign often spoken of as visibility and (b) attention gaining characteristics of the sign when it is well within visibility range.

### Visual Detectability Studies

One group of studies dealt with visibility through tinted windshields or glasses. These usually involved night conditions and visibility of low contrast objects on the highway. These studies therefore are not of direct applicability and interest in connection with sign visibility.

Another research series studied threshold visibility. These measured the various brightness, contrast, illumination, atmospheric absorption, stimulus size and shape and other characteristics affecting the longest distance and the smallest target which can be visually detected. Among these Middleton (24) summarized much of the earlier work and Blackwell (25) reported one of the more recent studies. Other studies compared fluorescent and nonfluorescent painted targets for visibility at maximum visual range and reported some advantage for certain fluorescent colors (26, 27).

These studies are of most importance for visual search from aircraft and similar

problems. They are probably less applicable to the problem of what causes traffic signs to be seen or not seen when well within visual range. Some of the same factors may be of importance but probably not others.

The studies in the preceding paragraph were most concerned with day legibility. Stalder and Lauer (28) measured visibility at night from reflectorizing low-contrast objects. They showed that a few larger areas were better than many small reflectorized spots for this purpose.

### Need for Attention Gaining Characteristics

Attention gaining characteristics are of importance when signs must be seen in competition with other signs or background objects. This is usually a situation where signs are well within the visibility distance threshold and, therefore, can be seen and read without any question of limitations from legibility or threshold of visibility. Forbes (5) reported a study in which drivers followed a test course on the highway and reported all signs as they saw them. From this, two classifications of factors were defined: (a) those contributing to "target value," which applies to physical characteristics such as brightness and color contrast or sign, which make one sign stand out relative to other signs and the background; and (b) "priority value" was defined as those factors of driving habits or reading habits, etc. which lead to one sign being seen earlier than others. As examples, target value would result from large size and high contrast of a sign with background and with other signs, whereas priority value would occur from such habits as reading from left to right and, therefore, would result in the greater likelihood of top, left hand name of a destination sign being seen first.

The need for such characteristics for sign effectiveness was shown in this study by certain yellow warning signs, such as a crossroad symbol sign, which were reported only one-half as far away, approximately, as they could be seen and read if the observer were intentionally looking for them (observed under daylight conditions against a straw-colored terrain).

Roper (29), in a study of seeing at night, reported unexpected objects to be seen only about 50 percent as far as the same objects under the same conditions when the driver was actively looking for them. Thus when multiple tasks are involved, as in ordinary driving, both objects and signs can be expected to be seen at less than their legibility or visibility threshold distance. Under these circumstances factors increasing the relative attention value of signs are of great importance.

### Studies Involving Physical Attention Gaining Characteristics

Relatively few studies of attention gaining characteristics of signs have been carried out in the highway field. Elliott (30) traced the history of pictorial symbols for use on traffic signs and pointed out their advantage, especially where multiple languages are involved. A study of highway signs in Virginia by Decker (31) included both signs (green on white and white on blue) and striping (red on white, yellow on black, and black on white) of different widths for obstacle marking. Both day and night observations were made with observers in a vehicle moving toward the test targets. Average legibility distances were given for the signs and preference ratings for the striping.

The 6-in. diagonal striping was preferred to the 5-in. and 3-in. stripes, although there were some reversals in the results. This was true for both day and night observations. The white letters on blue background were reported to give somewhat longer legibility distances at night compared to the green letters on white background. There was little difference during the day. Some interaction between color and illumination was indicated for the three levels of illumination used (high-beam, low-beam and daylight). Since the targets were always presented in pairs on opposite sides of the road, there may also have been an attention gaining factor included in the legibility measurements.

Odescalchi (32) made experimental determinations of conspicuity of signs in rural surroundings. Observations were made against a background of trees, hedges, and fields. Observers viewed colors representative of the British standard and the U.S. Interstate standard colors in open and shaded locations. Observers looked down the

road and not directly at the panels. Ratings of adequacy were made of different sized panels, as judged by observers. Results indicated yellow, white, and red to be more effective than the darker colors. This is an interesting approach. The results may have been conditioned by the background used and by observer opinions but such work should be carried farther.

Shoaf (33) reported a policy for advertising signs near freeways in San Francisco to limit the distraction effect of such signs on highway signs as a matter of safety. Expert opinion was consulted on factors affecting distraction and retention. Limits were set on brightness, units of change, rate of change, continuous motion, and flashing lights. The limits were related to distance of the distracting sign from the freeway in San Francisco.

Powers (41) found an advantage from a prewarning route turn marker in urban traffic. In addition to the position factor, the prewarning sign design appeared to give better target value.

In the field of advertising research, it is well-known that relative size and intensity, brightness and color contrast, motion or brightness change, are physical factors especially effective in attracting visual attention. Brightness contrast, change and motion are especially effective when a sign is seen in peripheral vision (34).

Practical application of such principles has been the use of oversize stop signs in many places in the United States. To our knowledge, however, effectiveness of these factors has not been systematically studied in relation to attention factors as such.

#### Advantage of Familiar Legend and Symbols

Also from earlier work in advertising psychology, it is well-known that familiar symbols, colors, and legends have an advantage. The advantage is increased when public education is used to associate them with special meanings. Certain of these meanings are more easily attached to certain symbols because of their use in other parts of our culture. A study of U. S. and European sign shapes and symbols (14) showed certain symbols to be more effective in Great Britain. Another study of European road sign and U. S. road sign symbols (35) showed more of the U. S. symbols to be effective in the United States, bearing out this principle.

A study of lane control symbols (36) showed a red X to be more naturally associated by the uninstructed observer in the U. S. with the meaning "do not use this lane" than were several other symbols. This probably reflects the use of crossing-out of a page and other such use of an X indicating "do not use." This symbol has proved useful in actual practice. The same principle may be of importance in signing.

Birren (37) used four reflectorized signs with 8-in. letters. On the basis of "the average of several observers" he found black-on-white and white-on-green "best" during daylight and black on yellow and white on red best at night. These were apparently based on legibility distances but no data on reliability were given. He noted the value of color for visibility and for "impulsive attraction" and "psychological interest" and recommended white on green in spite of longer legibility distances of black on white. The 0.4- to 0.6-sec difference in legibility distance at 50 mph he thought less important than the interest and attention value of the colored sign background.

Hulbert and Burg (38) showed the value of dividing a sign by "underlining" to group the material relating to a given destination. Such organization of the legend reduced errors in relating arrows to destinations.

#### Summary

The reports in this area are all too few and mostly unsystematic in their approach. They do indicate, however, the importance of attention gaining factors since signs may not be seen anywhere near the threshold legibility distance of the sign. This means they may not be seen at threshold visibility distance either. There is also great importance to attention gaining characteristics where signs must be seen in competition with other objects such as advertising signs or similar features of the environment.



## VISUAL ACUITY FACTORS

Both static and "dynamic" visual acuity may be of importance.

### Ordinary Visual Acuity

Visual acuity as ordinarily measured is known, of course, to affect the distance at which signs may be read. Most of the legibility studies mentioned have taken this into account by measuring the acuity of the subjects and providing for 85 or 90 percent of the drivers. This is usually a visual acuity of 20/40 or 20/50.

### Dynamic Visual Acuity

More recently much interest in "dynamic visual acuity" or acuity measured with a moving target has been aroused in connection with highway and automobile driving problems. Odescalchi, et al. (12) quote Westheimer as giving 30 deg per sec as the target speed at which acuity begins to be seriously affected. Hulbert (39) indicated that the critical speed is probably over 60 deg per sec. Therefore, this factor should not be serious in the case of highway signs unless the lettering is very small so that the sign must be seen at high speed from close by at a large angle from the centerline of the highway (much more than the recommended 10 deg). With the lettering sizes presently recommended, this should not be a problem of any appreciable extent.

### Central vs Peripheral Vision

It is well-known that color sensitivity and greatest acuity occur in vision using the central part of the retina and that within 4 or 5 deg each side of the center vision becomes considerably less acute. Also well-known is the greater sensitivity of peripheral vision to brightness, brightness changes and stimulus motion (40).

## NEEDED RESEARCH ON TRAFFIC SIGN REQUIREMENTS

From the foregoing review of previous research reports it appears that the greatest need for further research is on the subject of attention gaining factors. The present recommendations of letter size and color combinations provide a legibility distance which should be adequate when these recommendations are properly calculated for the design speed and other characteristics of the driver and highway (11, 12).

Previous studies in the field of advertising psychology suggest various combinations of factors which would be expected to affect relative attention gaining characteristics of signs in competition with other objects, signs, or characteristics of the environment. Although several studies have pioneered on measurements of certain attention characteristics, there is a need for further systematic studies of the interrelated effects of the considerable number of variables previously mentioned.

In conducting such systematic studies of attention factors it is important to take into account the effect of other driving tasks and the need for the driver to alternate his attention. Therefore a multiple response task for observers is of basic importance.

Conferences and correspondence have indicated certain studies under way in some aspects of highway sign requirements. Two of these studies involve the relative night effectiveness of destination signs and stop signs with different degrees of brightness. Two other studies involve the experimental investigation of time sharing between driving signs and of the driver's visual search at intersections. Destination sign effectiveness using a driving simulator is being studied in at least one other. Still another project involves the various effectiveness of certain physical characteristics of available sign materials and characteristics. And finally, one study is investigating the effect of colored signs and lining on motorist use of freeway ramps.

## TENTATIVE PLANS FOR THIS PROJECT

In this research, systematic experimental work on various combinations of the relative attention gaining factors is planned in the laboratory with later full-scale field



checks. The studies will avoid duplicating those known to be under way. Various types of visual presentation from movies to slides and actual light source projections may be used. Measurements will be made of effects on a multiple task for observers to simulate the interacting effects of seeing of signs and of the driving task. A pilot project is estimated to require some six months and additional projects at least one additional year before results may be available.

Finally, certain of the laboratory results will be spot checked with experimental observations in the field, using vehicles and full-scale installations.

#### ACKNOWLEDGMENT

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# The Effect of Glare in Simulated Night Driving

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Two experiments were carried out in the laboratory in which illumination and glare conditions in night driving were simulated. Steering accuracy was measured as the dependent variable. The interactions between roadway illumination, glare illumination, glare duration and glare frequency were investigated.

It was found that there were no differences in performance between the glare illumination levels used in these studies, and that the duration and frequency variables (which reflect traffic speed and density) required further clarification. Road illumination was clearly important as well as the overall effect of glare in tracking performance. The presence of high order interaction effects showed that the investigation of the glare phenomenon was complex.

It was suggested that the glare hazard and the problems of night visibility could be alleviated by increased reflectance of road surfaces and objects in the road. With respect to the glare source it was felt that the power of current headlamp units should not be decreased since this would lead to undesirable loss in road illumination. Headlamp units would require further redesign to reduce glare.

•A NUMBER of approaches are used in the study of highway accidents, none of which is entirely satisfactory. Laboratory investigations are frequently too specific in nature and lack the power of generalization, because accidents are caused by multiple factors. Thus, although vision is unquestionably important to vehicle operation few useful correlations have been obtained between vision and accidents. The survey approach, while yielding data of considerable interest pertaining to the cause of accidents, lacks the convenience and precision of controlled research and since it must obtain data after the accident has occurred, it must deal with inferences which would be difficult to validate.

