NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 99

VISUAL REQUIREMENTS IN NIGHT DRIVING

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VISUAL REQUIREMENTS IN NIGHT DRIVING

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Bureau of Public Roads, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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This report was prepared by the contracting research agency. It has been reviewed by the appropriate Advisory Panel for clarity, documentation, and fulfillment of the contract. It has been accepted by the Highway Research Board and published in the interest of effective dissemination of findings and their application in the formulation of policies, procedures, and practices in the subject problem area.

The opinions and conclusions expressed or implied in these reports are those of the research agencies that performed the research. They are not necessarily those of the Highway Research Board, the National Academy of Sciences, the Bureau of Public Roads, the American Association of State Highway Officials, nor of the individual states participating in the Program.

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FOREWORD

By Staff

Highway Research Board

This report will be of interest to traffic engineers, illumination engineers, and human factors scientists interested in the quality of the nighttime roadway visual environment, because it presents basic information on the visual requirements of night driving and on the results of night driving under severe visual degradation. Also presented are the results of basic research employing a specially constructed eye marker camera that indicates what the driver sees.

The visual information needed by a driver for safe operation of his vehicle at night includes information deliberately provided by the roadway design, as well as control and other information incidental to the roadway. These types of information may vary with roadway geometrics, background topography, adjacent land uses, and lighting, if any. They may also depend on operating conditions such as speed and volume. It was with these thoughts in mind that this project was initiated during the fall of 1964.

The over-all objective of the project, carried out by the Ohio State University, was to determine information needed by motorists at night. The assessment and relative significance of the various items of needed information were studied in an effort to develop criteria for the environment. It was expected that the type of information would vary with roadway geometrics, background topography, adjacent land uses, and lighting, if any, along with operating conditions such as speed and volume.

The research was designed to determine minimum information necessary to maintain control stability and identify the information that is normally used. Visual degradation studies were conducted to determine limits of performance stability based on driver performance criteria previously established, and mapping of the visual field through selective degradation was conducted to identify classes of information used by nighttime drivers. Research was conducted to determine times and distances to satisfy information needs for optimal control. Visual cues were scaled by photometric calibration of viewed object contrasts and edge markings, and an eye marking unit was employed to assess relative cue importance in maintaining performance. An attempt was made to formulate the effect of freeway informational features on driving performance based on perceptual and highway design factors.

As the authors point out, basic research often presents more problems than it solves. This is true in the case of this study. As an example, this research clearly differentiates between the importance of certain viewing areas over others in the dynamics of driving. Within the viewing areas of concern, a determination of which elements or interaction of elements are being utilized by the driver in the control task would be a worthwhile subject for the further research that is needed to ultimately provide the driver with the visual information that he requires for safe operation of his vehicle on freeways at night.

CONTENTS

ACKNOWLEDGMENTS

The research reported herein was conducted at The Ohio State University under the general supervision of Thomas H Rockwell, Professor of Industrial Engineering, and Ronald L Ernst, Associate Professor of Computer and Information Sciences, both of the Systems Research Group, Department of Industrial Engineering, as Co-Principal Investigators. Michael J Rulon, Research Associate, in addition to writing Chapter Four, also integrated the various studies reported and served as the principal author of the rewrite of the final report Visual instrumentation and measurements for Chapter Four were supervised by Andre Birkhoff of the Institute of Research on Vision (now with the Department of Civil Engineering), who also authored Appendix A. Highway comparison data were collected under the direction of Dr. Joseph Treiterer of the Department of Civil Engineering, who supervised the work of Robert Vecellio, those research findings are integrated in Chapter One.

Chapter Two describes a study conducted by Francisco Matanzo. The research in Chapter Three was conducted by Norman E. Lobdell assisted by Michael J. Rulon Chapter Five involved the services of John Whalen, Dr Charles Overby, and Ronald Mourant. Chapter Six, as well as the aperture described therein, was prepared by Andre Birkhoff

Significant supporting activities were contributed by a number of individuals; principal among these were Larry Tracewell, Clarence James, and John Snider in the design, equipping, and maintaining of vehicle instrumentation. Data analysis was facilitated through the efforts of Jack Arnold and Dave Martin Finally, graduate students Don Nameche, Duane Knauer, and James Gandee were instrumental in executing the research

Special acknowledgment must also be given to the Ohio Department of Highways for the use of its instrumented vehicle in this research

VISUAL REQUIREMENTS IN NIGHT DRIVING

SUMMARY

The methods and results of the research on the informational needs of the nighttime driver are summarized herein. In addition, some conclusions are made based on an analysis of the results of the four studies taken together.

At the outset, the visual environment for the nighttime driver was conceived to consist of numerous elements—some relevant and some irrelevant to the driving task. The research plan was to subdivide, or partition the visual environment into elements by various methods, and look at the effects of each of these elements on driving performance. From this approach, it was hoped that some clues might be obtained as to which method of subdividing the visual environment was most meaningful, and some statements made concerning the necessary and sufficient visual information required for performing the driving task adequately.

The first study partitioned the visual environment into different levels of highway luminance (light to the eye) and explored the relationship between the intensity of highway luminance and the night driver's ability to control his vehicle. Luminance was manipulated experimentally by means of Polaroid plates in a pair of optometrist's frames worn by each subject. It was found that a driver at night can do remarkably well with only 1 percent of the normal nighttime luminance. At this level it was found that the subjects elected to position their vehicle slightly away from the shoulder on the road (four-lane freeway). This study pointed to the need for investigating selective degradation of the visual field rather than a general over-all reduction in luminance.

The second study partitioned the visual environment into 15 discrete areas of the roadway and studied driver performance on two types of roads, one with good center and edge linings and one without such markings. The roadway was selectively illuminated with a multi-lamp rack, and the luminance at the driver's eyes was controlled by a Polaroid eye mask. In this study, the night driver was even more severely visually degraded than in the first study, and was allowed only a small area on the road by which to drive.

It was found that different drivers preferred to select different control responses as their dominant response and were consistent in the use of this response over luminance levels. It was further found that velocity selection was determined by the distance of the available information, whereas velocity maintenance (variance) was a function of the angle of the available information. The results also indicated that the distance of the available information affected lateral control. It was found that, of the 15 areas tested for, the lamp placements located approximately 75 ft away produced the lowest variability in velocity and steering-wheel movements and the highest average velocity. This indicates, for this experiment, an optimal location of information in terms of preference and control. Insofar as the angle of the lamp placement is concerned, those that fell conveniently on a lane marker resulted in a compensatory tracking type of behavior (high velocity,

low variance), whereas those lamp placements that did not fall conveniently on a lane marker resulted in a search-type of behavior. It appeared as though the subjects searched for lane markers because they were the feature of the roadway with the highest contrast. This conclusion is supported by the data comparing the performance of drivers on the lined road with the performance of drivers on the unlined road. There was no evidence of tracking-type behavior on the unlined road for any of the lamp placement locations.

In the third study the visual environment was partitioned according to distance viewing constraints in order to provide a clearer statement of the effects found in the second study. Partitioning the visual environment into elements with distance constraints was accomplished by the use of a veiling luminance device which cast a field of glare onto a screen in front of the driver which was then used to create "windows" of available viewing area on the roadway. Subjects were asked to select a comfortable speed for a given viewing area, or to elect a minimum area they preferred to have as available when driving a determined velocity.

The results of this study indicated, in agreement with Study 2, that subjects preferred information located approximately 75 to 100 ft away for velocity selection. Selected velocity generally increased with an increase in the minimum allowable sighting distance, the maximum allowable sighting distance, or the region defined by these two points. When elapsed times to arrive at points of available information were examined, the data show that driver allowance for time was very nearly linear with respect to preview distance and velocity. Finally, the data indicated that information beyond 90 ft from the driver is of relatively less value for desired velocity.

In this case the tracking task is defined as similar to compensatory tracking in that the subject attempts to minimize a measure of error that is to the vehicle's position with respect to the relatively invariant road markings.

The final study was exploratory research on the eye movements of the day versus the night driver. A technique is described whereby a driver's eye fixations can be recorded onto 16-mm movie film superimposed on the scene he is looking at. In general, it was found that drivers tend to drive with their focus closer in front of the vehicle at night than during the day. Differences in visual search patterns were also suggested for night as contrasted to day driving by these data. The technique used in this exploratory research shows a great deal of promise for helping to better describe the visual information sensing characteristics of the night (as well as day) driver, his ability to read road signs, detect hazardous conditions, etc. Clearly, a great deal of future research will take advantage of this approach.

When the four studies are looked at together, some general conclusions can be made concerning the state of knowledge about defining the informational needs of the night driver. To begin with, it appears that the approach of subdividing the visual environment into elements and testing each of these elements for their effects on driving performance is a promising one. The approach is promising because the studies completed have shown that specific elements have selective effects on different parts of the driving task. If one could completely relate which elements affected which subtask of the driving task, one could describe accurately the information requirements of the night driver. Note that the visual environment can, and should, be partitioned in many more different and potentially promising ways.

From the results of the four studies it is concluded that the level of illumination on the road is not the most important factor to consider when attempting to provide sufficient information to the night driver. It appears that a far more important factor to consider is the availability of monitoring specific areas on the roadway. If the night driver is provided the capability for seeing a region of roadway approximately 75 to 90 ft in front of himself and some capability of seeing the lane markings on either side of the road, he will be able to, in general, select a desirable velocity, and maintain that velocity with little variability. Added luminance provides greater protection against unexpected hazards, but adds little to better driver control. It might be noted that normal low-beam headlamps provide the capabilities mentioned. It should be stated, however, that these conclusions are made only for the conditions under which experimentation took place—namely, no other traffic present.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

This research project was concerned with determining the visual information needed by the driver at night. The term "visual information" can, unfortunately, refer to as wide and diverse an interpretation as one would care to make. Therefore, "visual information" is defined here as the elements in the visual environment of the nighttime driver which serve as the input for a particular class of control activity. The visual environment is then defined as that part of the nighttime environment that a driver is potentially able to see. Implicit in this definition is the idea that the visual environment can be described either in visual terms (contrast, luminance, solid visual angles, etc.) or in spatial terms (distance, angle, width, location).

The specific classes of control activity of interest in this research included lateral control of the vehicle, longitudinal control of the vehicle, and tracking ability.

To specify the information needed, it is first necessary to specify the elements in the visual environment from which the "needed" cues can be determined. However, the visual environment may be partitioned into elements by any number of different criteria, and, depending on the criterion by which the environment is partitioned, the elements "needed" by the night driver may vary extensively. Also, it is hypothesized specific elements relate to specific control performance and the level of information will affect the level of control. It is reasonable to expect that different visual elements may have differential effects on different control modes. Lateral control, longitudinal control, route guidance, and emergency control may call for different levels of different elements.

For example, numerous studies have attempted to ascertain the role of roadway elements in accidents. In such studies, the elements studied are the physical features of the driving environment which are independent of any specific action on the part of the driver (i.e., whether he is looking at these elements or whether he is traveling fast or slow, etc.). When this approach is taken and the elements of the visual environment are equated with the physical features of the roadway, the data of such studies suggest the following:

1. Sharp curves exhibit higher accident rates than flat curves.
2. Steep grades exhibit higher accident rates than moderate grades.
3. Edge lining is an accident-reducing feature.
4. Wider shoulders are safer than narrow shoulders.

(This list does not pretend to be complete or comprehensive. It is intended only to serve as an example.) These conclusions imply that the nighttime driver would benefit by receiving the information contained in these elements of the visual environment—namely, information about sharp curves, steep grades, roadway edges, and shoulder widths.

This method of analyzing elements of the visual environment can be useful to the design engineer, for he can use this information in designing future highways with wider shoulders, less steep grades, less sharp curves, and pavement edge marking. But for the highway engineer who must usually contend with an existing system of highways, this information is of use only for providing highway signing, unless he can afford to have major construction work done on the highways. Studies based on roadway elements allow nothing to be said about the variant conditions in the driving environment, illuminating one area of road surface more than another area, the amount of contrast needed,

Independent Variables	Experiments: Chapter 2	Chapter 3	Chapter 4	Chapter 5
Illuminance Level				
Normal	X		X	X
Degraded	X	X		
Road Geometry				
Normal	X			X
Angular Constraint		X		
Distance Constraint		X	X	
Type of Highway		X		X
Task Instruction				
Normal	X	X	X	X
Lateral Control	X			
Longitudinal Control	X			

Figure 1 Independent and dependent variables studied in each department

etc. Therefore, specification of "needed" elements in the visual environment is entirely dependent on the method for partitioning the visual environment. Obviously, only those elements included in the partitioning of the environment can be considered when designating "needed" elements.

In the research that follows, the visual environment was partitioned into elements for investigation by four different methods (Fig. 1). The first experiment investigated the over-all brightness level of the visual environment for the nighttime driver. This procedure equates the elements of the visual environment to the levels of illumination tested, and allows a direct assessment of which elements (levels) are needed by the nighttime driver.

The second experiment investigated 15 discrete elements (elliptical areas) in the driver's visual environment. These areas were defined by a distance-angle location from the driver. Each area was investigated for its differential effects on control responses, and, as such, a definition of which areas are "needed" by the nighttime driver can be only suggested at a relative level.

A similar partitioning of the visual environment was also done in the third experiment. Fifteen elements were investigated for their relation to velocity selection and maintenance. These elements were full lateral viewing areas of the roadway defined by their distances from the driver Conclusions concerning these elements must be in terms of their ability to allow a driver velocity selection and control.