Simulation mediates between the strictly laboratory study and the survey approach and has some of the advantages of both methods. Compared to laboratory studies of very specific aspects of behavior, simulation can measure relatively more complex responses as found in the actual driving task, thereby insuring more valid transfer of results. Its advantage over the survey method is that it allows accurate measurements to be taken of various facets of behavior with control over environmental and other factors for systematic investigations.

The extent to which a simulated task and environment should approach the real situation can only be decided when the scope of the behavior to be studied is known, but it is the basic psychological variables that have to be carefully considered in the design of all simulators for effective use. High physical fidelity of simulation may add little to the value of the device (4). Inasmuch as the major problem in the design of a general purpose driving simulator lies in the construction of the visual display, it should be apparent that a night driving simulator could be a relatively simple device. This is

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because the visual display in night highway driving is relatively bare, and at mesopic luminance levels resolution is comparatively poor. The wealth of detail present in daytime driving is not visible at night and the task becomes, basically, one of tracking the road and maintaining vigilance for obstacles upon it, including the maneuvers of other traffic. The principal limitations to night driving visibility would appear to be the luminance of the road and objects in the road and the effects of glare from the headlamps of approaching vehicles.

The studies reported seek to investigate the interaction of the latter variables using a simple simulation device.

### METHOD

Two experiments were carried out in a sequential order and they are described in detail by Mortimer (3). However, since the major findings of these studies were essentially similar, the present paper will report the details of only one of them.

#### Apparatus

The apparatus consisted of a tracking device in which a simulated gray roadway (reflecting 27%), 3 in. wide, was attached to a continuous, black, neoprene conveyor belt (reflectance 9%), 42 in. wide and 46 ft long, mounted on a series of rollers driven by an electric motor (Fig. 1). The roadway described a complex sine wave course. By means of a steering wheel which acted as a velocity control the student subjects



Figure 1. The roadway conveyor with the cursor above the simulated road; driver's cab is partly visible on the left, a glare light is on the glare conveyor.



controlled a 3-in. wide cursor which was free to move laterally across the conveyor in response to the steering input. The subject's task was to maintain the cursor above the moving gray roadway, tracking errors being electronically scored in terms of the time and distance that this alignment was not kept within some tolerance limit.

On the subject's left was another conveyor system which carried four lights that moved toward and past the subject, and simulated the headlamps of oncoming vehicles. Shadowless roadway illumination was provided by a source mounted on the roof of the driver's cab. The apparatus and the room in which it was housed was painted a flat black to minimize reflected light. The experimenter's booth was in the same room but partitioned off from the other apparatus. All experimental events during a trial were automatically programmed.

### Independent Variables

The values of roadway illumination and glare illumination to be used in the experiments were obtained by taking readings at night using an actual vehicle and observing the road illumination at various distances from it produced by the headlamps, and by observing the glare illumination at the eye position from oncoming vehicles. All readings were made using a Weston light meter. The measures that were obtained corroborated those reported in the literature (1, 7). The variables of interest and the value of the levels of each were as follows:

- |                             |  |
|-----------------------------|--|
| 1. Roadway illumination (I) | $I_1 = 0.10 \text{ ft-c}$<br>$I_2 = 0.60 \text{ ft-c}$               |
| 2. Glare illumination (G)   | $G_1 = 0.30 \text{ ft-c (mean)}$<br>$G_2 = 0.90 \text{ ft-c (mean)}$ |
| 3. Glare duration (D)       | $D_1 = 7.3 \text{ sec}$<br>$D_2 = 14.6 \text{ sec}$                  |
| 4. Glare frequency (F)      | $F_1 = 1/\text{min}$<br>$F_2 = 2/\text{min}$<br>$F_3 = 4/\text{min}$ |

### Subjects

Fourteen male college students were paid for serving as subjects. None wore corrective lenses and all had better than 20/20 vision.

### Experimental Design

A complete factorial design was used. A subject received all combinations of the levels of the four factors ( $2 \times 2 \times 2 \times 3 = 24$ ) and two additional treatments, in which glare was not present, for a total 26 treatments. Each treatment was received once and the order of presentation was randomly determined. There were two replications (R) of the experiment with 7 subjects in each replication. In the second replication speed was 11 percent greater than in the first.

### Procedure

Each subject served for 7 consecutive days for one hour each day. The subject was seated in the driver's chair and its height adjusted until a specified area of the cursor and display were visible—the same for all subjects. Subjects were read the instructions. The room lights were turned off and the conveyor systems set in motion. A driving condition was then presented, as required by the experimental plan. When the roadway was illuminated, it was the subject's signal that the trial had begun and he would commence tracking by maintaining the cursor over the roadway with appropriate movement of the steering wheel.

A trial lasted  $12\frac{1}{4}$  min with the last 12 min only being scored. There was an inter-trial interval of 2 minutes. The first two trials were used to allow the subject to become familiar with the apparatus and procedure.

RESULTS

The data were analyzed by obtaining mean tracking error scores for the first and last six minutes of scored steering performance in each trial. Figures 2, 3, 4 and 5 show the interaction of driving time with the other variables. Low road illumination, long glare duration and high glare frequency led to performance decrements. Differences between glare intensity levels were slight. Figure 2 also shows that large improvements in tracking were found in the no-glare treatment ( $I_1$  no-glare) and when illumination was raised ( $I_5$  no-glare) to 12.5 ft-c to simulate a low daytime level.

The analysis of variance of these data is shown in (Table 1) in abbreviated form by presenting only the significant effects and their error terms. The main effects for

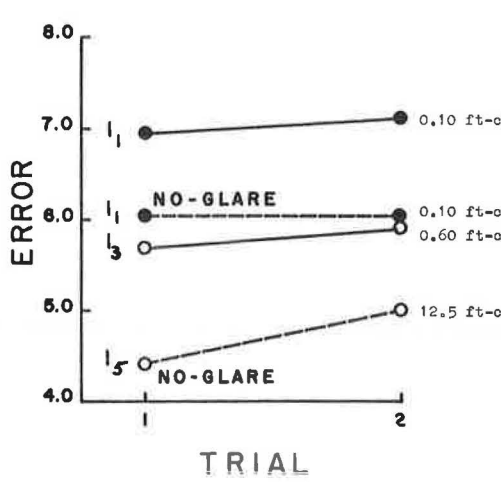


Figure 2. Mean tracking error as a function of roadway illumination and trial periods.

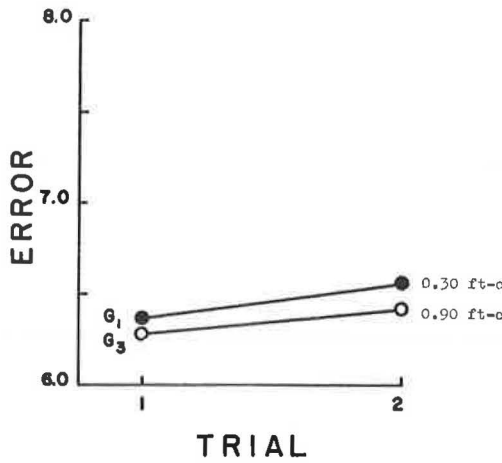


Figure 3. Mean tracking error as a function of glare illumination and trial periods.

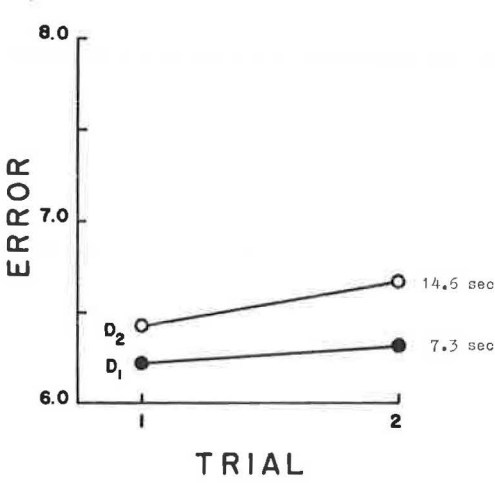


Figure 4. Mean tracking error as a function of glare duration and trial periods.

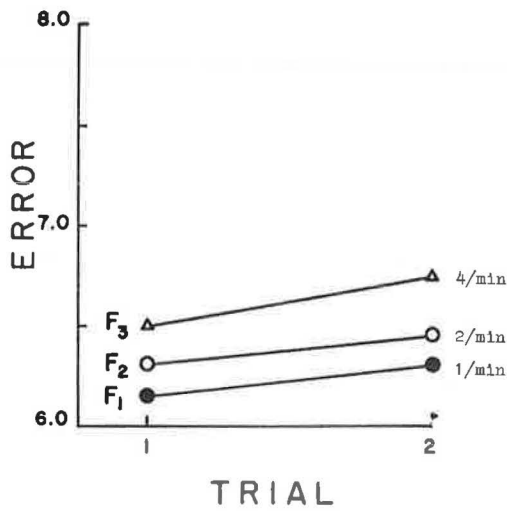


Figure 5. Mean tracking error as a function of glare frequency and trial periods.

TABLE 1  
ABBREVIATED SUMMARY OF THE  
ANALYSIS OF VARIANCE

Source	df	MS	F
Road illumination (I)	1	257.102	90.656 <sup>a</sup>
Glare duration (D)	1	13.070	4.830 <sup>b</sup>
I × R	1	22.947	8.091 <sup>a</sup>
I × D × R	1	27.905	9.839 <sup>a</sup>
Error	372	2.836	-
D × G × F × R	2	26.774	6.336 <sup>a</sup>
D × G × F × Ss in Reps	24	4.225	-
I × G × F × R	2	29.845	5.275 <sup>b</sup>
I × G × F × Ss in Reps	24	5.657	-

<sup>a</sup>Denotes significant at less than 0.01 level.

<sup>b</sup>Denotes significant at less than 0.05 level.

road illumination and glare duration were significant. The I × R (road speed) and D × G two factor interactions, I × D × R three factor interaction, and the I × G × F × R and D × G × F × R four factor interactions were significant.

## CONCLUSIONS

On the basis of this experiment it is noted that the effects of glare are complex as shown by the presence of high order interactions. This makes it difficult to provide clear-cut interpretations of results. However, it was seen that a large decrement in tracking accuracy occurred due to the overall effects of glare from the lights of simulated approaching vehicles. Glare

can then be considered to be a potential hazard in the night driving situation. When glare was not present in the simulated night driving task, the reduced illumination available from vehicle headlights, as compared to low daylight levels, caused a marked decrease in tracking accuracy. The effect of roadway illumination in the presence of glare was also seen to be quite large. When illumination was reduced to 0.10 ft-c the decrement in performance was highly significant compared to the 0.60 ft-c level. Thus, roadway illumination between levels of 0.10, 0.60, and 12.5 ft-c as used in this study had a decided effect on tracking efficiency under both glare and no-glare conditions. As illumination was raised, performance improved.

The main effect of glare duration was significant with 14.6 sec of glare causing greater decrement in performance than 7.3 sec. But, the significant high order interactions in both studies showed that the difference was specific to relatively few treatments so that there was no practical effect of glare duration for the levels used.

The glare frequency of 4 per minute resulted in poorest performance compared to lower frequencies. However, few significant differences were found in the analysis of simple effects of the complex interactions so that the effect of the frequency variable was probably not marked.

Both the glare duration and frequency variable would require further systematic investigation.

There was practically no differential effect attributable to the levels of glare illumination employed. This finding suggested that increasing levels of glare intensity have little effect beyond some minimal level and up to some maximum that was not attained in this study. In the field studies (5), it was found that the glare from the first few hundred candlepower of approaching headlights reduced visibility distance sharply, with a relatively decreased effect as beam candlepower was increased. These two sets of data pose an immediate problem in the alleviation of the glare phenomenon in night driving. It would appear that glare levels will have to be drastically reduced below some minimal intensity in order to be effective. Since it would be undesirable to reduce headlamp intensity due to the concomitant loss in road illumination, it would be necessary either to increase road illumination by some means without increasing glare, or to reduce glare without reducing road illumination. This has, of course, been the aim of headlamp lighting engineers who have attempted to reach a compromise between glare and road illumination by the design of optimal beam patterns. Our results have shown that reduction in headlamp intensity should be avoided since the road illumination variable was at least as potent as the glare factor and is operative under conditions of glare and when no glare is present.

One relatively simple means by which visibility of the roadway can be increased is to increase the reflectance of the surface. Concrete roads range from 25 to 50 percent in reflectance whereas black top has a reflectance of about 10 percent (2). Roper (6) has shown that an increase in reflectance of 3 to 14 percent of a dummy placed at the

side of the road, for a driver not expecting the obstacle and at a car speed of 50 mph, doubled the distance at which it became visible. The recommendation from such data and from this study is to increase the reflectance of vehicles, pedestrian clothing and the roadway itself.

Finally, it may be suggested that since some correspondence between the results of this simulation approach and those from studies using actual vehicles has been found the simulation method may be useful in further studies to evaluate engineering, environmental and driver variables in night driving. This is not to say that proper validation of simulation methods is not important. On the contrary, it is a prime requirement to determine the transfer characteristics of laboratory driving simulators. With proper design, reasonable transfer should be attainable and establish the simulator as a valid and useful research tool.

#### ACKNOWLEDGMENT

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# A Study of Dew and Frost Formation On Retro-Reflectors

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•THE formation of dew and, at subfreezing temperatures, frost, may occur on a solid body if proper atmospheric conditions prevail. The condensation of atmospheric moisture occurs when the temperature of the solid body is lowered by radiation of heat below the dew point of the surrounding air. Because of the high surface tension of water, its condensation occurs as minute spherical droplets having distinct optical properties. Their formation on retro-reflective materials, which depend on collimated incident light for efficient reflection, refracts and scatters the light beam, rendering them less bright. Certain environmental conditions must be met for dew formation:

1. Relatively clear sky. The solid body must lose sufficient heat by radiation to fall below the dew point of the surrounding air. A relatively clear path to open sky must be available because trees, buildings and cloud cover will effectively reflect radiation back to earth, inhibiting heat loss by radiation. Open sky acts as a radiant source at absolute zero temperature, therefore no radiation is received from the sky. Under this condition, heat loss occurs at all surfaces of the object (both front and rear) with access to open sky. Portions of the supporting sign structure may shadow radiation or provide sufficient heat mass to inhibit it otherwise. Thus on rare occasions, the image of structural members has been observed from the face, caused wholly by a differential in radiation rate.

2. Still air. Unless fog is present, the air temperature is above the dew point and heat loss by radiation must proceed at a greater rate than heat input to the object by convection currents. Thus, if air currents are present the object is maintained at air temperature and no dew can form.

3. Moisture. Adequate moisture must be available in the air. When high humidity is present less heat loss is required for dew formation.

## SCOPE OF STUDY

The purpose of this study was to find means of relief; the study was not for the purpose of correlation with weather observations or for the exploration of the precise heat loss and temperature relationships. Prior tests revealed practical difficulties in the laboratory testing of this natural phenomenon and indicated that conventional reflex-reflectors of all types, mounted on conventional and experimental backings, would require testing out-of-doors at night. Yearly incidence of dew and frost was desired together with hourly progress, under circumstances that would permit simultaneous direct comparison of all materials whenever dew occurred.

## DATA COLLECTION SITE

The test site is located in the southwest corner of Washington County, Minn., approximately 2,000 ft from the Mississippi River. It is 119 ft above river level; the site elevation is 806 ft. Dew formation has been observed to be extremely random within a given locality and the site was selected for its relatively low elevation, proximity to the river and unobstructed sky view. It was felt that these circumstances would provide a relatively humid environment with maximum radiation opportunity. The

findings at this site can likely be compared only to localities having similar average climatological data, relative elevation and exposure.

### EQUIPMENT

The experimental sign structures (Figs. 1 and 2) are arranged on a scaffold 80 ft in front of a small building housing photographic monitoring equipment. Signs face northwest. Flood lamps adjacent to the camera permit signs to be observed by reflex-reflection. A 16-mm movie camera within the building is operated automatically a single frame at a time throughout the night (Fig. 3). A panel showing the date and a clock are within camera view to provide the time sequence. A simple wind indicator consisting of a suspended, lightweight plastic sphere establishes the presence of air currents. If the sphere is observed to move, little or no dew occurs.

### RESULTS

The data reported were obtained over a 16-month period (through November 1963) during which 234 nights were recorded. Recording was on a regular weekly basis with occasional omissions due to minor difficulty with the recording apparatus. For the period spanned, this represents an extensive 50 percent sample under all prevailing weather conditions. Dew or frost was observed on a minimum of one test panel on 86 of the nights for an occurrence of 37 percent. The total hours for which dew was observed was 413.

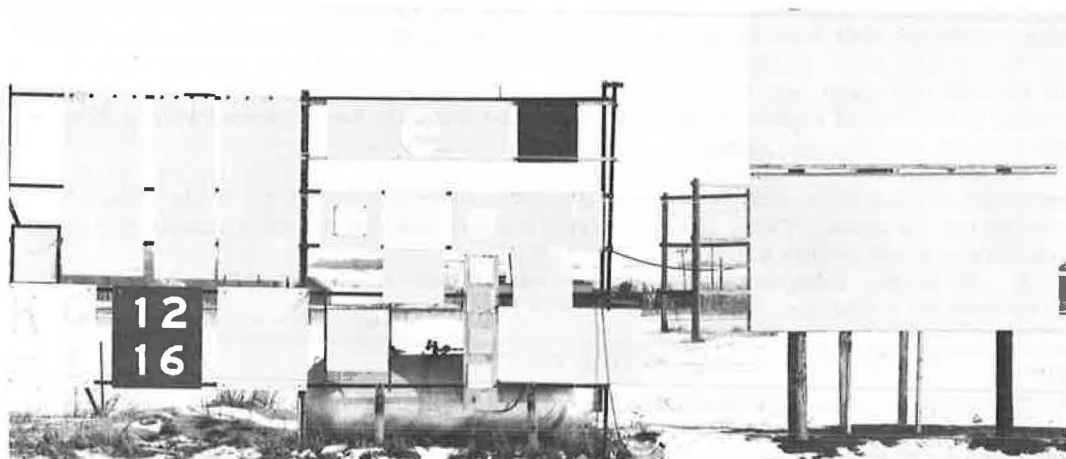


Figure 1. Experimental sign structures, day view.

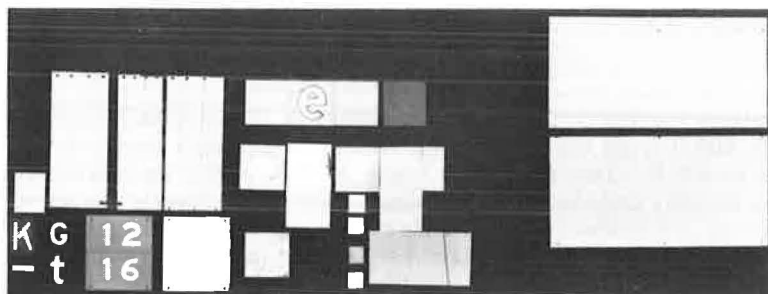


Figure 2. Experimental sign structures, night view.

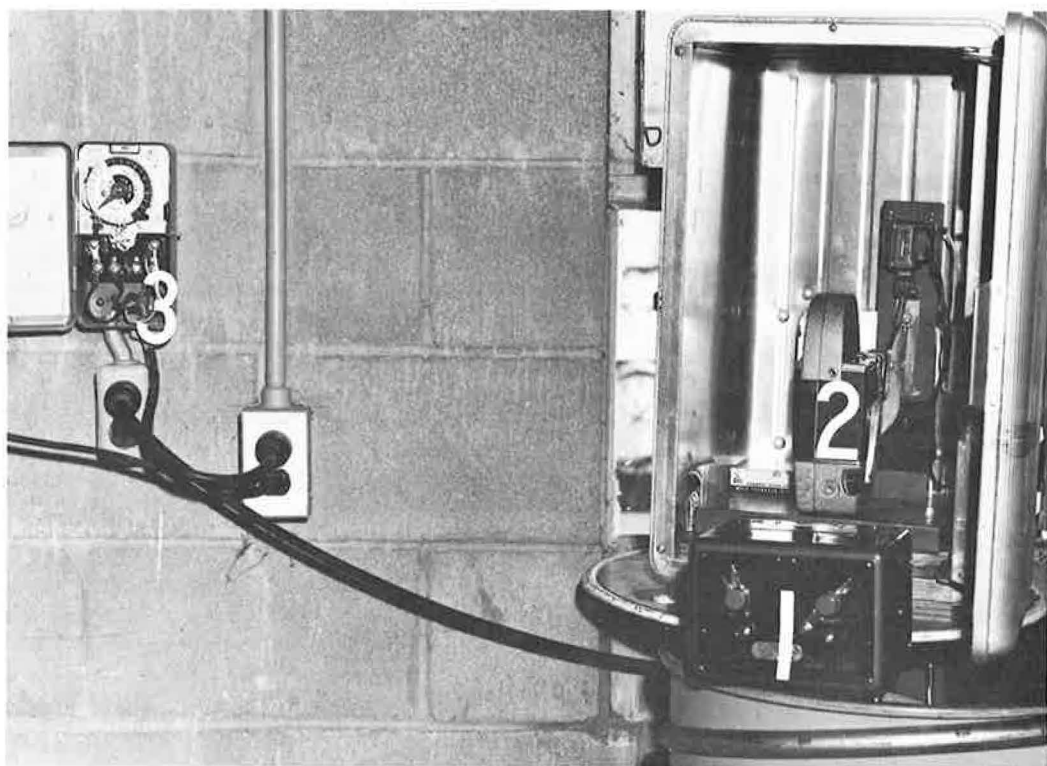


Figure 3. Photographic monitoring equipment: Intervalometer (1) actuates camera's (2) single frame shutter; sequence is started at dusk by astronomical timer (3).

The results are shown for average time after sunset to the formation of dew, average duration of dew, and percent of total dew time. Total dew time was recorded whenever dew appeared on any test panel.

The test materials for which results are shown are type of backing (Table 1) and type of background reflector and reflectorized demountable letter (Table 2).

The data illustrate the value of a heat-conductive backing material. Daytime heat storage is provided to some degree by any backing material. Superficial heat losses are, however, not readily replaceable if insulated from the heat mass of the backing. Therefore, thermally insulated surfaces are observed to have a somewhat earlier dew period and greater duration. Comparison of conductive backings (aluminum) may be made with an insulated backing (plywood) in Table 1. Although the differences appear to be slight, they have been consistent throughout the observation period.