In the previously mentioned three experiments, the method of investigating informational needs of the nighttime driver was to conceive of the visual environment, partition it into elements according to some criterion, and investigate differential effects of these elements In each instance the visual scene was degraded to affect control of elements presented to the driver.

The final study to be reported is the first of probably a long line of research to be done using an eye-marker camera to record on film a driver's fixations in the visual environment. This technique is uniquely useful in that partitioning of the visual environment into elements need not be done until after the data are collected. Partitioning may then be done at any time and according to any rule that appears to have promise. Informtional needs, however, must be inferred from the driver's selection process, and, until the selection or scanning process is fully understood, only guesses can be made concerning actual "needs" The criteria for elements used in this particular study were invariant quadrants on the roadway defined by angle and distance ahead of the test vehicle.

Through these combined research efforts, then, knowledge was sought on which elements in the visual environment are needed by the driver at night.

CHAPTER TWO

DRIVING PERFORMANCE UNDER NIGHTTIME CONDITIONS OF VISUAL DEGRADATION

The question of how much light should be provided for the performance of visual tasks has been a point of contention among illumination experts since it became economically feasible to provide large amounts of illumination. Disagreement on this point is still very much alive and stems at least in part from lack of accord regarding valid criteria for evaluating particular task requirements. Speed of hand movements, heart rate, and eye blink rate measures have been used by some researchers; others have preferred visual acuity and brightness contrast threshold indices.

This dispute originated with the experiments of Luckiesh and Moss (1934) at the General Electric Laboratories. Using nervous muscular tension, blink rate, heart rate, and visual acuity as performance measures, they arrived at a table of recommended illumination values for many industrial tasks. Tinker (1935) questioned their performance criteria and thus disagreed with the conclusions drawn. Tinker also objected to the claim that visual acuity was improved with higher illumination values because Lythgoe (1932) had shown visual acuity increases linearly to approximately 10 ft-L (ft-lamberts), but then reaches an asymptotic value. This was taken to mean that no appreciable gain in visual acuity could be made after about 40 to 50 ft-L of illumination, even allowing for individual differences.

One of the earliest night-driving experiments under actual highway conditions was conducted by Norman (1944). Drivers were studied on two-lane highways during the day and night using vehicle speed and lateral position as performance measures. Conditions of lighting from overhead lamps along the highway and no overhead lighting were employed. The results indicated that overhead roadway lighting did not affect the driver's travel speed, and caused only a small reduction in the variability of lateral positioning. The conclusions drawn from this study were somewhat limited because average speed over a given section was calculated on the basis of stopwatch readings and lane position was estimated by an observer. In a more recent highway study, Rockwell and Lindsay (1965) reported that subjects elected lower speeds with less variability under reduced lighting levels. Steering activity was unaffected by lighting, but gas-pedal movements were reduced by lower lighting levels.

This research tried to provide more accurate quantitative information on the problem of adequate nighttime highway illumination. Because vehicle speed and lane position are generally accepted as the two most critical outputs of a driver's control actions, they were studied in relation to different luminance levels. This study was designed to determine whether degradation of the visual input by reduction of luminance produces a noticeable difference in a driver's lateral positioning of the vehicle or in the selected driving speed. The study also explored the effect of task loading by varying the emphasis placed on two main objectives of driving behavior: positioning the vehicle in the center of the lane, and maintaining a constant high speed.

METHODOLOGY

Subjects

The 16 male subjects participating in this study had valid operator's licenses and emmetropic vision. The ages of the subjects ranged from 18 to 54, with a mean of 24 years. The subjects were motivated by being told that they could increase their monetary earnings by remaining alert and performing as well as possible. To have four groups matched for driving skill, all subjects were put through a daytime driving test to evaluate their driving performance

Apparatus

The research was conducted with a vehicle that was equipped to measure all control actions taken by a driver (e.g., deflection of the gas pedal) and the resulting speed and lane position. The speed measure was obtained through a tachometer attached to the drive shaft, whereas the lane position was measured by a new photosensitive device, the HiLi (Snider and Matanzo, 1965). This device measured the distance between the side of the vehicle and the white shoulder line as the vehicle moved along the road.

Because data were collected under highway conditions, it was impossible to control or manipulate ambient illumination levels per se. Thus, the manipulated independent variable was the density of the filtering interposed between the road luminance and the driver. Different degrees of visual degradation were produced with Polaroid plates mounted in a standard pair of optometrist frames worn by the subjects. The visual degradation frames are shown in Figure 2. The frames held two sets of plates, one set in each eyepiece The frames were completely adjustable for comfortable wearing and weighed slightly more than a regular pair of eyeglasses. Four different settings of filtering were used to give light transmission of 15, 7.5, 2.0, and 0.5 percent of that reaching the outside plate of each pair A sensitive light meter was used to measure the light entering the windshield from the roadway environment ahead. These measurements showed that the light entering through the windshield was fairly constant. This indicated that each subject received the same amount of illuminance on his eyes.

Experimental Design

The design used was a two-factor experiment with repeated measures on Factor B (Winer, 1962, p. 302) as shown in Figure 3. Factor B was the four levels of luminance, the value for any particular trial being prescribed by a Latin square. Factor A consisted of four driving tasks differentiated by their instructions. These are given as follows:

1. *Task 1*.—(CLP-ES. Constant Lane Position-Elected Speed) "You are to maintain the vehicle in the center of your lane. Speed is of little importance, so go as fast or slow as you please. Of course, stay within the posted speed limit (70 mph)."

2. *Task 2*.—(CLP-CS: Constant Lane Position-Constant Speed) "You are to maintain the vehicle in the center of your lane and also maintain the vehicle at a speed of 65 mph. Both tasks, I repeat, both tasks are of equal importance."

3. *Task 3*—(ELP-ES: Elected Lane Position-Elected Speed) "You are to drive to the next exit as you normally would."

4: *Task 4*.—(ELP-CS. Elected Lane Position-Constant Speed) "You are to maintain the vehicle at a speed of 65 mph Lane position is of no importance."

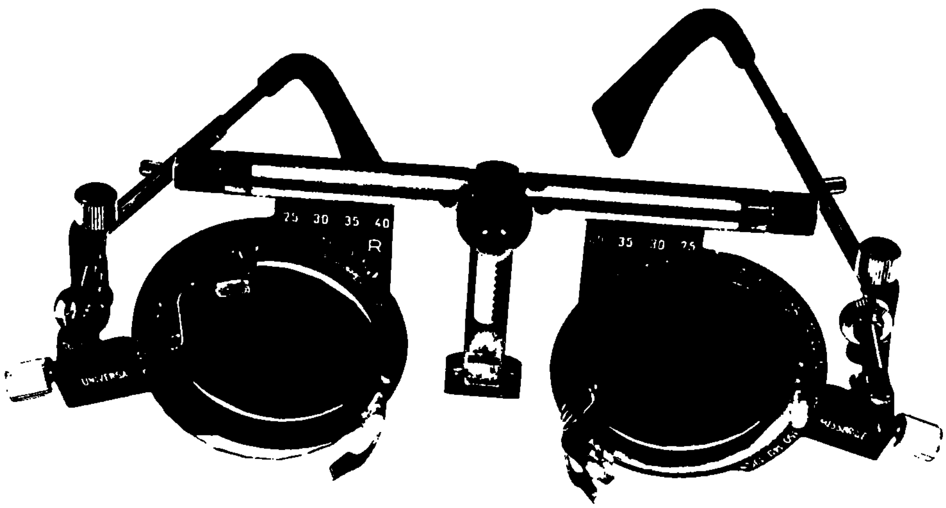


Figure 2. Visual degradation frames.

Subject		Luminance Level			
		L_1	L_2	L_3	L_4
Task 1	1	X_{111}			
	2	X_{112}			
	3	X_{113}			
	4	X_{114}			
Task 2	5				
	6				
	7				
	8				
Task 3	9				
	10				
	11				
	12				
Task 4	13				
	14				
	15				
	16				X_{ijk}

Figure 3. Experimental design.

Four matched groups were employed; each was assigned to only one task, with each group having four male subjects. The two dependent variables were vehicle speed and lane position.

Procedure

All data were collected on a level four-lane Interstate Highway between the hours of 12:00 midnight and 4:00 AM over a period of 2 months. This experimental situation allowed the study to be conducted during periods of light traffic and also eliminated any possible effects from the glare of oncoming vehicles. At the starting point, a tape recorder gave the subject for that night the instructions for his task. The visual degradation frames then were set to the first luminance level prescribed, and, immediately after the subject had adapted to that particular value, he started down the road for a trial. It should be noted that the subject had speedometer information at all times. This was accomplished by keeping the speedometer dashboard light at its maximum intensity. After 3 min of recording time, the experimenter asked the subject to pull over onto the shoulder. The experimenter then set the visual degradation frames to the next luminance level. This procedure was repeated 16 times for each subject. All subjects drove on the same stretch of road during the same early-morning hours.

RESULTS

Figures 4 and 5 show the speed and lane position performance curves of the four tasks for the four luminance levels. The speed is plotted in mph and the lane position is plotted in inches from the white shoulder strip. The solid horizontal lines mark the target speed of 65 mph and the target lane position of 30 in. from the white shoulder line. The luminance levels are given in mL, the amount of light reaching the pupil of the subject's eye for each setting of the visual degradation frames. The value of each luminance level was calculated from light measurements taken during the night trials. The mean values and standard deviations of the two performance measures are given in Table 1.

The analysis of variance summary of the speed measure is shown in Table 2. The task factor (A) was found to be significant at $p < 0.05$ and the luminance factor (B) and interaction term ($A \times B$) were significant at $p < 0.01$. No analysis of variance was performed on the lane position measure because a Min-Max test and a Kolmogorov-Smirnov test showed the data to be nonhomogeneous and not normal. Subsequent transformations of the data to square root and to logarithmic form also failed to satisfy the analysis of variance assumptions of homogeneity and normality. At this point, attention was given to a non-

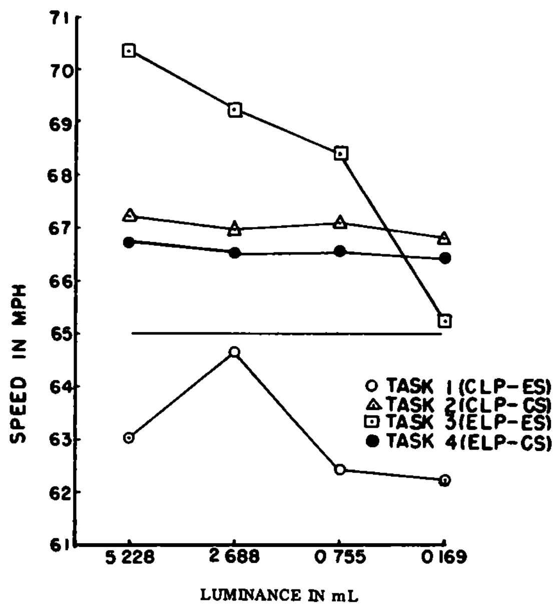


Figure 4. Vehicle speed as a function of luminance levels for each task group.

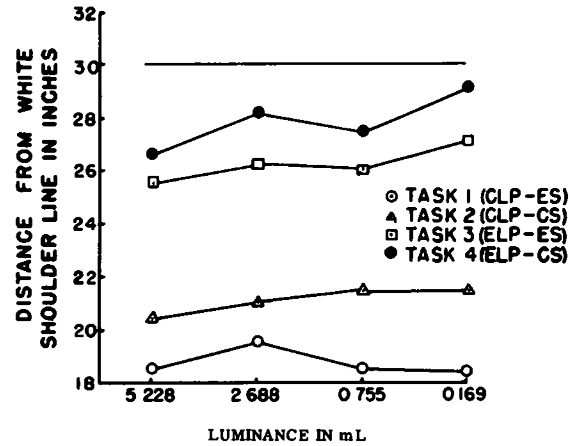


Figure 5. Vehicle lane position as a function of luminance levels for each task group.

TABLE 1

MEAN AND STANDARD DEVIATION VALUES FOR THE SPEED AND LANE POSITION MEASURES UNDER THE FOUR LEVELS OF LUMINANCE

	LUMINANCE LEVEL							
	L_1		L_2		L_3		L_4	
TASK	M	SD	M	SD	M	SD	M	SD
				LANE POSITION (IN.)				
Task 1	18.53	5.74	18.94	6.45	18.23	6.10	18.67	6.05
Task 2	20.31	7.13	21.01	7.17	21.54	7.46	21.72	7.02
Task 3	25.85	8.93	26.22	9.26	26.08	8.50	27.39	8.85
Task 4	26.78	9.36	28.15	9.98	27.62	10.99	29.12	9.80
				SPEED (MPH)				
Task 1	63.06	2.16	64.62	1.75	62.32	1.87	62.18	2.36
Task 2	67.14	1.27	66.96	1.36	67.09	1.41	66.82	1.50
Task 3	70.55	1 96	69.28	2.46	68.38	2.43	65.17	2.68
Task 4	66 88	1.23	66.70	1.15	66.76	1.21	66.53	1.56

TABLE 2

ANALYSIS OF VARIANCE SUMMARY FOR SPEED MEASURE

SOURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	*F* RATIO	*p* VALUE
Between subjects	464.06	15	30 937		
A (task)	247.42	3	82.473	4 568	$0.01<p<0.05$
Subject/task	216.64	12	18.053		
Within subject	135.36	48	2.820		
B (luminance)	32.14	3	10.713	6.822	$p<0.01$
A×B	46.69	9	5.187	3.303	$p<0.01$
B×subject/task	56.53	36	1 570		
Homogeneity Min-Max Test				7.385	$0.05<p<0.10$

parametric test, the Friedman two-way analysis of variance by ranks (Siegal, 1956, pp. 166-172). The results of the Friedman test applied to the main factors only are given in Table 3.