The more massive of the heat conductive backings provides the utility of greater daytime heat storage. In this respect, comparison may be made of aluminum sheet 0.081 in. thick, aluminum extrusion 0.125 in. thick and the 1 $\frac{1}{4}$  in. thick water or paraffin filled tanks. The percent of dew time, an important indicator, is 64 percent, 56 percent and 23 percent, respectively.

By comparing actual hours of darkness observed, 2,574 (234 nights at 11 hours per night) against the average dew time for the typical backing material of 256 hours (62 percent of the 413 hours observed for dew), it is apparent that the average backing was free of dew formation 90.4 percent of the time.

#### SUMMARY

Tests in the natural environment indicate that the typical sign backing was free of

TABLE 1  
SIGN BACKING MATERIAL

Sign Backing Material	Avg. Time <sup>a</sup>	Avg. Duration	Total Dew Time (%)
	Hr:Min	Hr:Min	
Aluminum extrusions	6:18	2:28	56
Aluminum sheet	6:16	2:39	64
Plywood (7/8-in. high density)	5:27	2:57	67
Average	6 hr	2½ hr	62
Experimental <sup>b</sup> :			
Tank (1¼-in. thick, water or paraffin filled)			
Honeycomb (aluminum faces bonded to fiber core, 1¼-in. thickness)			23 62

<sup>a</sup>From sunset to dew formation.  
<sup>b</sup>Reflectorized with enclosed lens sheeting.

TABLE 2  
REFLECTOR TYPE

Reflector Type	Total Dew Time (%) <sup>a</sup>
Background reflector (on 0.081-in. aluminum panel):	
Enclosed lens	64
Exposed lens	71
Demountable letter type:	
Enclosed lens (on 0.040-in. aluminum)	43
Plastic reflector button	68
Film overlaid reflective sheeting (on 0.040-in. aluminum)	23

<sup>a</sup>Percent of total dew time is the total time dew appeared on any test panel compared to samples shown.

dew formation on the average of 90.4 per cent of the nighttime hours. When dew was recorded it occurred on the average 6 hr after sunset and was of 2½-hr duration. Results would be expected to differ under other climatic conditions.

There are two general approaches of inhibiting dew formation. The first is to change the dew particle from a spherical droplet to a film. A relatively smooth film of water will not materially alter the light path of reflectors made with a smooth, flat outer surface. Alteration of the droplet by a chemical surfactant has been accomplished experimentally. Much more work will be necessary before a weatherable surfactant is possible. The second suggests the replacement of heat lost by radiation. The massive heat conductive backings illustrate (Table 2) that internal heat storage is quite possible. External heating by simple fan to transfer the heat energy of the air to the sign has not provided completely adequate results. However, external heating by portable radiant heaters had been tested and has proved to be effective. If factors of maintenance and vandalism are not excessive, this may be a practical consideration.

Extensive testing of dew formation on typical reflector media and sign backings has yielded useful performance relation-

ships and contributed basic understanding. Its incidence does not appear to be severe on the basis of yearly average for the natural climatic conditions tested. Means sought to inhibit dew formation offer promise for its reduction or ultimate elimination.



# Vision at Levels of Night Road Illumination

## X. Literature 1964

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•SOME contributions to the literature on vision applicable to night driving (76) include reviews by Duntly (36), Onley (71) and the Swedish symposium (49). Mrs. Wiener (97) gives a bibliography of the past decade, and form discrimination was examined at the Brown University symposium (7). Boynton (21) discusses receptor excitation and Bryngahl (22-23) uses sine wave stimulation and transfer functions for the analysis of mesopic vision. *Tabulae Biologica* adds another section on the eye (38).

Rules for night driving by a French physician resemble those in use elsewhere (95). The German symposium (42) and Sartori (82) consider the medical problems of evaluating adequate vision for driving and the first year of compulsory vision examination of drivers in Bavaria. The guidebook (5) of the American Medical Association gives visual and other criteria for driver evaluation. These problems become more important with periodic retesting of drivers and the need to decide whether the person almost passing the screening test can compensate for the vision deficiency, or should lose his license to drive.

The opposite problem of how to select the superior driver has led Uhlaner and Drucker (91) to conclude that psychophysical measures (such as vision tests) provide only minor help and that other attributes are of greater importance to safe driving. In England, Roslyn (81) proposed that the vehicle as well as the driver should have a certificate of fitness, but the Authority replied that such would only tell the condition at the time of examination, not at a later time, and also that standards would be needed. Connolly (26) reviews the nature of seeing from autos and comments on other vision problems (28). Kent's review (59) of the visual ability required for job performance on a submarine suggests a comparable study of automobile driving would be useful.

Accidents (101), driver error measurements (73), simulation methods (75), and following behavior (90) are reported, and the use of eye-movement cameras is again suggested for the analysis of driving seeing problems (64). Davey (32, 33) comments on the British Auto Show, mainly about night lighting and poor placing of headlights. American car lights are criticized as not being visible from the sides. Connolly reviews the problems of seeing rearward and the evolution of rear-view mirrors, and Davey (34) reports the conference on rear-view seeing at the Northampton College of Advanced Technology.

A standard daylight that avoids the variation in the ratio of sun and skylight, in sun angle (25), and atmospheric attenuation would be useful reference, and Judd (55) summarizes numerical data and reports progress towards such a standard. Moonlight luminances for elevation and phase of the moon are recorded by Nichols and Powers (69), also some night vision research with moonlight.

The American Standard Practice for Roadway Lighting is revised (8). An interesting summary of British research on road lighting (35) shows a 30 percent accident rate reduction at 64 sites lighted to group A (enough light that auto headlights need not be used). Amber direction beams of 100-500 cd are recommended. The American report (13) also proposes yellow signals.

Polarized light and its possible introduction was considered at the Swedish symposium on road lighting (49). The chapters by Schober and Wright give useful informa-

tion on night driving seeing and should be ready by workers in this field. The vertical distribution of light was considered to be of more importance than mere horizontal footcandle distributions. Wright emphasized the importance of gradient junctures in contrast which reveal or conceal an object, and that brightness (both footlamberts and the psychological perception) is more important for planning road illumination to give good seeing than are horizontal footcandles. Birkhoff (18) is investigating similar problems. Blackwell (19, 20) discusses lighting geometry and compares fluorescent, mercury and tungsten lighting for roadways.

Automobiles, Allen and Clark (4) believe, should have running lights of at least 4-in. diameter and  $1-3 \times 10^4$  fL to help compensate for the variation in visibility of the autos against various surrounds and the difficulties of seeing at twilight (3). Rooney (79) states that plastic reflective markers are useful in bad weather because they do not disappear when wet. Button and large area reflectorized stop signs compared by Hulbert (48) show little difference in effectiveness.

The autokinetic movement of an intermittent illuminant usually increases with less illumination, but the relation is curved upward for the 5 to 15 cps range despite the expected brightness enhancement (85). The discrepancy is attributed to redundancy in the visual field.

Grant (43) discusses definitions of glare largely in terms of the 1920-30's. Fatigue increases with continued exposure to glare in Hartmann's (45) simulation study. Glare recovery time averages from 2.9 sec at 0.2 fc for 1.5-sec exposure to 8.8 sec at 0.74 fc for 30-sec exposure. Changes in adaptation are of small consequence for ordinary car meeting as they only slightly affect the redetection time for a roadside object (54). Instant flash-blindness is being investigated (47).

Vision is essential to but is not a sufficient condition for safe driving. Many other factors are involved within and without the driver. Yet pleas to correlate accidents and vision continue (10). Jackson (50) states that there is no correlation between visual function and road accidents. Vision from the driver's seat is improving according to Fosberry and Moore (40), more so forward than to the rear.

Vision standards for French drivers vary from 0.6 (about 20/33) for light vehicles to 0.7 and 0.9, or 0.6 and 1.0 (about 20/30 and 20/22, or 20/33 and 20/20) for drivers of heavy vehicles.

The question of how well people see has two new answers. A large survey of binocular vision (92) found 76 percent of people (uncorrected) reaching 20/40 or better and when corrected 95 percent were 20/40 or better. A median acuity (with correction) of 20/30 was found to about age 75 and (uncorrected) 20/40 to age 58 for females and to 70 for males. An analysis of 1,000 refractions (16) showed one eye 20/30 or better to about age 70 and 20/20 to about age 50. Such information is essential to a decision as to what age and how often vision of drivers should be retested for safety and at an economical cost.

Foveal vision of targets (50-1,600 fc) was not greatly decreased by filters absorbing 99 percent when contrast was high, but with poor lighting vision was degraded (72). Luminance fluctuations of small magnitude did not greatly affect thresholds at screen luminances of 0.01 to 0.1 fL, but do so at 1 fL (67).

Burg (24) reports correlation between good dynamic visual acuity and driving citations (i.e., a good driving record), but not with static visual acuity or accidents. Form changes in a pattern can make it appear at various distances and Johansson (51) is using this interesting approach to examine depth perception. Accommodation and fatigue are problems when observing a target moving toward the eye at 0-200 cm/sec (87). Whiteside (99) reviews the illusions of movement perception. Threshold size is reported to be a linear function of the speed of motion; the constants of the equation have small variation between observers (17). An abstract (41) reports progress in mathematical description of the position, velocity, and acceleration for perspective transformation of the moving ground plane.

Wearing of tinted glasses (9-20 percent transmittance) reduced stereoscopic visual acuity an average of 21-29 percent for 57 percent of 34 subjects. No change was found for 29 percent, and 13 percent showed an increase in stereopsis (80). Lall and Kitching (62) report the average stereo acuity of emmetropes without phorias as 2.55 sec arc.

The acuity is poor at mesopic luminance and improves with increasing light. Stereoscopic acuity also increases with better correction of the errors of refraction of the eyes—another reason for the best possible correction of vision when driving is to be done at night. The visuo-motor reaction time is reported to be slightly less for binocular than for monocular vision (30).

Forbes et al. (39) provide an extensive bibliography on the detectability and legibility of signs, and incidentally on other aspects of vision. Johansson and associates (52) found speed limit signs to be seen 78 percent of the time, but unspecified warning signs and pedestrian crossing signs were seen only 18 and 17 percent of the time. Signs are seen in terms of their significance to person or property, and unnecessary signs distract the driver's attention to no significant purpose.

A hand-held driver vision screening device is described (93) and Young (100) gives details on how small photocells mounted on a spectacle frame are used to detect eye movements and send the information to the computer center. The continuously variable multifocal "Verilux" lens is reported good for driving except that they were dangerous when backing (74). Variation in the extent of nasal visual fields is reported by Cutler and Davey (31). Heimstra (46) finds mental fatigue more serious than skill fatigue as far as vigilance and target detection are parts of driving performance. It is difficult to conclude whether the decrements are due to changes in motivation or physiological changes due to fatigue. The effects of previous concentrated mental operations are not immediately apparent, but are progressively more noticeable as a function of time.

Luria and Dimmick (63) discuss color vision, Walraven (98) has written a monograph, and Wald (96) considers recent information on the retinal receptors and gives information on the transmittances of the internal eye media. Color vision at mesopic levels (0.1-0.01 fL) was measured by Kinney (60) and this information should be utilized in any attempt to color code signs for use in night driving. Connors (29) reported that surround brightness does not affect hue discrimination until the surround is three times brighter than the stimulus.

The U. S. Standard Colors for Signal Lights is available (94) and an instrument is described for measurement of the color of light from signal devices (83). The extension of the red limit of the U. S. Standard is believed undesirable because it is a handicap for people with deficient color vision (68). New measurements are published for the kinds of errors made by deficient and their significance is discussed. Nathan et al. (68) state further that no yellow filter tested was satisfactory for people with defective color vision. Richards (78) reviews the literature on yellow glasses, giving further evidence that yellow glasses should not be worn at night. Both Kleyhaur (61) and Richards (77) warn against wearing the darker shades of contact lenses when driving at night. The American Medical Association's warning against tinted glasses and windshields for night driving is republished (5).

The lighting study project (13) recommends amber signal lights, and Fosberry and Moore (40) list their advantages. Allen (1, 3, 4) advises against the use of yellow, because he doubts that the lower brightness of the yellow can be overcome and that replacing regular bulbs with yellow painted bulbs dangerously reduces the brightness (14). Blackwell has previously commented on the near impossibility of localizing a single flashing amber light. While two signal lights are better than one, usually only one light is used at a time as a direction signal. I find no satisfactory evidence that seeing is better with yellow light. It is a handicap for people with deficient color vision when red and green lights are also in the fields of view. Medium grade deficient will be hard put to tell whether a light is red, green or yellow and which way it is moving under poor conditions of visibility (in fog, rain, etc.).

Allen (102) recommends changing the rear red light on automobiles to green, because he believes that some two-thirds of the population see red behind green and think that red is farther away than it actually is.

Vibration effects on humans are reviewed by Nadel (66) and Teare and Parks (89) report severe deterioration of vision from 12-24 cps vibration, a possible linkage with the critical flicker frequency of the eye.

Drug effects on the driver's vision may well be dangerous (88), and general articles on

drug effects appeared last year (65, 70, 84). Bilberry pigment extract is reported to improve night vision (9); considering the widespread occurrence of anthocyanin, (e.g., in beets) this finding needs confirmation. Smoking two cigarettes within 15 minutes did not affect night driving ability (53). Feeding alcohol to 6 subjects did not affect visual acuity or color vision other than that their responses were slower. Eye phorias and ductions were affected adversely in half of the subjects and the peripheral visual fields of all were reduced (86). The diurnal variation of intraocular pressure in glaucoma (57) and other cyclic changes may affect night vision.

Medical problems and the responsibility of ophthalmologists are under consideration (42). When the patient has been warned by the practitioner that his vision is inadequate for driving, it is held that the practitioner has done his duty and is not responsible if the patient disregards the advice (37, 44). Allen (2) calls attention to the extent of eye injuries in automobile accidents. Degeneration of the retina and opacities of the lens may disqualify the elderly from driving (15). Thermal tolerances of the skin are available (58). Accident-prone drivers may be those who do not mature (56).

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# Effectiveness of Sign Background Reflectorization

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•PRESENT standards for directional signs on Interstate highways call for white legend on a green background. Where the sign is not self-illuminated the standards require that the legend be reflectorized; however, for roadside signs and illuminated overhead signs, reflectorization of the background is optional. There has been some question as to the degree of background brightness that is necessary and consequently the degree of reflectorization. The results of previous studies by the U. S. Bureau of Public Roads (1) have indicated little practical difference in legibility of signs with different degrees of background reflectorization, including no reflectorization. It is possible, however, that the degree of background brightness affects other sign-effectiveness factors such as detectability or reading time.

As an initial attack on this question, signs with different degrees of background reflectorization were compared by analyzing their effect on the ability of drivers to follow a test route to a given destination on controlled-access highways in a suburban area.

## DESCRIPTION OF STUDY

Test subjects drove over a fictitious route which included highways and parkways of the Pentagon network and other controlled-access highways in the Virginia suburbs of Washington, D. C. Changes in the direction of the route were marked by test guide signs in advance of the exits. An observer riding in the car with the test subject noted missed turns, and directed the test subjects back onto the route in case of a missed turn. In order to conceal the true nature of the experiment, subjects were informed that this was a study of "night driving characteristics" and they were being asked to use the same route so as to have a consistent basis for comparison.

The test route (Fig. 1) was approximately 25 miles long, and its controlled-access design was of the World War II era with fairly curvilinear alignment. All test turns were right-hand exits. Each turn was marked by a single test guide sign (Fig. 2) placed 400 ft or more in advance of the exit. All portions of the route on approaches to and in the vicinity of test signs and turn exits were on controlled-access divided highways with two or three lanes in each direction. Some exit ramps led to streets or highways of lesser design, but the route always led back to an access-controlled divided highway usually one-half mile or more in advance of a test sign location. Posted speed limits on the route ranged from 35 to 55 mph, but were predominantly 35 or 40 mph. Prevailing speeds on the same highways ranged, for the most part, from 35 to 45 mph. There were 18 test turns on the route, all of which were marked with green test signs having reflectorized white legends.

Three degrees of reflectorization were used for the test sign backgrounds: (I) a nonreflectorized green background; (II) a moderately bright reflectorized green background; and (III) a relatively high-brightness reflectorized green background (standard reflectorized sheeting). Specific luminance curves for divergence angles up to one degree at an incidence angle of  $\frac{1}{3}$  deg for these materials, and for the material used for the white legend, are shown in Figure 3. For comparison, the specific luminance of unity of a theoretical perfect white diffuse surface is included. Figure 4 shows the appearance of the different materials at one location. Because of the limited range of brightness that can be depicted by photographic process, the views are only approximate representations.

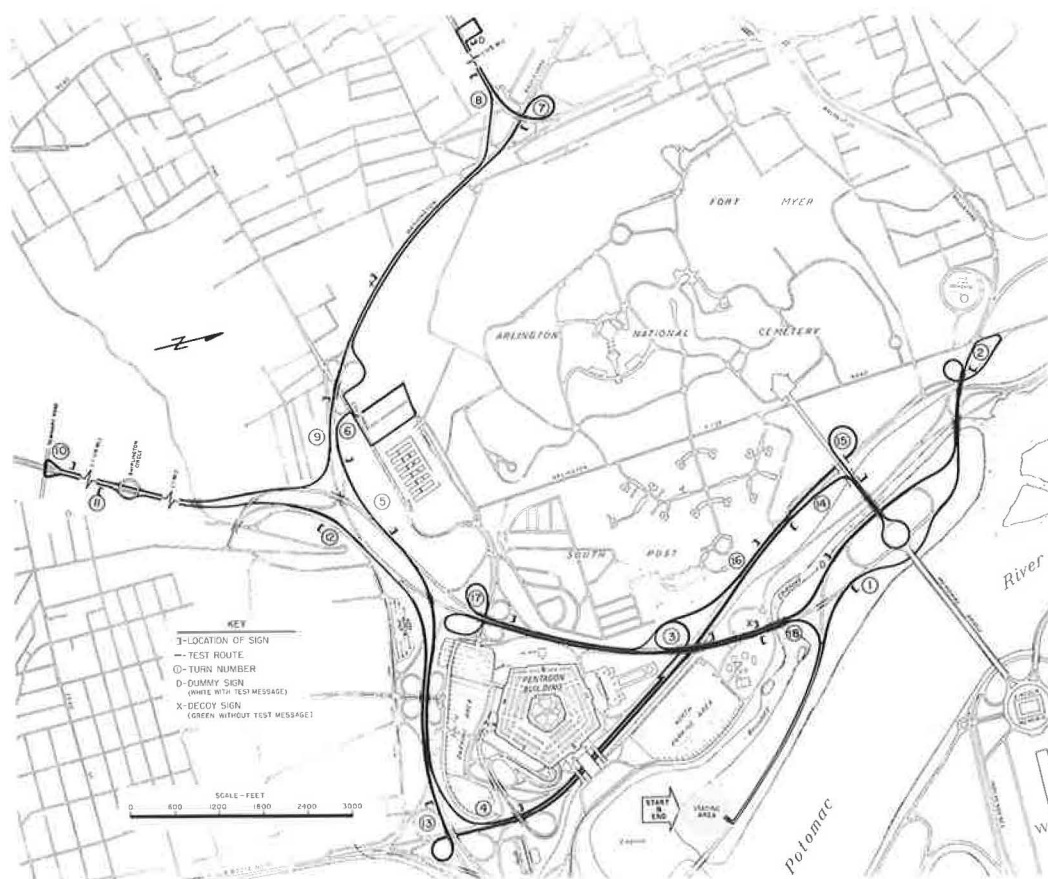


Figure 1. Map of test route.



Figure 2. Daytime view of typical test guide sign.

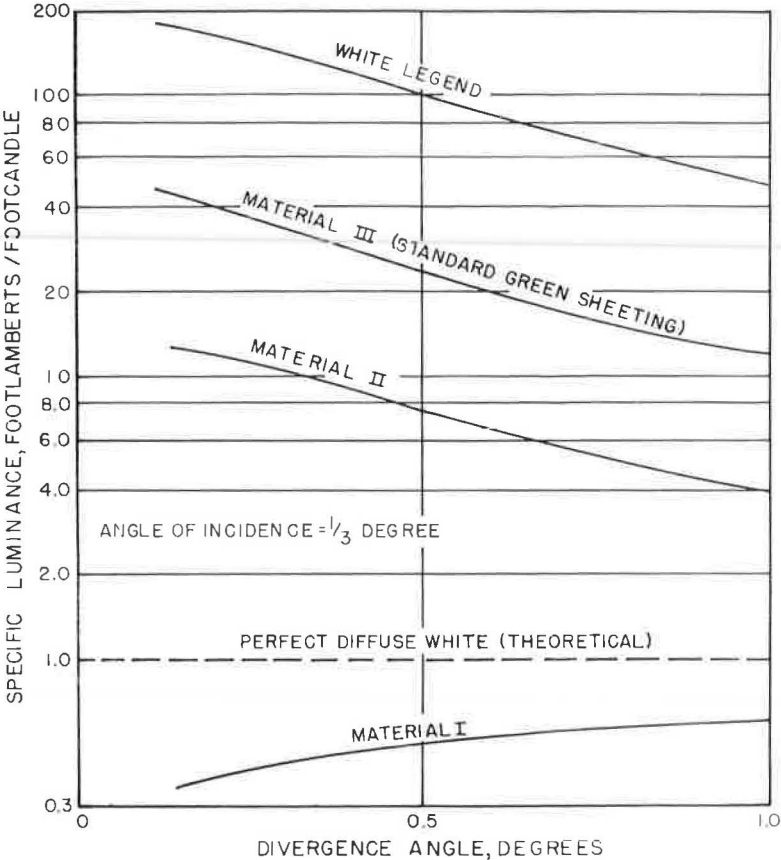


Figure 3. Specific luminances of the materials used on the test signs.

TABLE 1  
SCHEDULE OF SIGN BACKGROUNDS BY  
NIGHTS AND TURNS

Turn Number	Sign Background Designations <sup>1</sup>		
	First Night	Second Night	Third Night
1	I	II	III
2	I	III	II
3	III	I	II
4	III	II	I
5	I	II	III
6	II	I	III
7	III	I	II
8	I	III	II
9	I	II	III
10	II	III	I
11	II	III	I
12	II	I	III
13	III	II	I
14	III	I	II
15	I	II	III
16	II	III	I
17	II	III	I
18	III	I	II

<sup>1</sup> Roman numerals refer to degree of reflectorization as follows: I, nonreflectorized green background; II, moderately bright reflectorized green background; and III, relatively high-brightness reflectorized green background (standard reflectorized sheeting).