As a final analysis, the performance of Tasks 1, 2, and 4 was compared with that of Task 3. Because Task 3 had no specific instructions ("You are to drive to the next exit as you normally would"), the subjects in this group drove without any restrictions on their control behavior. This allowed a comparison to be made between the base line performance of Task 3 and the performance of the other three tasks as a percent deviation from the base line performance. Figure 6 shows the percent deviations for both the speed and lane position measures of Tasks 1, 2, and 4

DISCUSSION

The speed performance curves in Figure 4 show not only that the degree of visual degradation had an effect, but also that this effect was influenced by the performance goals of the task in question. For example, subjects in Tasks 1 and 3 drove at a slower speed for each succeeding increase in the degree of visual degradation, but subjects in Tasks 2 and 4 were unaffected by the increases in visual degradation One way of explaining this difference in the performance of four task groups of equal driving ability is by the instructions they received. Subjects of Tasks 1 and 3 were allowed to drive at their own selected speed. Both groups did what might be expected on the basis of their prior driving experience, for, as it became more difficult to see the roadway ahead, they drove slower. Task 2 and Task 4 subjects, however, who were instructed to maintain a speed of 65 mph, drove at a mean speed of 67 mph with a maximum standard deviation of 1.58 mph

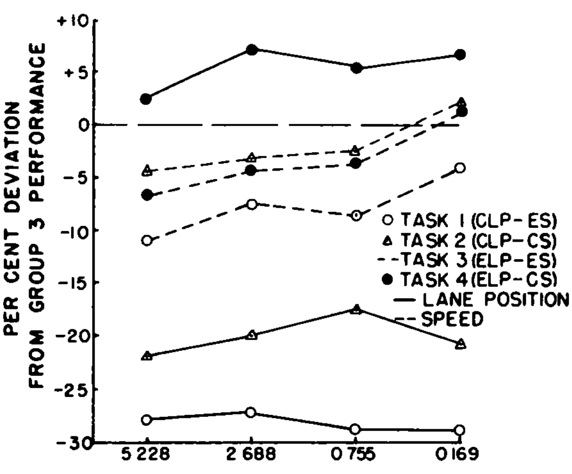


Figure 6 Vehicle speed and lane position as a percentage of Task 3 performance

TABLE 3

FRIEDMAN TWO-WAY ANALYSIS OF VARIANCE BY RANKS FOR LANE POSITION MEASURE

SOURCE	χ^2	PROBABILITY H_0 IS TRUE
Luminance level	8 70	$p=0\,014$
Task	12 00	$p=0\,000072$

A similar interpretation can be made of the results of the lane position measure shown in Figure 5. The presence of the large constant error between the target distance of 30 in. and the distance selected by the subjects performing Tasks 1 and 2 suggests that there was a constant visual angle position error involved in steering the vehicle. This could have been caused by the driver's position on the left-hand side of the car, especially if he used the shoulder line as his guide for keeping the vehicle centered in the lane A gradual positive slope of the performance curves indicates that the driver steered farther away from the shoulder as it became more difficult to see the roadway. Because the subject drove on a four-lane highway with a median strip approximately 30 ft wide, he selected what he felt to be a safer position in his lane Oncoming traffic posed no problem, so he had only to stay alert for any vehicles attempting to pass This conclusion is supported by the performance of Tasks 3 and 4 Neither group was required to drive in any particular portion of the lane They only had to stay within the outside (right) lane. Thus, subjects of Tasks 3 and 4 positioned the car farther away from the shoulder line than subjects of Tasks 1 and 2 for all degrees of visual degradation. The increased levels of visual degradation, however, still caused subjects of Tasks 3 and 4 to move even farther away from the shoulder line.

CONCLUSIONS

On the basis of this study, it can be concluded that the amount of reflected road light reaching the driver's eyes influences his speed and lane positioning behavior Low luminance levels cause the driver to travel at slower speeds and produce a response to steer toward the center of the road. This study also demonstrated that a driver is capable of maintaining a constant speed and lane position at extremely low levels of luminance (0 168 mL). This was shown by the performance of subjects of Task 2, which time-shared both control tasks with little decrement to the performance of either. This result may be explained in part by Wohl's study (1961) which reported similar steering performances at different speeds. In addition, the performance of Task 2 shows that maintaining a constant lane position does not hinder the driver's ability to simultaneously maintain a constant speed.

CHAPTER THREE

THE EFFECTS OF SELECTIVE AMOUNTS OF VISUAL INFORMATION ON LATERAL AND LONGITUDINAL CONTROL RESPONSES OF THE NIGHT DRIVER

All driving research that describes the information given to the subject, describes the subject's task, and makes an attempt to relate the two also has implied some description of the environment and some description of the driving task. That is, if the subject's primary task is to drive in the center of his lane, his chief task is one of lateral control.

To define those elements in the visual environment needed by the night driver to perform the driving task adequately, a description of the driving task and a description of the visual environment are needed.

For this experiment, the driving task was described simply as a time-sharing task consisting of a lateral control task and a longitudinal control task. It follows then that the elements in the visual environment needed for information may then be described by the combination of those elements in the visual environment needed for maintenance of longitudinal control and those elements needed for maintenance of lateral control.

To provide for an investigation of "elements" in the visual environment, the environment was partitioned into 15 discrete areas, each of which was tested for its specific effects on longitudinal and lateral control. The method of partitioning the visual environment into 15 discrete areas (or elements) was based on defining the elements in terms of their distance-angle relationship to the drivers.

Performance of the driving task (composed of a lateral control task and a longitudinal control task) was evaluated by recording the subject's and the vehicle's responses. Performance of the lateral control task was indicated by the variability in steering-wheel movements and variability of the lane position of the vehicle. Variability in velocity was used as a measure of performance in the longitudinal control task.

Two luminance levels were investigated to assure that the effects found were not entirely dependent on one specific level of illumination This was important because in order to develop a methodology that was sensitive to the different "elements" a highly artificial driving situation was produced Some estimate, therefore, was needed for the generality of the differences found due to the luminance level

Initial analysis of the data indicated that the road markings were the dominant physical feature of the roadway which mediated the subject's responses. Consequently, it was decided also to investigate just how extensive the effects of road markings were on the degraded night driver's responses. A similar study, therefore (Task 2), was performed on a road with no markings on it.

METHODOLOGY

Subjects

Nine male subjects were used in this experiment. With the exception of one, all were college students between the ages of 20 and 25. The subjects were paid for their time. All nine subjects were tested under the Task 1 experimental conditions (described as follows), although two subjects were unable to complete enough trials to be useful in the data analysis. Seven of the nine subjects were tested under the Task 2 experimental conditions, following completion of the Task 1 portion of the experiment.

Apparatus

The research vehicle used in the data collection was an instrumented 1963 Chevrolet (Fig. 7). In it was equipment capable of recording on photographic film the velocity, lane position, and steering-wheel movements. In addition, the front of the vehicle carried a multi-lamp rack (MLR) which was used to selectively illuminate small areas in the visual environment of the night drivers.

Pilot work indicated that, to obtain any differentiation of effects due to lamp placements, the driver's vision had to be severely degraded. This was accomplished by having the subject wear a swimming mask fitted with two polaroid sheets crossed at 90°. Figure 8 shows an example of how a single lamp placement providing information appeared to the subject

For the purposes of this study, 15 narrow-beam (2° beam angle) aircraft landing lamps were mounted on the multi-lamp rack. These 15 lamps were adjusted to illuminate areas, as shown in Figure 9. The lamp locations were numbered, as indicated, strictly for reference.

Procedure

Two separate tasks were used in this study. The first task was conducted on Ohio Route 3-C (Ohio 3-C) between Westerville and Ohio 37. This section of wide two-lane blacktop highway had only slight curves and hills, and had wide shoulders and white lines on the center and side edges of the road. The second task was conducted on a country road paralleling Ohio 3-C and of approximately the same length. The road was slightly more than one lane in width, with no line markings of any kind, and with very poor shoulders.

There were two experimenters in the vehicle with the subject. The experimenter in the front seat controlled the lamp bar and the headlights. The headlights were turned on by the experimenter whenever the subject lost his way

Figure 7. The instrumented vehicle.

and whenever other cars approached the test vehicle. The experimenter in the back seat took notes on the proceedings and keyed test conditions onto the film.

To provide familiarization, the subject drove the 20-min trip from the laboratory to Interstate Highway 71 (I-71) and Ohio 37. A coffee break gave the subject a chance to fit the goggles on his face so that they would be comfortable during the testing. The subject was then given approximately 10 min to adapt to the mask before testing began. The subject was instructed to drive as though he had found himself in some nonexperimental situation (e.g., damaged headlights) and was simply attempting to get somewhere. He was also told to inform the experimenters if at any time his eyes became tired, and he wanted to take a break. For each trial, the car was brought to a stop, the experimental lamp placement turned on, and the subject instructed to begin when ready.

Each subject in Task 1 received a different random order

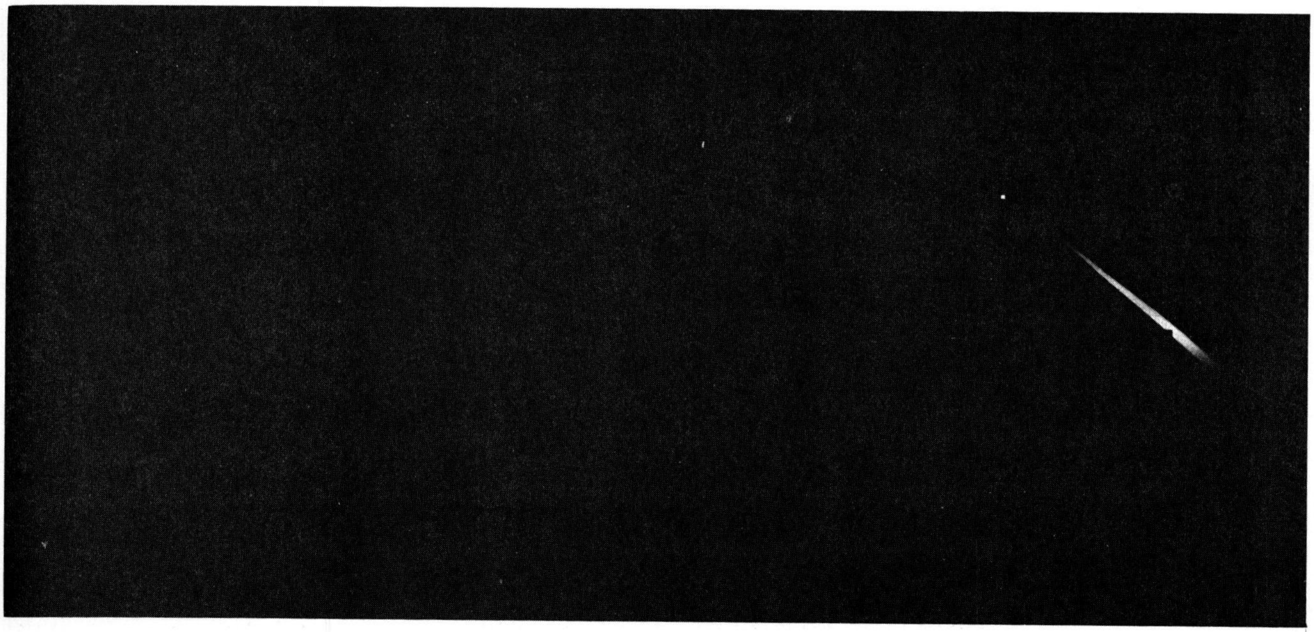


Figure 8. How a single lamp placement providing illumination appeared to the subject.

of presentation for the 15 lamp placements at the brighter intensity. When these 15 trials were completed, a second coffee break was taken, after which the 15 lamp placements in differing order were run at a dimmer intensity.

In Task 2 only the seven even-numbered lamp conditions were run (Fig. 9), and these were run only on the brighter lamp intensity. The absence of white lines made it impossible to obtain a lane-position trace and, therefore, steering-wheel movements were the only measure of lateral control. The same general procedure that was used in Task 1 was used in Task 2. Actual trials took considerably more than the 4 min of data desired, as the trial was voided during the times when other vehicles were approaching.

RESULTS

A comparison of the bright-lamp placement trials versus the dim-lamp placement trials indicated that each subject's performance was generally consistent on one or more control responses. Table 4 gives the rank order correlation coefficients between the bright- and dim-lamp placement trials for each of the dependent variables measured for the four subjects tested at both levels of illumination. Clearly, subject G.R. was highly consistent in his use of steering-wheel movements over the levels of illumination, whereas subject D.M. was consistent with the use of his lane position. It is interesting to note that each subject chose different controls with which they were consistent. These results indicate that the individual subjects did exhibit consistency between the two illumination levels, although not for all control responses. Certainly, this is understandable because the driving task was originally conceived of as consisting of a time-sharing task between lateral and longitudinal control. Obviously, if one cannot perform both tasks, it is conceivable that one might pick one of the subtasks to which he devotes his energies.