The type of background at each turn was assigned randomly each night. The only limitation on the random assignment was that the sign marking each turn had to have a different background each night, and that each night the signs at one-third of the turns had to have each of the background treatments. Therefore, there were six turns each night marked with signs of each of the background treatments. On successive nights, the sign background was changed at each test turn. Each of the 18 turns on the route was therefore marked by a sign with each of the background types on successive nights. Three nights of testing (or multiples of three) were needed to balance the experimental design by background treatments and turns. A schedule of backgrounds by nights and turns is given in Table 1.

To facilitate changing the sign backgrounds on successive nights, three signs were fabricated for each test turn, which were identical in legend and legend spacing



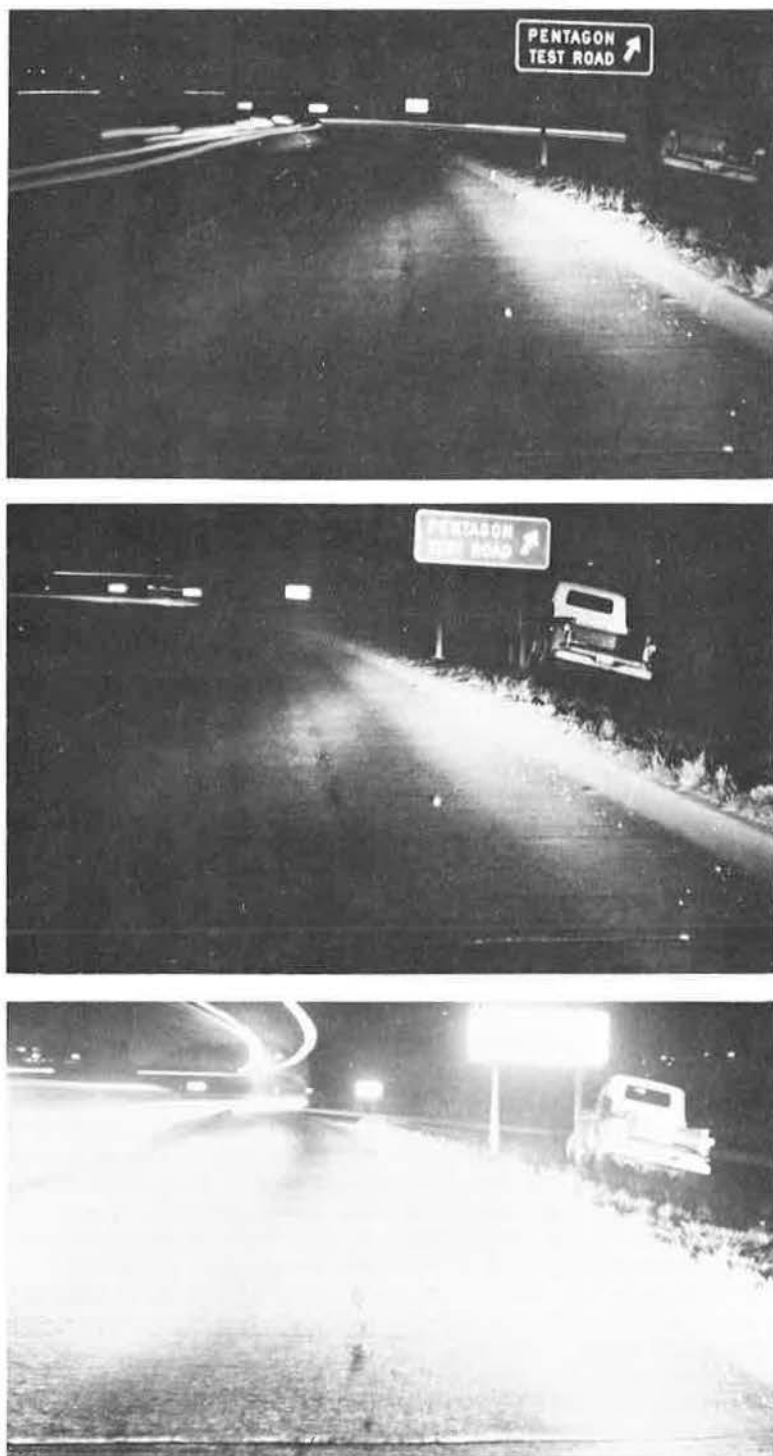


Figure 4. Night views of signs with different background materials at same location.

and differed only in background treatment. Legends and borders consisted of white reflectorized sheeting. Eight-inch series D letters were used. The test sign carried two lines of copy and appropriate arrows: the first line gave a legitimate destination on the route, e. g., PENTAGON; and the second line, in all cases, read TEST ROAD. All test signs measured 96 by 32 in.

The test signs were designed so as not to appear conspicuously different in size and legend style (letters and arrows) from the permanent directional signs along the route, most of which had either black legend on a white reflectorized background or white reflectorized legend on a nonreflectorized background. None of the test signs gave directions which conflicted with, or appeared to duplicate, the existing signing. In a few cases, a test sign replaced an existing sign.

Even with these precautions, it was felt that the subjects would have learned to associate, either consciously or subconsciously, the test message with signs having green backgrounds. This would have biased the results in favor of reflectorized backgrounds. Furthermore, subjects might also have learned to associate the test message with the test-sign shape (a low, wide rectangle) or design (two lines of legend, and arrows). In order to further camouflage the differences between the test signs and the existing signs, two dummy signs (Fig. 5) displaying the test message which more nearly resembled the existing signs in dimension and color combination (black legend on a white reflectorized background), were placed along the route; two other signs were placed which resembled the test signs in shape, design, and color combination, but with the test message omitted (Fig. 6). The latter signs termed "decoys," supplemented by the few existing green background signs along the route, were intended to prevent the subjects from associating green backgrounds with the test message. Small 24- by 30-in. auxiliary signs used for directions on ramps and other connections on the route had black legends on white reflectorized backgrounds (Fig. 7).

Test signs were mounted in horizontal channels on posts to facilitate changing them each night. The signs were mounted at a height 5 ft from the bottom of the sign to the pavement, and laterally at a minimum distance of 2 ft beyond an unmountable curb or edge of shoulder. They were mounted at approximately right angles to the roadway, but the angle with the roadway always exceeded 90 deg in order to minimize specular reflections.

Test subjects were volunteers from organizations such as local Junior Chambers of Commerce, a local sports car club, the Bureau of Public Roads (other than the Traffic Systems Division), and other agencies of the Department of Commerce. Subjects were scheduled in advance for specific nights and times of arrival at the staging area.

## PROCEDURE

The test procedure was essentially the same as that used in a previous study of route turn markers (2). On arrival at the staging area, subjects received a printed sheet containing explanations and instructions. They were asked to complete a questionnaire on driving experience and to undergo a vision test on a Keystone Visual Safety Tester for acuity, stereopsis, and far-point fusion. Color vision also was tested. The questionnaire and vision test were included as part of the facade of a general study of night driving characteristics, and in addition, tests served to screen subjects for visual defects. The questionnaire and visual acuity data are summarized for the different groups of subjects taking part in the study every night (Table 2).

Subjects were told only that the aim of the study was to observe typical night driving characteristics and that, in order to have a consistent basis of comparison, they were to drive over the same route. The subjects were instructed to drive normally, and were told that the accompanying observer would not judge their driving but only observe their normal night driving characteristics. In order to retain anonymity, subjects were identified by code number. It was explained that the observer would usually be too busy to give directions, and that the subjects were expected to follow the course which was marked by signs with the message TEST ROAD. Subjects were not specifically informed that the observer would guide them if they missed a turn. Furthermore, a missed turn was not called to their attention; the observer merely began giving cor-



Figure 5. Dummy sign—test message with black legend on reflectorized white background.



Figure 6. Decoy sign, similar in design and color to test signs, not carrying test message.



Figure 7. Auxiliary sign used for directions on ramps and other connections.

TABLE 2  
CHARACTERISTICS OF TEST SUBJECTS

Characteristic	Number of Test Drivers		
	First Night	Second Night	Third Night
Organization <sup>a</sup> :			
Bureau of Public Roads	20	20	20
Sports car club	23	19	31
Jaycees	9	9	7
Others	12	15	6
Sex of driver <sup>b</sup> :			
Male	47	45	43
Female	3	5	7
Age of driver (years) <sup>b</sup> :			
Under 20	2	1	0
20 - 29	18	13	20
30 - 39	14	10	15
40 - 49	7	16	6
50 - 59	8	7	6
60 and over	1	3	3
Visual acuity:			
Below 20/40	50	49	49
Above 20/40	0	1	1
Familiarity with area <sup>c</sup> :			
Very familiar	10	11	8
Moderately familiar	24	28	25
Unfamiliar	16	11	17
Avg. age	35.1	39.3	35.9
Median age	33	40	33

<sup>a</sup>Estimated from mail return and schedule of volunteers—since subjects were identified by code number at the site, there is no way of identifying the 50 subjects who participated each night by organization.

<sup>b</sup>Taken from first questionnaire.

<sup>c</sup>Taken from second questionnaire; subjects queried after completing course.

rective directions. In the case of a choice of roadways, subjects were further instructed to stay on the main road except when directed otherwise by signs or by the observer. It was hoped that the foregoing explanation would somewhat satisfy the understandable curiosity which would have arisen by giving the subjects a plausible reason for following the signs, and minimize emphasis on the signs themselves being the object of the study. To obtain further consistency, subjects were instructed to keep their headlights on low-beam during the study. Subjects drove the route only once during the test, with 5-min intervals between the dispatching of each subject to prevent overtaking.

In order to reduce public exposure to the signs, they were put in place at approximately 6:00 p.m. and taken down after the last subject had traversed the route.

At the beginning of the test, the observer directed the subject to drive to the exit of the staging area parking lot where one of the small auxiliary signs reading TEST ROAD was placed. From

this point on, the subject was on the test route. The observer noted turns made correctly or missed. Whenever an error was made the subject was directed back onto the route in such a way that he would not encounter any of the remaining test signs out of sequence.

After returning to the staging area, a second questionnaire was completed dealing with such items as the subject's familiarity with the area of the route and problems in following the route.

## REFLECTIVE PROPERTIES OF SIGN MATERIALS

The specific luminance curves (Fig. 3) were derived from outdoor measurements on 24-in. square plaques identical to the materials used for the test sign. Similar measurements made on a sample basis of the actual test signs were compared with those on the plaques and were found to be essentially the same. The curves as plotted were derived from the measurements on the plaques. Because of the limited number of measurements on these materials, the curves shown should be considered as representative of the relatively specific luminances of the materials rather than the absolute specific luminances.

The values for the non-reflectorized background materials appear somewhat high. This is probably because the material was a smooth sheeting and exhibited some specular reflection. However, the material when used on the test signs would have exhibited the same characteristics.

Figure 8 shows how the brightness of the sign materials varied with distance from the sign for each turn. These data represent actual field measurements of the plaques mounted on the sign supports and illuminated by the low beams of a single vehicle. With the vehicle stationary at a measured distance from the sign, brightness measurements were made by a Pritchard photometer mounted at the driver's head position. The plotted numerals represent the turn at which the brightness values were obtained for the standard sheeting sign background material at the indicated distances from the sign. A curve has been drawn through the median brightness for all turns at each distance (the median value for the 700-ft distance is based only on those signs which were

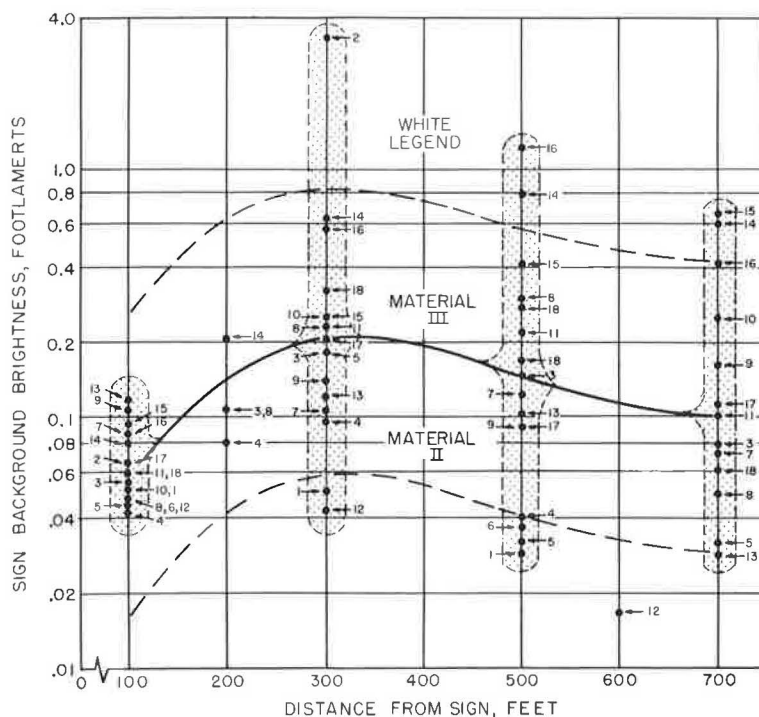


Figure 8. Brightness of the sign materials in place by distance from the signs for two-lamp low beam illumination. (The plotted points are all for material III, the standard green sheeting, shown here as the solid curve; numbers next to the points refer to the turns at which the measurements were made; and the dashed curves represent the median brightnesses for material II and the white legend material.)

not obscured at that distance). The median curves for the intermediate sheeting and the white legend material are shown by broken lines below and above the curve for the standard sheeting, respectively.

The wide range in brightness is caused by the variations in horizontal and vertical curvature on the approaches to the signs at the individual sign locations, which resulted in differences in incidence angles and in the amount of head-lamp illumination incident on the signs. To a lesser extent, variations in the approaches also resulted in differences in divergence angles. For each sign location and distance, the incident illumination and incidence and divergence angles were the same for each material, and thus the brightnesses were in the same ratio as the specific luminances. Although there is considerable overlap in the brightness ranges for the three materials at different locations, the brightnesses of individual materials at the same location were in the same ratio. The median curves are therefore parallel, and the individual measured points for the other two materials, if shown, would have fallen as far from the corresponding turn points indicated for the standard sheeting as the distances between the medial curves for the other two materials.

These brightness values were obtained under low-beam illumination by a single vehicle and are therefore minimum values. The brightnesses of the signs during the tests could have been higher as a result of illumination contributed by other vehicles on the highway.

### TEST SUBJECTS

The number of test subjects was limited by the need to run the study for a period consisting of multiples of three nights in order that the three background treatments



could be balanced by turns. It was not considered feasible to extend the test to six or more nights because of increased field crew requirements and possible publicity of the test project.

Test runs began after 6:30 p.m., when the evening traffic peak had ended, and were terminated shortly after midnight, which was as late as volunteers would remain on week nights. Therefore the requirement of 5-min intervals between test subjects permitted about 60 subjects to be scheduled each night. Actually more than 60 subjects were tested on each of the three nights. However, because the last test sign on the route was inadvertently removed on the first night while some subjects were still on the route, these subjects were not completely exposed to the balanced experimental test design and their data were not used. In addition, a few erratic drivers missed almost all the turns and were hopelessly lost. Since there were complete data for 50 test subjects on the first night, data for only the first 50 subjects (after elimination of the erratic drivers) were used for the other two nights in order to maintain a balanced experimental design.

Several factors which may have acted to confound the results became apparent during the course of the field operations or on inspection of the data sheets.

Toward the middle of the second night's runs and, to a lesser extent, later in the evening of the third night, temperature-humidity conditions caused moisture condensation on many of the signs. This resulted in a lowering of the brightnesses of the reflective materials.

It became apparent also that some of the test subjects had not fully grasped the intent of the written instructions, which had of necessity emphasized the TEST ROAD message rather than the type of sign. Since the first sign carrying this message was the small auxiliary sign encountered at the exit from the staging area, a psychological set was apparently often formed; and for the first few turns, these subjects were looking only for the small white signs and ignoring all others. Some evidence for this is the fact that more than one-half of the total errors occurred at the first three turns. Furthermore, an analysis of consecutive turns missed showed that several subjects missed the first two or three turns before they realized that the test message appeared on types of signs other than the small auxiliary signs.

Finally, it became apparent during the study that some of the exit gores and throats were poorly defined. Since the study was conducted in the middle of winter, the pavement markings were somewhat obliterated and the melting of previous snowfalls had left debris and dust at the curbs and road edges. (At the time of the tests, however, there was no snow on the ground and the pavements were dry.) Often the observers commented on the data sheets that the subject called out when he saw the sign, or reduced speed and operated his turn signal but failed to make the turn. From these comments, it was concluded that many of the errors were due to missing the exit rather than to missing the sign. On the basis of the observer's comments, an attempt was made to cull out those errors which should not have been attributed to the signs. These errors were termed "doubtfuls."

Consequently, the data have been analyzed by nights and by backgrounds for several categories: total errors, for all turns, and for turns 4-18 only; and total errors with doubtfuls excluded, for all turns, and for turns 4-18.

## RESULTS

Table 3 gives the number of errors by nights and by backgrounds for each turn on the route and for selected groups of turns. The results of chi-square tests performed on these frequencies of errors are given in Table 4. The probability shown is the probability of obtaining by chance alone a chi-square value as large as or larger than that observed; e.g., a chi-square value as large as or larger than 0.46 would be expected to arise almost 8 times out of 10 merely from chance.

The chi-square tests give no evidence of any significant differences between the numbers of errors for any of the breakdowns, either by nights or by background treatments (Table 4). Chi-square tests on the relative frequencies of errors by turns were generally significant at the 1 percent level or less, indicating that there were signifi-

TABLE 3  
NUMBER OF ERRORS BY TURNS, NIGHTS, AND BACKGROUNDS

Turn Number	All Errors							All Errors Less Doubtfuls						
	First Night	Second Night	Third Night	Back-ground I	Back-ground II	Back-ground III	Errors by Turns	First Night	Second Night	Third Night	Back-ground I	Back-ground II	Back-ground III	Errors by Turns
1	16	19	19	16	19	19	54	13	15	18	13	15	18	46
2	11	7	13	11	13	7	31	10	5	11	10	11	5	26
3	16	8	13	8	13	16	37	14	3	11	3	11	14	28
4	3	4	4	4	4	3	11	2	4	4	4	4	2	10
5	4	8	4	4	8	4	16	4	6	4	4	6	4	14
6	1	2	3	2	1	3	6	1	2	2	2	1	2	5
7	1	2	2	2	2	1	5	1	2	2	2	2	1	5
8	1	1	2	1	2	1	4	1	1	2	1	2	1	4
9	5	1	0	5	1	0	6	4	1	0	4	1	0	5
10	2	2	2	2	2	2	6	2	2	2	2	2	2	6
11	1	4	5	5	1	4	10	1	3	4	4	1	3	8
12	10	7	9	7	10	9	26	5	6	4	6	5	4	15
13	1	1	0	0	1	1	2	1	1	0	0	1	1	2
14	1	0	0	0	0	1	1	1	0	0	0	0	1	1
15	1	0	0	1	0	0	1	1	0	0	1	0	0	1
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1	4	2	2	1	4	7	1	2	1	1	1	2	4
18	0	1	1	1	1	0	2	0	1	1	1	1	0	2
Summary:														
Turns 1-18	75	71	79	71	79	75	225	62	54	66	58	64	60	182
Turns 1-3	43	34	45	35	45	42	122	37	23	40	26	37	37	100
Turns 4-18	32	37	34	36	34	33	103	25	31	26	32	27	23	82

TABLE 4  
SUMMARY OF CHI-SQUARE TESTS

Item of Comparison	$\chi^2$	Probability <sup>1</sup>
By nights:		
All errors:		
Turns 1-18	0.46	0.79
Turns 4-18	0.37	0.83
Doubtful errors omitted:		
Turns 1- 8	1.34	0.51
Turns 4-18	0.78	0.69
By background material:		
All errors:		
Turns 1-18	0.46	0.79
Turns 4-18	0.14	0.93
Doubtful errors omitted:		
Turns 1-18	0.31	0.86
Turns 4-18	1.54	0.47

<sup>1</sup> The probability shown is the probability of obtaining by chance alone a chi-square value as large as, or larger than, that observed; e. g., a chi-square value as large as or larger than 0.46 would be expected to arise almost 8 times out of 10 merely from chance.

cant differences in frequencies of errors among the turns. These differences had been anticipated and the experiment was designed accordingly.

Figure 9 shows the numbers of errors for the different breakdowns plotted by relative specific luminance of the background materials at a  $\frac{1}{2}$ -deg divergence angle. The scales on the right-hand side of the graph are the percentages of errors based on the number of sign encounters for each of the breakdowns. Consideration of the errors for all turns shows the occurrence of errors to be approximately  $8\frac{1}{2}$  percent. Omission of the doubtful errors brings the percentage down to 7. If the first three turns are eliminated, total errors drop to approximately  $4\frac{1}{2}$  percent; and with the doubtfuls omitted,  $3\frac{3}{4}$  percent. Differences in the percentages of errors between the different background materials do not amount to more than about 1 percentage point. These differences were previously shown not to be statistically significant.

## FURTHER CONSIDERATIONS

This study was designed to test one aspect of the relative effectiveness of different degrees of sign background reflectorization—the ability of subjects to react correctly to information displayed on signs. Therefore, the analysis is directed primarily to a comparison of the relative frequency of errors for signs with different background materials. Although the study did not take account of the differences in the actual

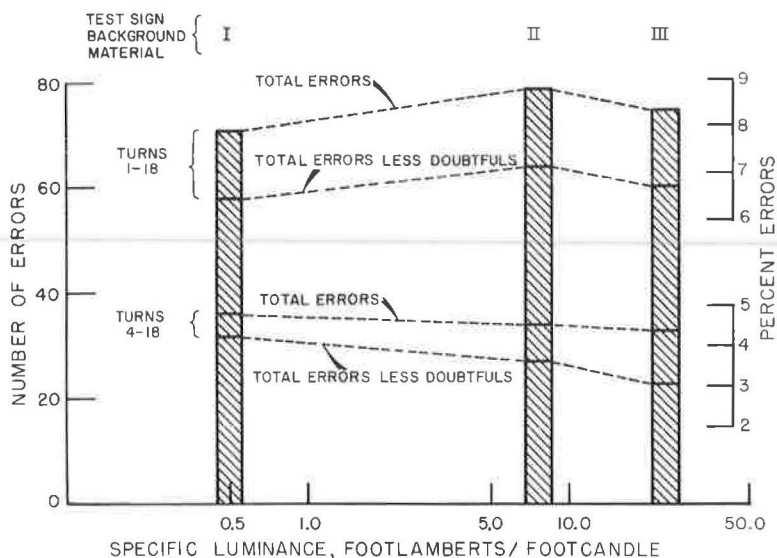


Figure 9. Frequency and percentage of errors by specific luminance of test sign background materials for the different types of error and turns. (The upper scale of percent errors is based on 900 possible correct turns for each material for turns 1 to 18; the lower percent scale is based on 750 possible correct turns per material for turns 4 to 18.)