The specific control responses were next analyzed for their sensitivity to different individual lamp placements, using the data from the bright-lamp placement trials. When the effects of the different lamp placements are compared separately, as shown in Figure 10, it is evident that some lamp placements resulted in higher velocities than did other lamp placements. Figure 10 shows that the lamp placements located approximately 75 ft away from the driver (Nos. 6 to 10) generally resulted in the highest velocities. Analysis of variance shows this effect to be significant.

Analysis of the velocity variance data shows that the angle of displacement of the lamp produced differential effects, whereas the distance of the lamps did not. Figure 11 shows the velocity variance for the subjects grouped and illustrates the effects found. This effect also was significant.

This possibly indicates that selection of velocity depends on the distance of the available information, whereas the maintenance of velocity is a function of the angle of the available information.

The lateral control response data shows that the amount of variability in steering-wheel movement differs for the separate lamp placements and is most differential with respect to the distance of the lamp placements. Figure 12 shows the variability produced with each lamp placement. It can be seen that, in general, the lamp placements 75 ft away (Nos. 6 to 10) produced the least variability, those

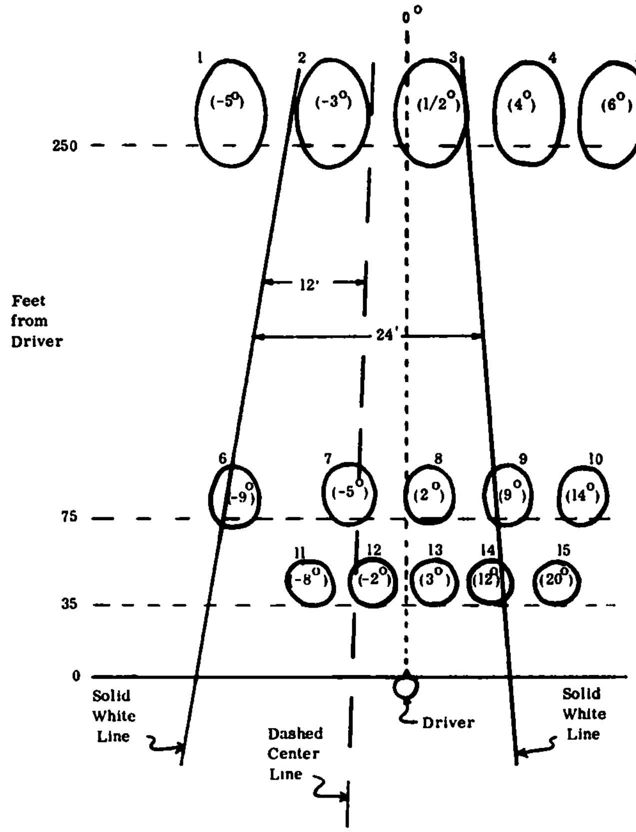


Figure 9. Lamp placements.

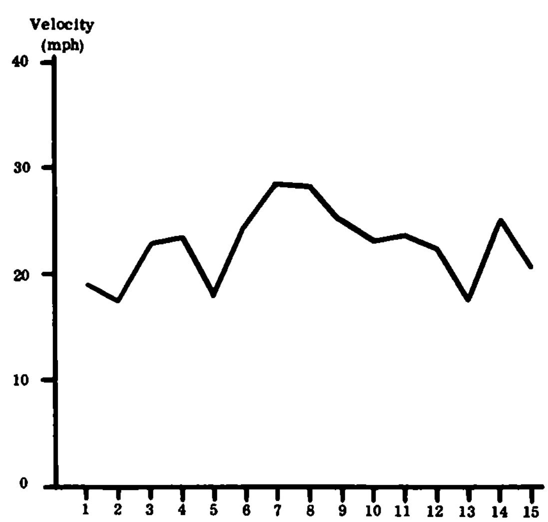


Figure 10. Mean velocities for the bright-lamp placement trials

TABLE 4

RANK CORRELATIONS BETWEEN PERFORMANCE OVER BRIGHT AND DIM ILLUMINATION TRIALS

DEPENDENT VARIABLE	SUBJECTS G.R.	D.M.	R H	N T.
Mean velocity	0 101	0 462	—	−0 085
Velocity variance	0 193	−0.049	—	0 733
Steering-wheel variance	0 911	0 536	0 429	0 315
Lane position mean	0 243	0.860	−0 099	0 685
Lane position variance	0.254	0 248	0.064	0 127

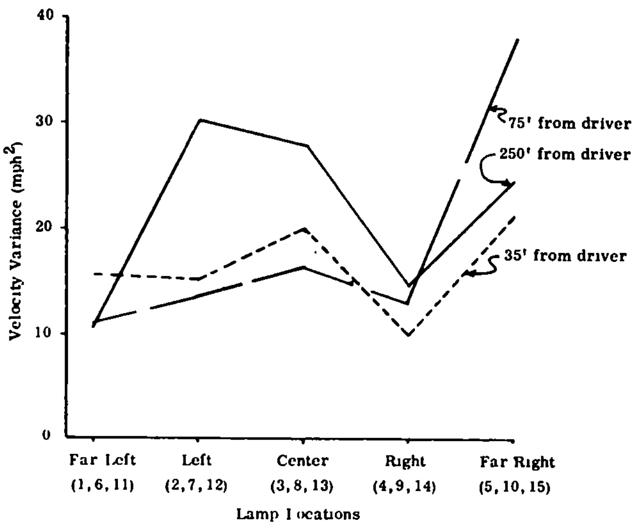


Figure 11. Velocity variances of the grouped subjects, plotted by lamp locations.

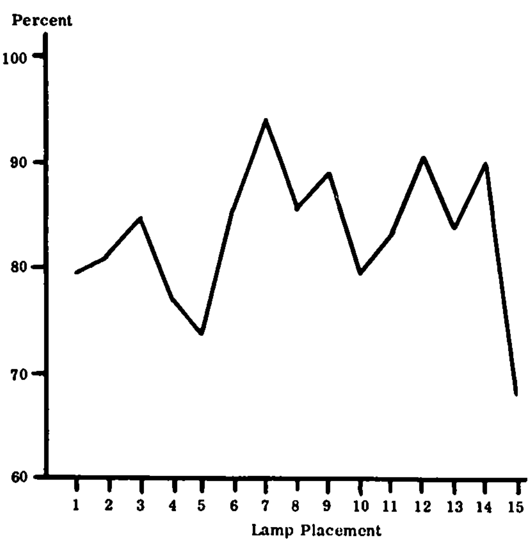


Figure 13. Percentage of time spent in correct lane with the bright-lamp intensities for Task 1

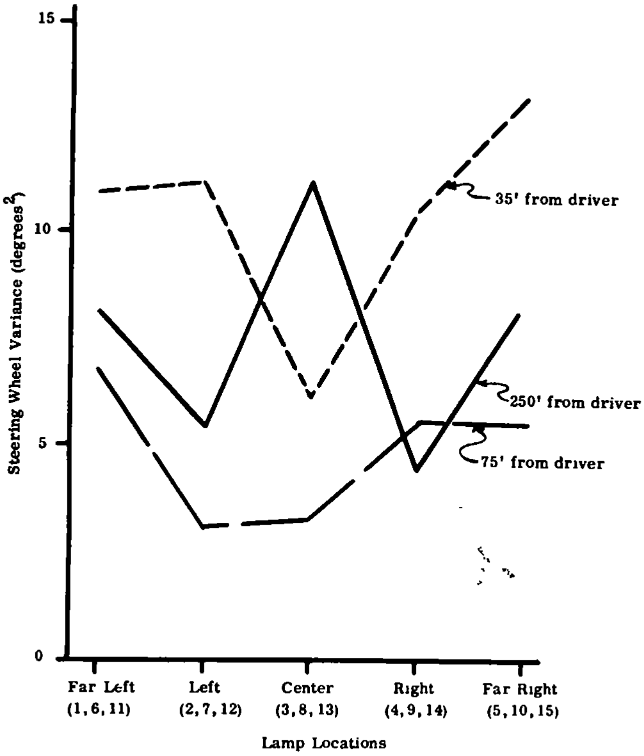


Figure 12. Average steering-wheel variance for the location of the lamp placements with respect to the vehicle

placed 35 ft away somewhat more variability (Nos. 11 to 15) and those placed 250 ft away (Nos. 1 to 5) the largest amount of variability.

Another lateral control response is the amount of variability in lane position. Because of the large amount of variance in all trials due to the severe degradation of the visual environment, variability in lateral control was computed from the percentage of time spent in the correct lane The results are shown in Figure 13.

This figure shows that a higher percentage of time was spent in the correct lane when the subjects were driving under those lamp placements located approximately 75 ft from the driver (Nos. 6 to 10) or under these lamp placements conditions when the lamp placement fell directly on a white edge marking (Nos. 12, 14).

Once again, it appears that the lateral control subtask is affected by the distance of the lamp placements.

When the data of the subjects driving on the lined road were compared with the data of the unlined road it was evident that the lane markings allowed a greater variety of responding to occur. The velocity for each of the lamp placements on the unlined road was approximately 8 mph, with little effect between the lamp placements. Analyses of their steering-wheel movements support the same conclusions. Consequently, the degradation was so severe as to mask any placement effect on steering-wheel effects.

To summarize, it was found that the velocities selected were affected by the distance of the lamp placements, whereas the maintenance of velocity (longitudinal control) was affected by the angle of the lamp placement. The lateral control task, as measured by steering-wheel movements and the percent of time spent in the correct lane was affected by the distance of the lamp placements

DISCUSSION

The results of this research have some very interesting implications for future designers of highways and vehicles and for future researchers in this area.

It appears that the technique of relating specific classes of information to specific control tasks is highly promising, even in such a "black box" system as the driver-vehicle-roadway system. This research has shown that the maintenance of particular subtasks of the driving task is related to particular subclasses of information in the driver's visual environment.

It has been demonstrated that velocity selection appears to be a function of distance of available information, whereas velocity maintenance (i.e, low variability in velocity) is a function of the angle of the available information.

Because it was determined that, under these severely degraded conditions of experimentation, drivers were most dependent on road markings, it is reasonable to hypothesize that it is these road markings (or lane definitions) that are instrumental in a driver maintaining longitudinal control Furthermore, if this is the case, then those designers who wish to maximize traffic flow by minimizing the variability in a driver's selected velocity might be well advised to provide distinct lane markings. Traffic flow, however, is generally conceived of in terms of vehicles following one another at some optimal headway, and this experiment did not investigate the effects of a car-following task.

Analysis of the velocities selected by the drivers for the different lamp placements shows their relationship to the distance of the lamp placements. It is interesting to note, however, that the relationship is not monotonic. Both the lamp placements 250 ft away from the driver and the lamp placements 35 ft away from the driver resulted in lower selected velocities than did those lamp placements located 75 ft away from the driver. These results may all be to the specific constraints of the experiment (suggested by velocities obtained); moreover, lamp placements 75 ft away from the driver might have produced a spot of light large enough and bright enough to illuminate visual cues with enough intensity to be recognized, whereas lamp placements 35 ft away from the driver may not have produced as wide a spot of light, and lamp placements 250 ft away from the driver may not have produced a bright enough spot of light. (The lamps were equated for intensity at the three distances by a light meter, but contrast was difficult to maintain constant because of variability in atmospheric conditions such as dust and smoke.) It is possible then, that current headlamp standards are adequate for selection and maintenance of velocity, although the question is still open on illuminating potentially dangerous or unexpected obstacles.

The maintenance of lateral control (as measured by the variability in steering-wheel movements) is a function of the distance of the information. Once again, the results show that this relationship is not monotonic, and, once again, it is the lamp placements approximately 75 ft away from the driver that yield the lowest variability in lateral control. If these results can be generalized from the severely degraded experimental conditions to the normal night-driving conditions, then present standards for headlamps are quite adequate for providing the night driver the information that is needed to perform the lateral control task in driving.

A tracking-type of behavior was also found in these data. The performance of the subjects under lamp placement No. 14 (located to the right of the driver near the vehicle) showed selection of a high-velocity and a low-velocity variance. This indicates that a driver is able to do the driving task well under the isolated lamp placement by resorting to a tracking type of strategy (rather than a time sharing of lateral and longitudinal control). It is significant to note that this type of behavior was not found during testing on the unlined roads.

This experiment does not pretend to establish the necessary and sufficient information needed for the specific control tasks in driving, but it does establish that certain elements in the visual environment of the night driver are related to the adequate performance of control subtasks in driving. Obviously, it must be remembered that this experiment is analytical and, as such, an assumption it made is that the total information (needed and obtained) from the visual environment is the sum of the elements of the visual environment. To the degree this assumption is false, the significance of the approach taken in this experiment is reduced.

Finally, because the approach taken in this experiment seems promising, additional research would be profitable in which elements taken in combination could be tested for differential effects on driving control tasks and thereby bridge the analytical assumptions made in the present research

CHAPTER FOUR

THE RELATIONSHIP BETWEEN VELOCITY AND THE NIGHT DRIVER'S SIGHTING DISTANCE

The previous experiment investigated the effects of different specific areas of information on lateral or longitudinal control responses. In this experiment an investigation was made of specific visual areas varying only in distance and size (excluding angle) for their effects on a driver's selection of velocity. The visual environment was partitioned into strips of information, or windows, that were bounded by a minimum sight distance and by a maximum sight distance from the driver.