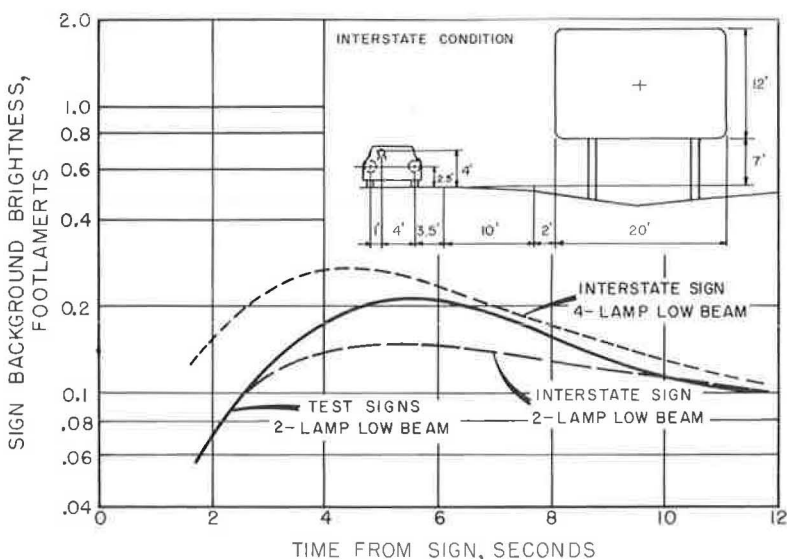


Figure 10. Comparison of center-of-sign brightness of standard sheeting background material under low-beam illumination for the test signs and for typical Interstate highway signs. (The solid-line curve is the median curve for the standard sheeting test signs for 2-lamp illumination; and the upper and lower broken-line curves have been calculated for 4-lamp and 2-lamp illumination, respectively, for the assumed Interstate geometry shown in the inset.)

brightnesses of the signs at the different locations, it should be pointed out that the same material varies in brightness, depending on the highway alignment on the approach to the sign. Alignment affects the incidence angles and the intensity of headlight illumination on the sign. In fact, because of the differences between locations, the moderately reflective material II was brighter at some locations than material III, the standard sheeting, was at other locations. Although the experimental design was set up so that turns were balanced by background material, there was no balance between turns and brightnesses of the backgrounds. This was further confounded by the reduction in the brightness of some of the signs due to the moisture condensation. However, since the relative frequencies of errors by nights was not statistically significant, it is concluded that the reductions in sign brightness did not result in an increase in errors.

A plot of errors (not shown) by sign background brightness (measured at 300 ft from the signs, at which distance the maximum median brightness was found) showed such scatter that no definite trend could be observed. A possible trend toward fewer errors at higher background brightnesses was indicated, but the small number of locations at which high background brightness occurred and the lack of balance between turns and brightness made an analysis of errors by brightness virtually meaningless.

The actual brightnesses of the sign materials on the signs in place were shown in Figure 8. Although the analysis of the study results gave no evidence of any difference in the relative frequencies of errors between the materials for the range of brightnesses covered, it is possible that a still higher brightness level might result in fewer errors. Before considering this possibility, it might be well to compare the sign brightnesses achieved in the study with those which would exist in actual practice on an Interstate highway. The standard sheeting median brightness curve for the test signs and brightness curves of standard sheeting for Interstate signs, calculated for 4-lamp and 2-lamp low beams, are plotted in Figure 10. To allow for differences between speeds on the test route and those on Interstate highways, the abscissa is in units of time before reaching the sign based on 40 mph for the test route and 60 mph for Interstate highways. This illustration shows that for the same material, the brightnesses of the test signs fell in the same range as that of Interstate signs. In fact, since the brightness measurements on the test signs were made under the illumination from the low-beams of a two-lamp vehicle, comparison of the curves for two-lamp illumination indicates that the test signs were, on the average, slightly brighter than the Interstate signs. Therefore, sign background brightnesses higher than those tested would have had to be higher than brightnesses ordinarily available from standard sheeting on Interstate signs.

It was pointed out that the highways on which the study was conducted were designed to lower standards than current Interstate highways; and prevailing speeds were also lower. Compared to Interstate conditions, speeds on the test route were approximately two-thirds those on Interstate highways; sign legends were about one-half the size; and the signs themselves were about one-fourth the area of Interstate signs. Therefore, the size ratio between the test signs and Interstate signs was smaller than the ratio between the speeds on the respective facilities and, except for the multiplicity of signs and exits so close to each other, the study conditions may have constituted a more difficult test of signing than would have been the case for Interstate conditions.

The methodology employed for this study may have applicability in other related work. A relatively large number of subjects are needed, however, because of the small proportion of errors typically observed. As in all studies involving test subjects as drivers, precise and concise instructions are essential in order to minimize confusion on the part of subjects. Temperature, humidity, and precipitation are additional factors outside the realm of control.

## FINDINGS

The relatively few number of errors and the presence of confounding factors which entered into the tests limit the findings from this study. Observed differences, by type of sign background material, in errors made by test subjects in following the route were not statistically significant, and no evidence is therefore available from the study

to support a conclusion of any difference in the effectiveness of different degrees of sign background reflectorization. Because the data are enumeration data, and therefore insensitive to small differences, much larger samples or larger differences would be required to establish statistical significance.

The occurrence of errors, in absolute terms, was relatively small: total errors from whatever source averaged  $8\frac{1}{2}$  percent; and errors attributable to the signs and not to the conditions of the study amounted to less than 4 percent. If the probability of missing a single sign, regardless of the degree of background reflectorization, is in the order of 4 percent, it follows that the probability of missing two advance signs would be in the order of 0.16 percent.

On the basis of the observers' comments it would seem that one of the major problems in providing guidance to drivers is enabling them to relate the information on the sign and the placement of the sign to their desired actions. Another problem facing drivers is that of locating the geometric features to which the sign relates, particularly the exit gore.

#### ACKNOWLEDGMENTS

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Region 15 of the Bureau of Public Roads fabricated and erected the sign supports, and placed and removed the signs during the study. The Arlington County Highway Department, the Virginia Department of Highways, and the National Park Service of the Department of the Interior granted permission to erect signs on highways under their jurisdiction. Government Services Incorporated provided the Columbia Island Marina parking lot and boathouse for a staging area, and D. C. Department of Highways and Traffic fabricated the auxiliary signs. The Junior Chambers of Commerce of the District of Columbia and Maryland suburbs, local chapters of the Lions Club, and the local chapter of the Sports Car Club of America provided test subjects. The group of men training as Junior Engineers in the Washington office of the Bureau of Public Roads also took part in the study.

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# Night Visibility for Opposing Drivers with High And Low Headlight Beams

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## ABRIDGMENT

•THE RELATIVE visibility of two tasks which are typical of those encountered in the nighttime driving situation was explored using the Visual Task Evaluator (VTE) measurement technique. The tasks were illuminated with either high or low headlight beams. An opposing vehicle was located at one of several longitudinal separations with the same beam configuration as that of the observer's to simulate a single approaching vehicle at one of four different median widths. Disability glare measurements were made with a Pritchard photometer and the overall visibility evaluated through an analytical procedure.

The two tasks studied were (a) a red retro-reflector on the rear of an unlighted, black car, parked 500 ft from the observer on the right shoulder, and (b) a section of standard pavement stripe, 200 ft ahead on the right-hand pavement edge.

The results are given in terms of a Supra Threshold Factor (STF). This factor is a measure of how many times above threshold the visibility of an actual target is.

Figure 1 shows the mean value of STF for each task and beam condition, for all median widths combined, at each of the 5 longitudinal separations measured between approaching vehicles. It appears that the optimum beam choice depends, to a large part, on the task studied. For the driver looking at a section of pavement stripe, the low-beam headlamps facing oncoming low-beam lamps produced better visibility conditions. However, to see the car's retro-reflector, the condition was high-

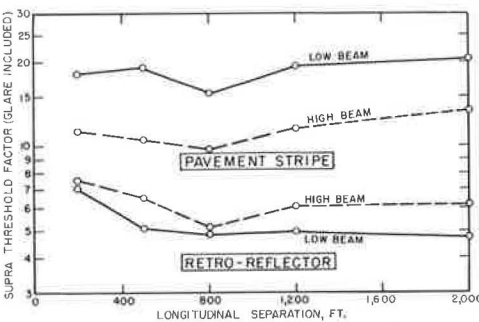


Figure 1.

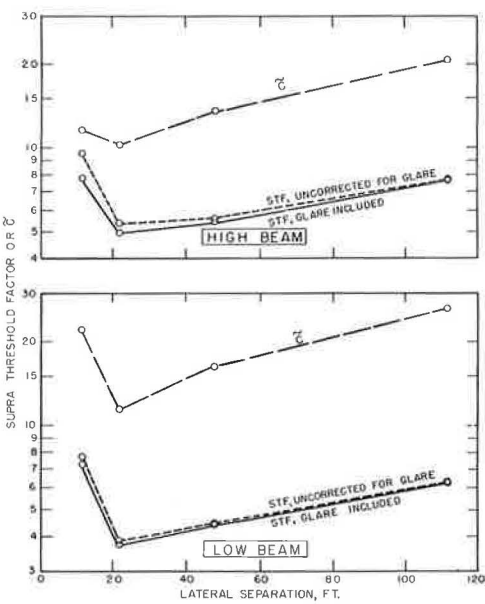


Figure 2.

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beam lamps on both vehicles led to better visibility. There are individual exceptions to the above trends, especially at narrow separations. In general, however, the results show the danger of using a single, simplified target in research on driver visibility.

If the results are plotted, as shown in Figure 2 for the retro-reflector, in terms of the equivalent contrast ( $\tilde{C}$ ) of a standard target, the data show that the target's visibility is affected in some way other than by the illumination from the opposing vehicle's headlight, since this measure is independent of the disability glare effect. An effect, appearing similar to the driver, due to the scattering of light flux by small particles in the atmosphere between the driver's eye and the target, is a possible explanation of this change in visibility due to the opposing vehicle.

The STF values (Fig. 2) have been calculated with and without disability glare being considered. The effect of the disability glare (i. e., scattering of light within the eye-ball) appears minor when compared to the atmospheric scatter effect.

Since STF is independent of background luminance and  $\tilde{C}$  is not, the curves in Figure 2 being approximately parallel to each other and generally of the same shape would indicate that background luminance is not too important. Since the task size, shape, and duration were not changed, the contrast must, therefore, play the dominant role in determining the visibility for these high contrast tasks.

Further analysis of the data, however, reveals that the shifts in visibility which accompany the switching from low to high or high to low beam are largely determined by changes in the level of adaptation, since contrast for these tasks will show little change. It is, therefore, the adaptation level which largely determines the beam that would give the highest visibility in the particular case.