One of the more significant questions regarding driver informational needs is, "How far does a driver sight ahead for selection of velocity?" This sighting distance may be characterized by some distribution of sampled distances from which a driver obtains information for velocity selection.

Wohl (1961) presents a theoretical analysis for a concept of forward reference distance. In his analysis, he assumes that this forward reference distance is directly proportional to velocity (or desired velocity). Several studies have been performed which are relevant to this concept.

Senders (1967) manipulated sampling rates for given velocities by periodically raising and lowering a visor attached to a helmet that his subjects wore while driving. He reports that sampling rates of approximately ½ sec every 3 sec is sufficient to maintain adequate velocity control at 50 mph. This may indicate that a driver is able to do without information farther than 3 sec away. Thus, his sighting distance at 50 mph would be somewhere less than 210 ft. Gordon (1966) conducted an on-the-road experiment to determine the features of the road and terrain to which the driver responds. An aperture was used to restrict vision and to isolate the input information; a head-mounted camera was used to record where the driver was looking. It was found that drivers, other than attending to road markings, exhibited no systematic scan patterns that could be interpreted as forward reference information. The study concluded that a forward reference distance hypothesis may be useful as an abstraction, but has little practical application.

Both studies present interpretive difficulties. Because speed was a dependent variable in Gordon's situation, it was difficult to determine which of two possible driving modes existed. Did the subject set his speed on the basis of available visual information, or did he select a speed and then decide to what information he would attend? This latter consideration also applies to Sender's study.

The present study was designed to determine if a velocity-sighting distance relation exists for the night driver. Both of the previously mentioned driving modes were tested using an apparatus which did not overly encumber the driver. It was intended that, with these conditions, a sighting distance could be determined and an evaluation of the forward reference distance hypothesis could be performed

METHODOLOGY

Subjects

The subjects were six male college students. Their ages ranged between 19 and 23 years and their driving experience between 3.5 and 7 years. Testing took approximately three nights per individual and was completed within 10 weeks. The subjects were paid for their services and were encouraged through task instructions to drive as best they could. Only four of the original six subjects were available for testing on all three tasks.

Apparatus

An instrumented 1963 Chevrolet was used in this experiment. It was equipped to record velocity, steering-wheel movements, and gas-pedal movements (see Rockwell and Snider, 1965, for a complete description of this vehicle).

In addition, a system termed the selective visual field attenuator (SVFA) was developed to control sources of visual input to the driver. It consisted of a veiling luminance device (VLD) and a multi-lamp rack (MLR) (see Fig. 14). The subject looked through the VLD at the road which was illuminated by the MLR mounted on the front of the vehicle that he was driving. The slanted glass made it possible to interpose a luminous field between the subject and the target. Both the MLR and the VLD were energized and controlled from within the vehicle.

The subject was seated so that his eyes maintained a height of 49 in. above ground level. This was accomplished by a padded brace installed in the roof of the vehicle, against which the subject kept his head. The subject then had an interposed veiling luminance which affected a lateral width of approximately 35° and a vertical width of approximately 15° of his visual field (see Fig. 15). The diffuse top panel of the VLD was in a horizontal position and, as such, formed a horizontal table, on top of which strips were placed to allow a "window" of visibility in the glare fields. Through this "window" the subject could see the roadway. The top of the "window" determined the furthest point on the road the subject could see; the bottom of the "window" determined the closest point on the road the subject could see. The former was referred to as the maximum allowable sighting distance (X_2), and the latter was referred to as the minimum allowable sighting distance (X_1). By varying the size and location of the strips, the location on the roadway visible

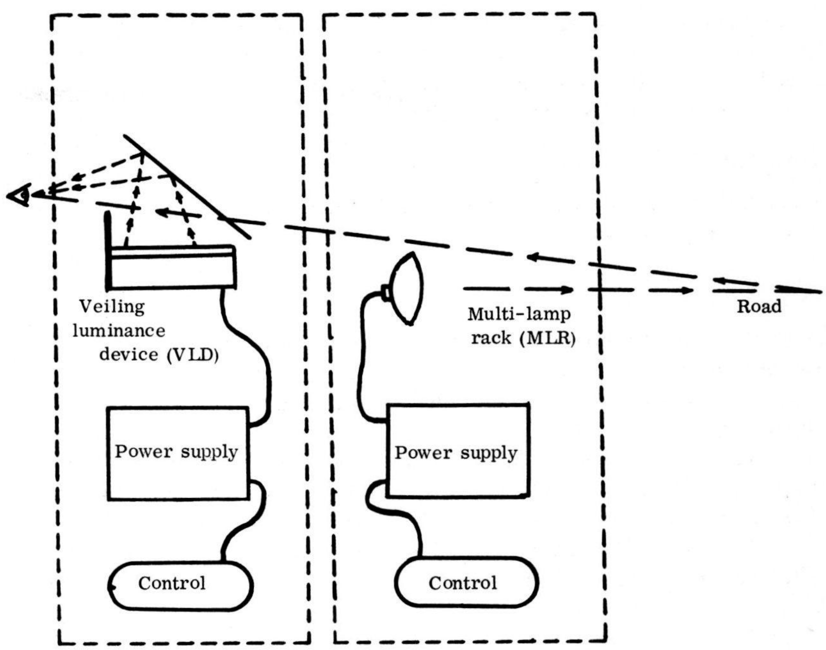


Figure 14. Selective visual field attenuator system.

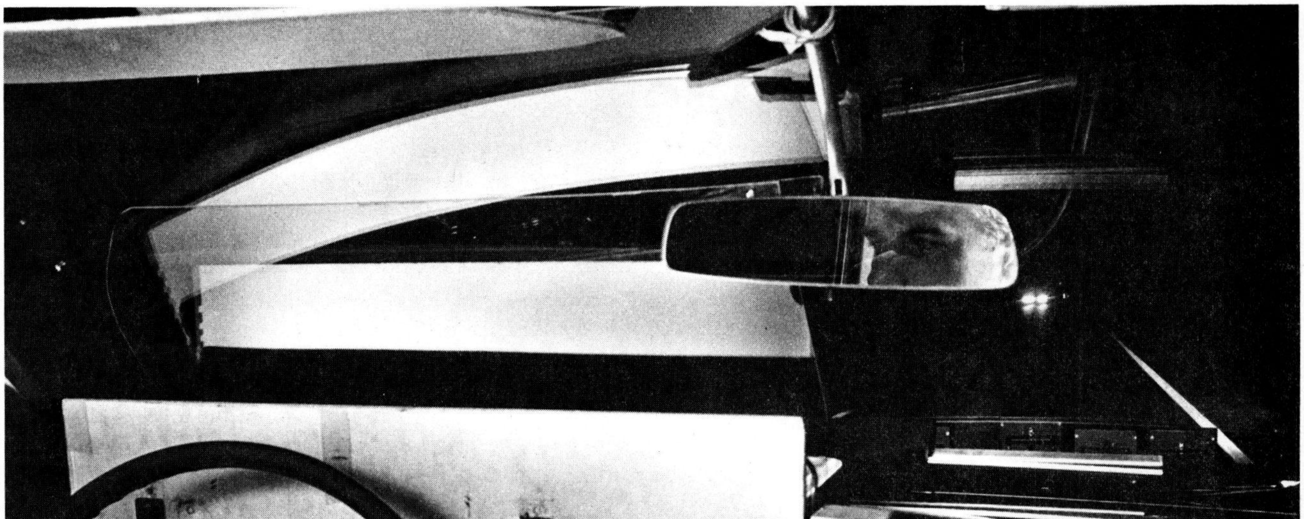


Figure 15. Veiling luminance device.

to the subject was controlled. The experimenter was seated adjacent to the driver and had a full view of the roadway ahead of him. The controls were conveniently housed in a flat box that was controlled by the experimenter.

Procedure

Each subject was presented with three driving tasks The tasks were as follows.

Task 1

A total of 15 combinations of viewed area and minimum sighting distance were used. These were generated from three strip viewing widths and using minimum allowable sighting distances of 30, 45, 60, 90, and 150 ft for each stop. The combinations of viewed areas of the highway are given in Table 5. The lateral visual angle subtended by these apertures was approximately 35°. The subject was given each of the 15 conditions and was asked to drive at what he considered a comfortable speed

Task 2

The subject was required to drive at 20, 30, 40, 50, and 60 mph. He then selected, for each velocity, where he wished the "window" of information for each of the three sizes

Task 3

The subject was instructed to drive at what he considered a comfortable speed under each of the following conditions.

1 Condition a.—The visual field was entirely obscured by glare except for an aperture extending from the driver to a distance of 30 ft ahead of the driver. A series of five increments in the visual field, each increment corresponding to one of the five minimum allowable sighting distances of Task 1, taken in increasing order, was then executed. At the end of the fifth increment, the entire visual field, as seen through the veiling luminance device, was available.

2. Condition b —The visual field was entirely obscured by glare except for an aperture extending from 150 ft ahead of the driver to the horizon. Through five decreasing steps the visual field was increased until all the field was available. This subtask is essentially the inverse of the first.

3. Condition c.—The entire visual field was available. The field was gradually obscured in five steps starting from 30 ft in front of the driver to a minimum allowable sighting distance of 150 ft down the road.

4. Condition d.—The entire field was available and degraded in five descending steps Thus, the field was moved down to a maximum allowable sighting distance of 30 ft in front of the driver's eye.

The first two conditions (a and b) are shown schematically in Figures 16 and 17, respectively. The other two conditions (c and d) are shown in Figures 18 and 19, respectively.

Each task was executed separately. In Tasks 1 and 2 the conditions were taken in random orders, with each condition lasting approximately 2 min. For Task 3, each step of the subtasks lasted for approximately 1 min.

Testing was done on a rural two-lane highway that had little change in horizontal or vertical curvature, and that was provided with edge and center lines

Prior to the performance of the tasks, the subject was allowed to familiarize himself with the vehicle by driving to the test site, a distance of 10 miles. Each subject was then run through a series of velocity-control pretests to establish base line performance. These were maintenance of constant velocities of 20, 30, 40, 50, and 60 mph. All were conducted using the veiling luminance device but with no obscuring of the visual field

RESULTS

Primary analyses of the data were concerned with two independent variables—namely, (1) the minimum allowable sighting distance (X_1) available to the driver and (2) the size of the aperture available to the driver. The latter was defined by two methods First, it was defined as the size of the "window" in the field of glare located directly in front of the driver (being either ¼ in , ⅜ in or ½ in).

TABLE 5

DIMENSIONS OF THE "WINDOW" VIEWING APERTURES FOR EACH SIZE AND PLACEMENT (IN FEET)

FOR ALL SIZES	WITH APERTURE SIZE 1 (LARGEST SIZE)		WITH APERTURE SIZE 2 (MIDDLE SIZE)		WITH APERTURE SIZE 3 (SMALLEST SIZE)	
MINIMUM ALLOWABLE SIGHTING DISTANCE (X_1)	MAXIMUM ALLOWABLE SIGHTING DISTANCE (X_2)	APERTURE SIZE (X_2-X_1)	MAXIMUM ALLOWABLE SIGHTING DISTANCE (X_2)	APERTURE SIZE (X_2-X_1)	MAXIMUM ALLOWABLE SIGHTING DISTANCE (X_2)	APERTURE SIZE (X_2-X_1)
30	39	9	35	5	32 5	2.5
45	60	15	56	11	53 5	8 5
60	100	40	85	25	75	15
90	180	90	150	60	135	45
150	400	250	300	150	210	60

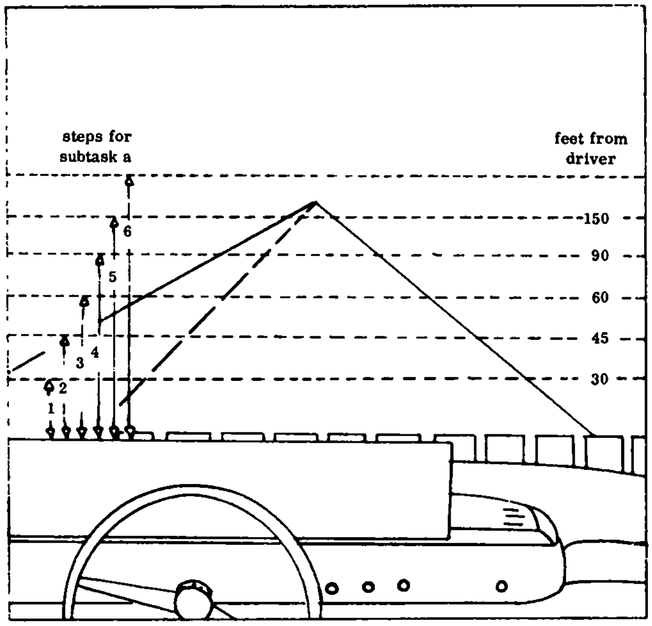


Figure 16 Steps for which subjects were tested under Condition a of Task 3

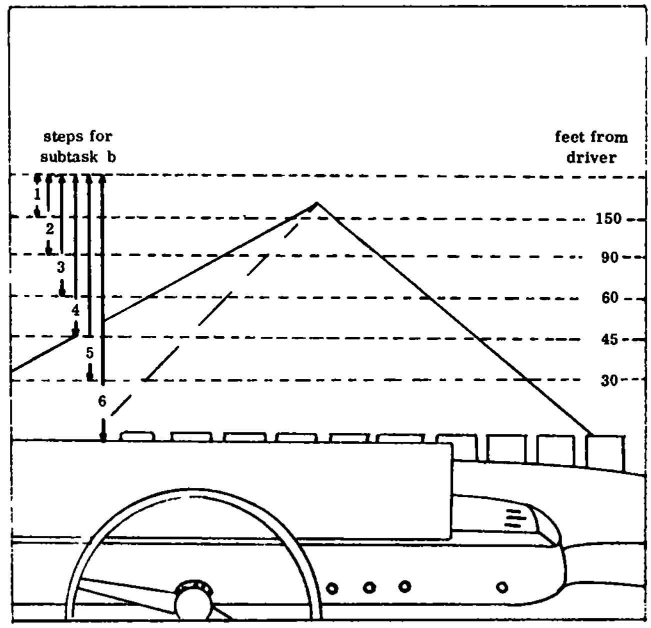


Figure 17 Steps for which subjects were tested under Condition b of Task 3

Secondly, it was defined as the amount of roadway the driver could actually see through the glare $(X_2 - X_1)$. This measure varied with distance; i.e., an aperture of ½ in. would reveal more roadway when near the horizon than when close to the vehicle A third independent variable was also examined—namely, the maximum allowable sighting distance (X_2). This variable was not varied systematically, and was determined by X_1 and the size of the aperture $(X_2 - X_1)$

Task 1

The average velocities of the subjects grouped are shown in Figure 20 as a function of X_1 and $(X_2 - X_1)$. Although it is difficult to see readily, the selected velocity

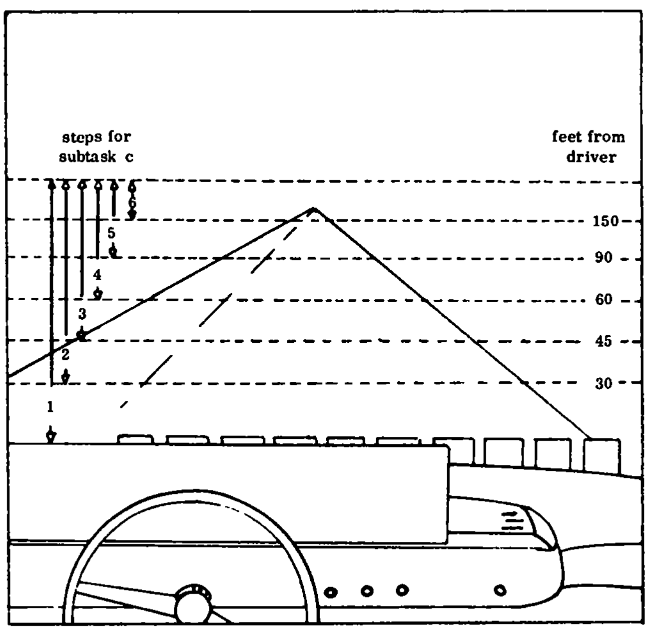


Figure 18 Steps for which subjects were tested under Condition c of Task 3

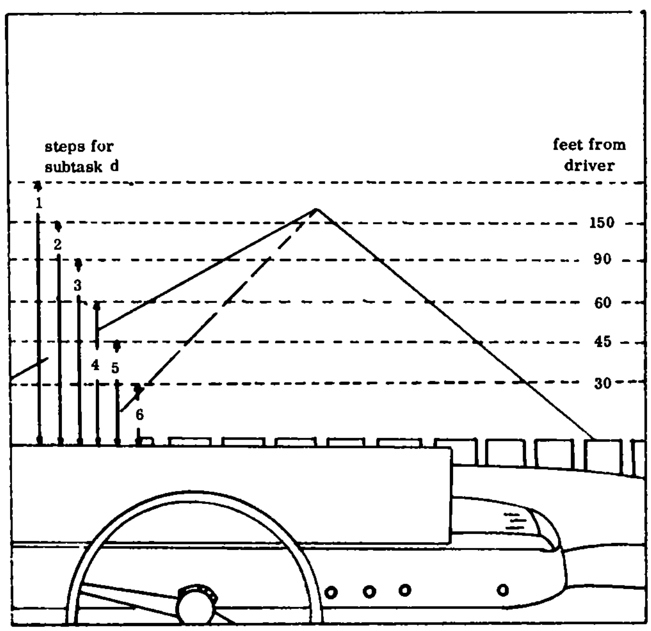


Figure 19 Steps for which subjects were tested under Condition d of Task 3

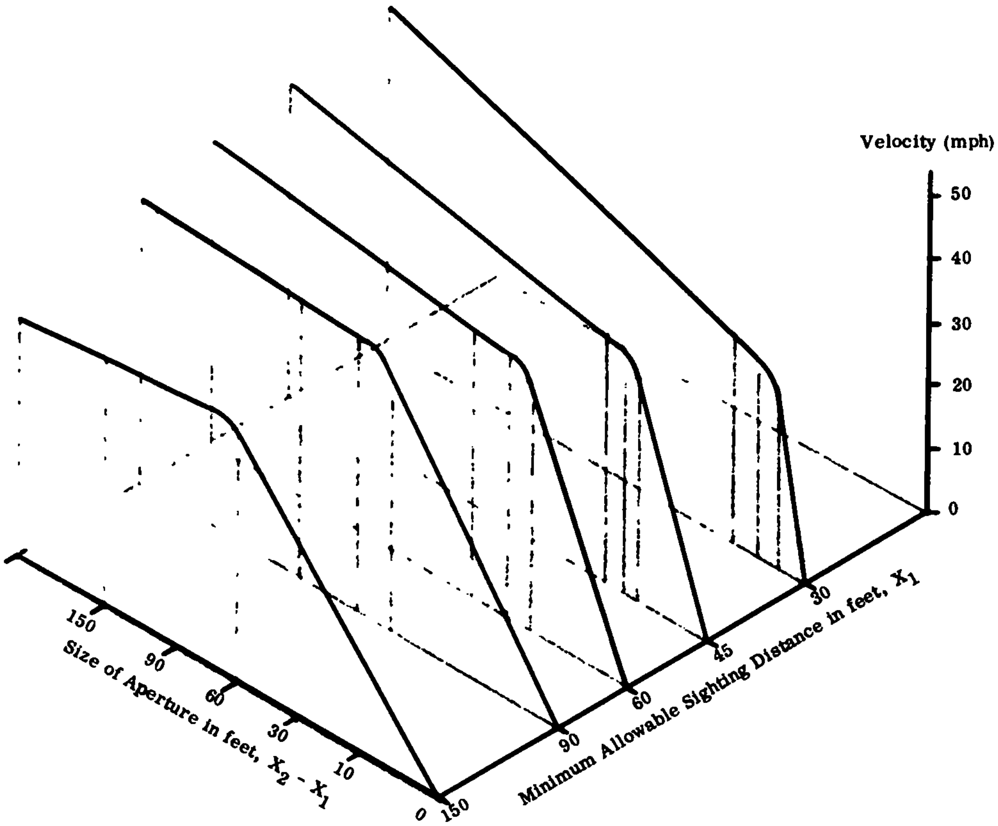


Figure 20. Velocity means for subjects grouped under Task 1 conditions

increases with an increase in $X_2 - X_1$. It is difficult to determine exactly what selective effects X_1 has on velocity selection from this graph. If one disregards the extreme aperture size (labeled ∞), it appears that an increase in the minimum allowable sighting distance produces an increase in selected velocity. When the extreme aperture size is now included, it appears as though these effects are interactive; i.e., an increase in the minimum allowable sighting distance results in a decrease in selected velocity when the size of the aperture is boundless. This can be explained, however, in that the researchers were not able to get a measure of the size of the aperture ($X_2 - X_1$) when the maximum distance was the horizon, and, consequently, the size ($X_2 - X_1$) was not actually boundless Therefore, when the minimum allowable sighting distance is moved closer to the horizon, it is effectively removing a portion of the roadway available to the driver, and results in reduced selected velocity.

Task 2

For Task 2, mean velocity was an independent variable (rather than dependent) together with size of aperture. The data are in the form of minimum and maximum selected sighting distances. These data are presented in Figure 21. The top surface of the solid figure represents the maximum selected sighting distance, and the bottom (underneath) surface of the figure represents the minimum selected sighting distance. The size of the aperture ($X_2 - X_1$) is represented as the height of the solid figure

The minimum selected sighting distance (X_1, the underneath surface) was generally 70 to 110 ft from the driver. This implies that perhaps there is a minimum sighting distance that appears desirable for all velocity conditions. This minimum selected sighting distance is seen to increase somewhat as a result of velocity, but not to a very large extent. Rather, the more marked change occurs both in the maximum selected sighting distance and the aperture size ($X_2 - X_1$)

Task 3

Task 3 presented a problem to the subject similar to that encountered in Tasks 1 and 2, but somewhat more accentuated. Each of the subtasks exposed the entire available visual field either at the outset or the end of the run. That is, Tasks 3a and 3b began with a totally degraded field and progressed either by ascending or descending increments to the exposure of the entire field, whereas Tasks 3c and 3d began with complete fields and either through ascending or descending increments resulted in a degraded field. Fields intermediate between either extreme contained either progressively increasing or progressively decreasing amounts of information in terms of ranges of viewing distances exposed. For this reason, and to obtain some common basis for comparison, the data were arranged according to the size of the aperture (i.e., $X_2 - X_1$) achieved by degradation.

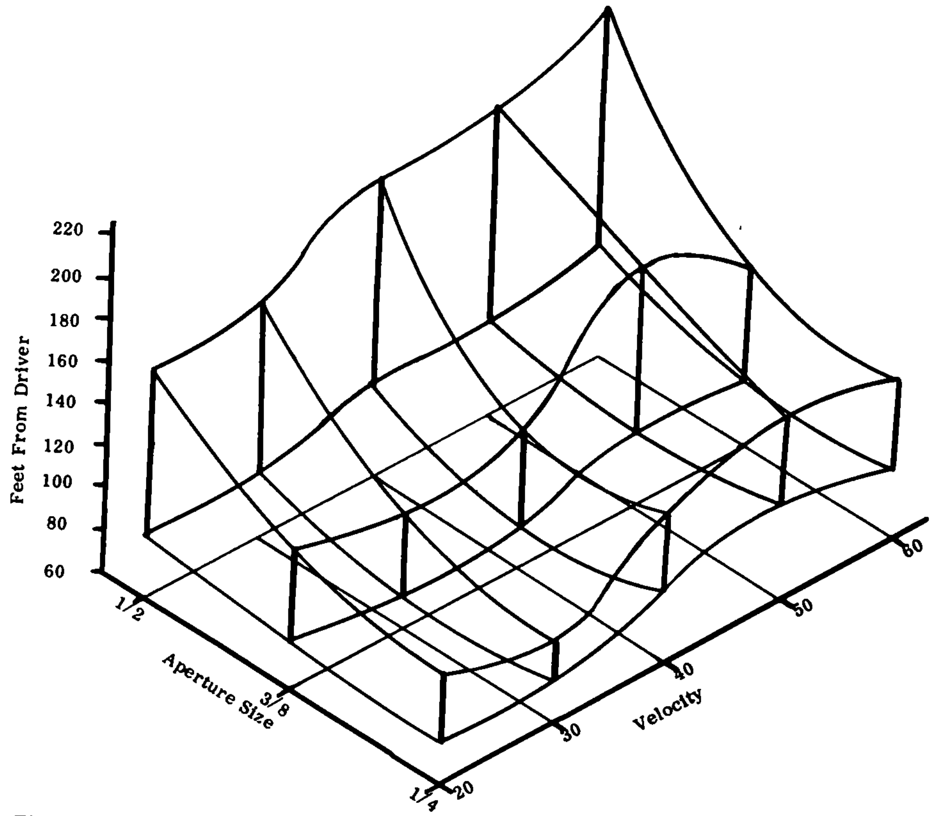


Figure 21 Minimum and maximum selected sighting distances for subjects grouped under Task 2 Conditions

Figure 22 shows the average velocity for the subjects grouped for the Task 3a and 3d trials. Similarly, Figure 23 shows Task 3b and 3c. The figures show, as in the case with Task 1, that an increase in selected velocity occurs with an increase in viewing area.

The data of Task 3 may be evaluated, in part, against the data of Task 1. That is, in some cases the minimum allowable sighting distances in both tasks were identical. The only way in which these tasks differed, then, was in the maximum allowable sighting distance. It might be expected that, because greater information was generally available in Task 3, the Task 3 velocities would be higher than the Task 1 velocities. Figure 24 shows the data of Task 1 and Task 3 together. The figure shows that Task 3 velocities for comparable minimum allowable sighting distances were considerably higher up to 90 ft, and then Task 1 viewing conditions produced higher velocities. Thus, the situation exists that past 90 ft the task allowing less viewing area produced greater velocities.

The data of Tasks 1 and 3 also permit an assessment of sighting distance in terms of a time interval. Knowing the distance needed to travel from the point where the viewed information is encountered, and the velocity over this distance, allows the computation of an anticipatory time interval. This time interval was computed for the minimum allowable sighting distance in Task 1 and is shown in Figure 25 as a function of this distance. The driver anticipatory period is consistent for each of the apertures and each shows that he tends to allow greater anticipatory time at larger distances. The same relationship may be established for the Task 3 data. This is shown in Figure 26. The data show the same consistencies as those of Task 1. It also was found that the lines for elapsed time for the maximum and minimum allowable sighting distance intersect. The point of intersection is at approximately 75 ft and may be considered a point of equivalence of maximum and minimum times. In other words, given a region between either 0 and 75 ft and the horizon, subjects elected to drive at approximately 45 mph.

DISCUSSION

The major result of Task 1 was that mean velocity increases with increasing difference between the minimum and maximum allowable sighting distances. The major result of Task 2 was that the minimum allowable sighting distance selected lies within a range of 70 to 100 ft. From Task 3, it was found that, within a subtask, driver velocity increased similarly to Task 1. When elapsed times to arrive at points of displayed information are determined, Task 1 and Task 3 data show that driver allowance for time is very nearly linear with respect to preview distance and velocity. Finally, when anticipatory time is determined for maximum and minimum allowable sighting distances, an apparent point of equivalence at approximately 75 ft is

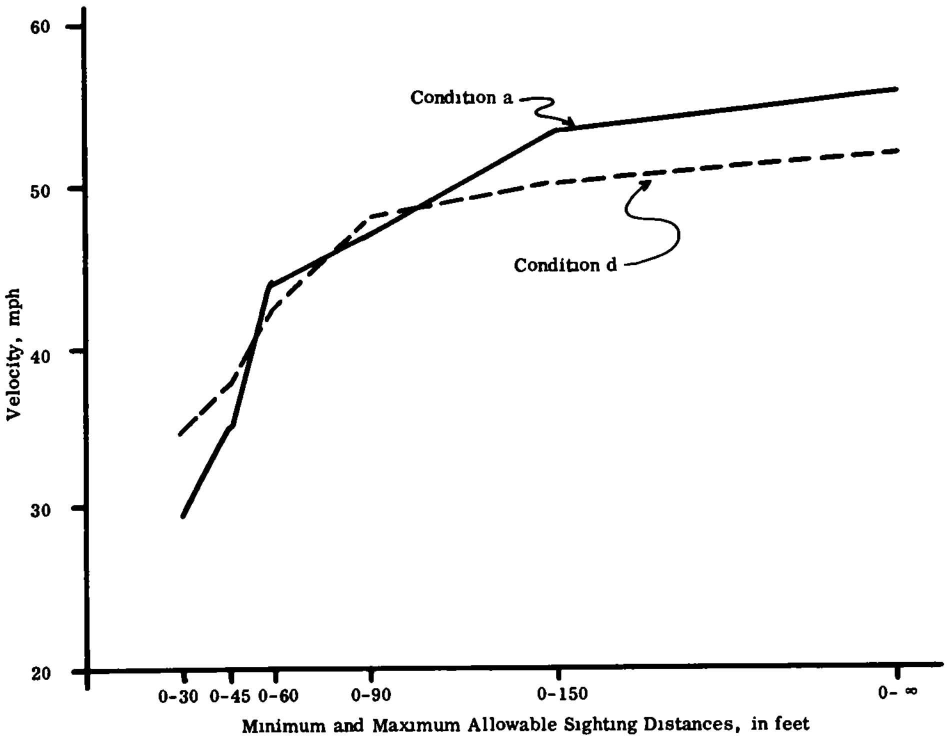


Figure 22 Velocity means for subjects grouped under Task 3 Conditions a and d

obtained, which is to say, drivers selected the same velocities when presented viewing areas of 0 to 75 ft and 75 ft to the horizon.

The purpose of this research was to determine possible sighting distances that may be used by the night driver. From the data of Task 2 it appears that a promising area would be in the range of 70 to 100 ft. This was the location of the minimum sighting distance chosen when the subjects were able to select location of information for various velocities The data of Task 3 further support this as the most plausible region. This task showed that a point approximately 75 ft away from the driver was of significance in that the information available up to that point (0 to 75 ft) apparently equaled the information beyond that point (75 ft to horizon), so far as velocity was concerned.

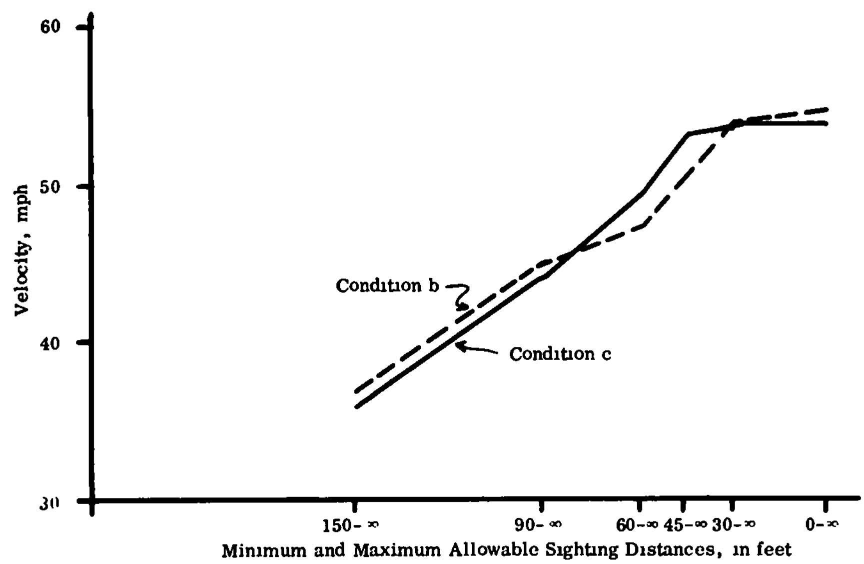


Figure 23 Velocity means for subjects grouped under Task 3 Conditions b and c

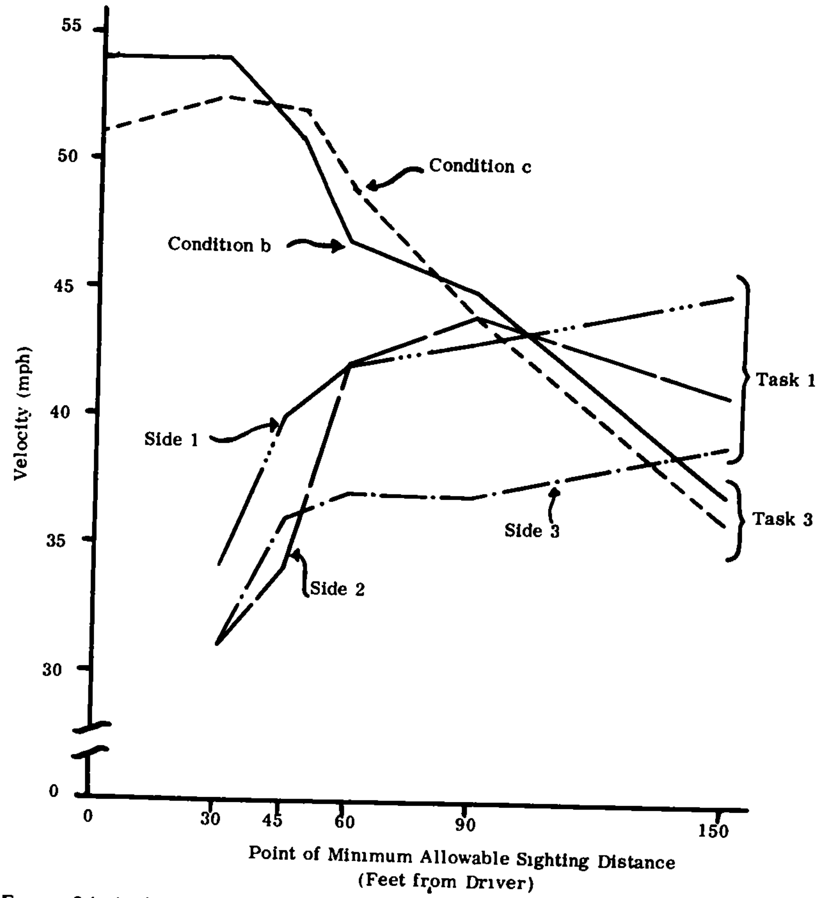


Figure 24 Velocity means for Task 1 and Tasks 3b and 3c for subjects grouped

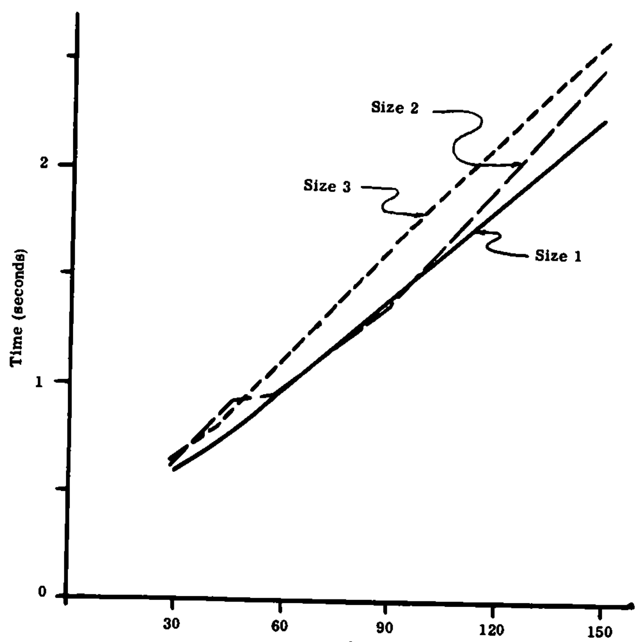


Figure 25 Grouped data from Task 1 plotted by the amount of time elapsed between the driver and the minimum allowable sighting distance

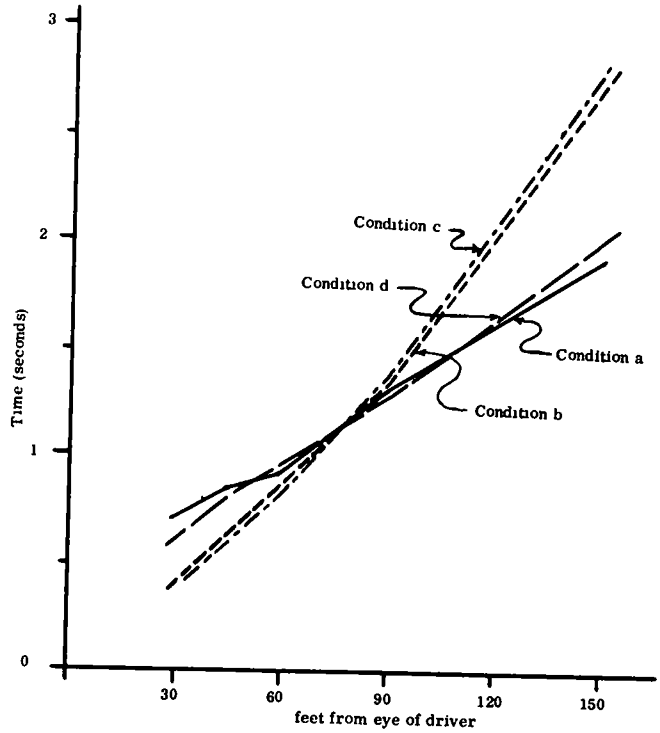


Figure 26 Grouped data from Task 3 plotted by the amount of time elapsed between the driver and the information Conditions a and d are plotted according to the point of maximum allowable sighting distance, Conditions b and c are plotted according to the point of minimum allowable sighting distance.

A comparison of Tasks 1 and 3 (Fig. 24) shows a region approximately 90 ft away that apparently served as sufficient information, because added information in terms of viewing area did not produce higher velocities. These data suggest, then, that there is some sighting distance that is useful to the driver for velocity selection, and, in the particular conditions of this experiment, is maximally effective in the region of 75 to 90 ft.* If this region is a critical region of information, then it would follow that under conditions such that information is available from 0 to 75 ft, the maximum point would likely be most important, and, if information is available from 100 to 300 ft, the minimum point would be most important.

Data relevant to the forward reference distance hypothesis were generated in Tasks 1 and 3. The anticipatory times recovered point out the consistency of the data with this hypothesis For both minimum and maximum allowable sighting distances, the times were very nearly linear, indicating that the forward reference distance is directly proportional to velocity. These data support the idea of a forward reference distance but do not confirm its existence, because the experimental conditions were favorable to the production of such a forward reference distance. It is the linearity of the anticipatory times that is significant.

One other finding was noteworthy. The comparison of Task 1 and Task 3 (Fig. 24) shows that beyond 90 ft a smaller viewing area resulted in greater velocities than a larger viewing area. These data are surprising but may be explained in one of the following ways. It is possible that the glare above and below the aperture in Task 1 encouraged some kind of perceptual focusing on the relevant information, and the subjects thus made more efficient use of the information than in Task 3 when the glare was only above, or below the relevant information. An alternative explanation is that the information that can be assimilated by the subject past 90 ft has a limit which was exceeded in Task 3, and the additional information produced confusion or interference. This study provides no basis for selecting between the two.

SUMMARY

This study was designed to determine whether drivers use a sighting distance for velocity selection.

* It should be noted, however, that the results may be due, in part, to the conditions specific to this experiment It may well be that the angle of his line of sight with the road (tan 49 in /75 ft$\approx$3°) is the critical factor in determining a driver's sighting distance

Three separate tasks were employed. Task 1 involved driving while viewing through a restricting aperture with minimum allowable sighting distances of 30, 45, 60, 90, and 150 ft. Three separate apertures which disclosed varying sizes of areas also were used. Throughout the task the driver was required to drive at a comfortable speed. In Task 2, the subject was required to drive at either 20, 30, 40, 50, or 60 mph, and was permitted to determine the location of the aperture. In Task 3, the subject was instructed to drive at a comfortable speed under each of the following subtasks:

1. Condition a.—The visual field was entirely obscured, except for a distance out to 30 ft in front of the driver. In five increments, the entire visual field was exposed.
2. Condition b.—The task was similar to (a) except that the visual field was blocked up to 150 ft ahead of the driver. In five decreasing steps, the entire visual field was disclosed.
3. Condition c.—The entire visual field was available to the driver and then obscured in five steps starting from 30 ft in front of the driver to 150 ft down the road.
4. Condition d.—The entire visual field was available and degraded in five descending steps.

The major results of Task 1 were that mean velocity increases with the amount of information defined by the difference between the minimum and maximum allowable sighting distances. The major result of Task 2, 20 to 60 mph, was that the minimum allowable sighting distance most preferred lies within a range of 70 to 110 ft. From Task 3 it was found that, within a subtask, velocity increased similarly to Task 1. When elapsed time to arrive at points of displayed information are determined, Task 1 and Task 3 data show that driver allowance for time is very nearly linear with respect to distance and velocity, and that this allowance is proportionately greater for greater viewing distances. Finally, when allowance for elapsed time is determined for maximum and minimum allowable sighting distances, an apparent region of equivalence of information at approximately 75 ft is obtained (45 mph).

These findings were interpreted to mean that a sighting distance exists for the night driver. In this particular experiment, it lay between 75 to 90 ft from the driver.

The "forward reference distance" hypothesis was supported to the extent that the data were highly consistent with a "forward reference distance" concept.

CHAPTER FIVE

VISUAL INFORMATION ACQUISITION BY THE NIGHT DRIVER

The intent of this pilot study was an experimental exploration of night-driving visual-information sensing. The method used was the recording of eye-movement behavior under realistic driving conditions on the highway.

It was hypothesized that characteristic eye-movement patterns can be identified and described for different driving conditions—specifically, differences between night versus day driving

METHODOLOGY

Subjects

Because the nature of this research was exploratory and techniques were still being developed for assuring good eye-marker data, the two subjects used were researchers on this project. This proved highly beneficial from the point of understanding what is required of the subject before and during testing.

Apparatus

Eye movements have long been studied by psychologists and eye specialists, with a wide viarety of techniques. A survey of the state of the art was done to assess the feasibility of these techniques, as well as to ascertain the availability of specific items of equipment. As a result of this study, the Polymetric Company corneo-reflective eye-movement camera system, model V-0165-1L4, with a 16-mm Pathe motion-picture camera and high-resolution fiber optic cables was chosen (Fig. 27).

Briefly, the Polymetric system consists of a light source to cause light to be reflected from the cornea of one eye, an optical system to detect this reflected light beam (eyespot), a second optical system to detect the scene viewed by the driver, and two fiber optic cables for transferring the eyespot and scene image to a 16-mm motion-picture camera. The eyespot is superimposed on the scene image before being photographed. Examples of the final result of all of this are shown in the clips of 16-mm film (Figs. 28 and 29).

As shown in Figure 27, the light source, eyespot detector system and scene lens are securely fastened relative to the eye and head in a headpiece which is further stabilized with a mouth bite board. As used in the automobile in this research, the camera was firmly supported from the roof of the car in such a position that the subject had reasonable freedom of head movement and also so that the experimenter riding in the front seat could operate the camera and periodically check on the adequacy of eyespot brightness and calibration by viewing it through the reflex viewfinder. The use of fiber optic cables under both day and night driving conditions imposed severe restrictions on the photographic phases of this research.

Both the fiber optics and the method of superimposing the eyespot on the scene image resulted in considerable light intensity attenuation. After experimenting with several high-speed films which failed to produce intelligible exterior detail at night, the researchers devised another approach in order to make inferences as to night visual patterns. Tests were conducted in a 1963 Chevrolet sedan equipped with a multichannel oscillographic recorder. This vehicle is instrumented so as to enable the recording of many aspects of control such as steering-wheel, accelerator, and brake-pedal movement, and vehicle velocity. Correlation studies between eye movements and manual control motions, however, were not attempted at this time.

A procedure was developed whereby each subject would tranverse the same test section of highway under both day and night conditions, with fixed reference points on the automobile visible on both the day and night film. Knowing the spatial location of these reference points and that of the driver's eyes, it was possible to project the eye focus spot at night to a particular sector of the highway, even though the road features were not visible on the film.

Two small low-voltage lights were placed approximately 12 in. apart on the hood of the car, 85 in. in front of the plane of the driver's eyes and 42 in. above the highway surface. With these dimensions fixed, the measurement of each driver's eye position in space enabled, through simple trigonometric relationships, the projection of the eyespot to sectors of the external visual field. These hood reference lights can be seen on both the day and night recordings in Figures 28 and 29.

Driver performance was observed during the day and night on three different highway sections north of Columbus, Ohio. Two of these test sections were on a 22-ft-wide rural two-lane highway (Ohio 315). One was on a section of unlighted four-lane divided highway (US 23) with an ample median strip. The rural two-lane road had a painted white dashed center line but no white edge line. The four-lane section had a painted white edge line. The first section (hereafter referred to as "rural straight") was a straight stretch of highway approximately 0.3 mile in length. The second section ("rural S curve") was approximately 0.3 mile in length, with the first turn of the S a right turn of 37° of arc (arc radius of 716 ft), and then a left turn of 34° of arc (arc radius of 819 ft). The third section (four-lane divided) was a straight section approximately 0.8 mile long. The second of the two subjects was also run in an exploratory study at two different velocities on another length of the same four-lane highway.

Data Analysis Techniques

The visual environment was partitioned into the seven areas shown in Figure 30. Note that these seven areas

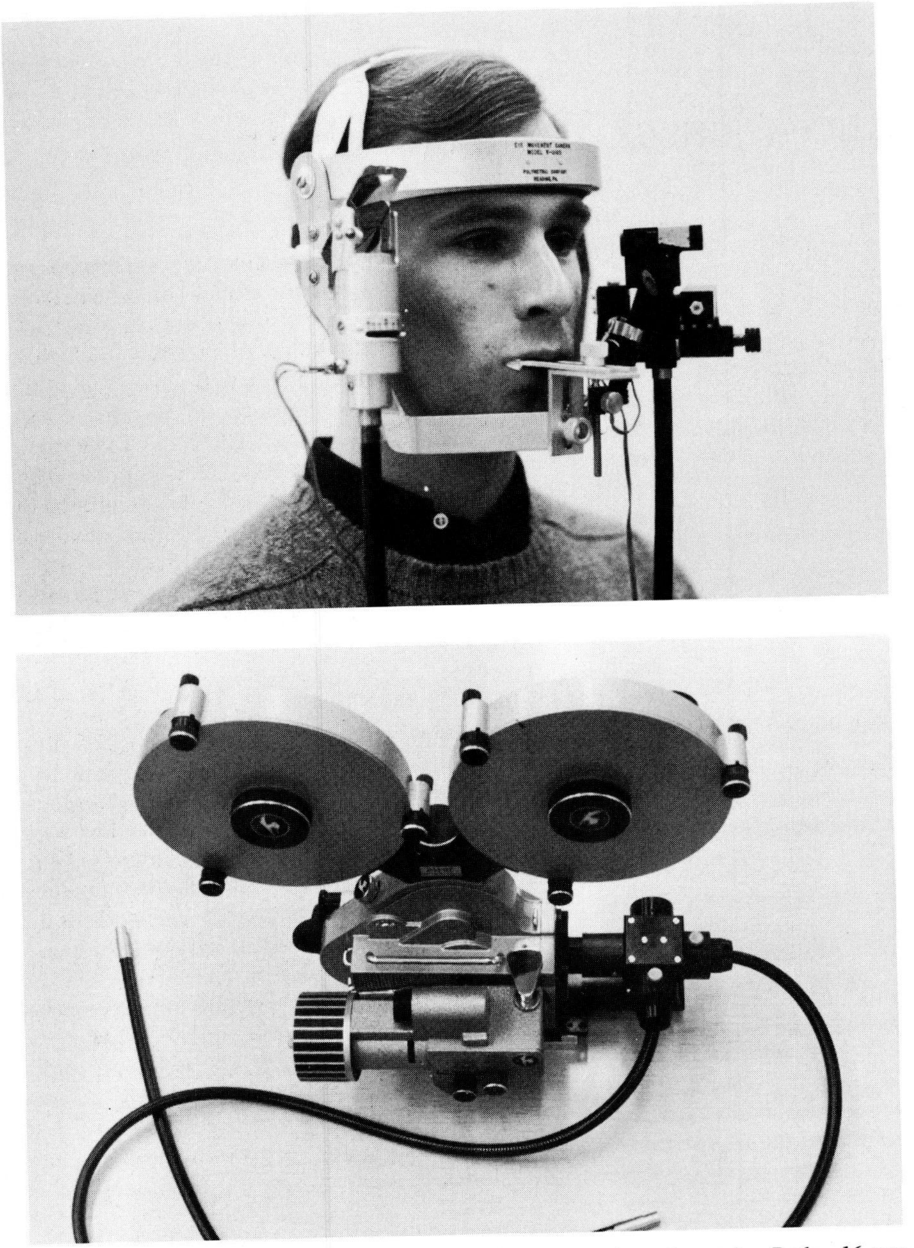


Figure 27. Subject with eye-movement head gear in place (upper). Pathe 16-mm camera and fiber optics (lower).

were chosen so as to contain prominent highway features that were found previously to be of significance as a source of information to the driver. Areas 1 and 4 encompass the left edge of the road, Areas 3 and 6 the right edge, Areas 2 and 5 the center line, and the triangular Area 7 included the entire road beyond 250 ft in front of the car. Distance spacings of 75 and 250 ft from the car were chosen to agree with the divisions used in the second and third experiments (Chapters Three and Four) done on this project.

To prepare for data analysis of both day and night films, a daylight film (straight road) was projected onto a 5- by 6-ft movie screen. The areas shown in Figure 30 were then laid out on the screen with thin black tape. Correct location of the reference lights relative to the grid on the screen was determined and marked on the screen for each subject.

For each of the test sections studied, the data analyst recorded the number of frames during which the eyespot was in each of the seven areas of the visual field. If the spot was either not visible or in some location outside the seven areas, the frames were recorded in the category "Other." All frame counts were reduced to percentage figures and are given in Tables 6 and 7.

To gain some insight into the nature of the scan patterns used, the data analyst counted frames during which the eyes were in definite transition from one area to another in the field of view. These data are given in Tables 8 and 9 as percentages of total frames in transition between areas. Data from Tables 8 and 9 were further reduced to emphasize the magnitude of links between the seven primary areas. This was done by taking, for a given trial, the total frames in transition between the seven areas as 100 percent. All between-area links were thus converted to a percent of total transition between areas. The results are given in Tables 10 and 11.

Figure 28. Six frames from 16-mm day data film. The two white sharply focused data spaced about ½ in. apart in each frame are the hood reference lights. The relatively unfocused larger white spot near the right hood light is the eyespot.

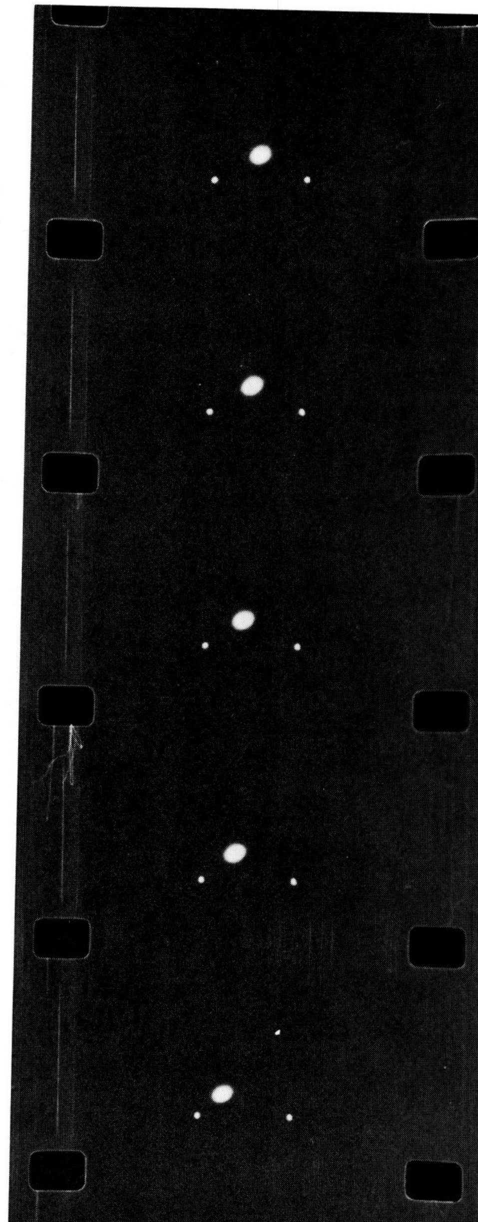


Figure 29. Six frames from 16-mm night data film. The large white dot is the eyespot and the two small dots spaced about ½ in. apart are the hood reference lights.

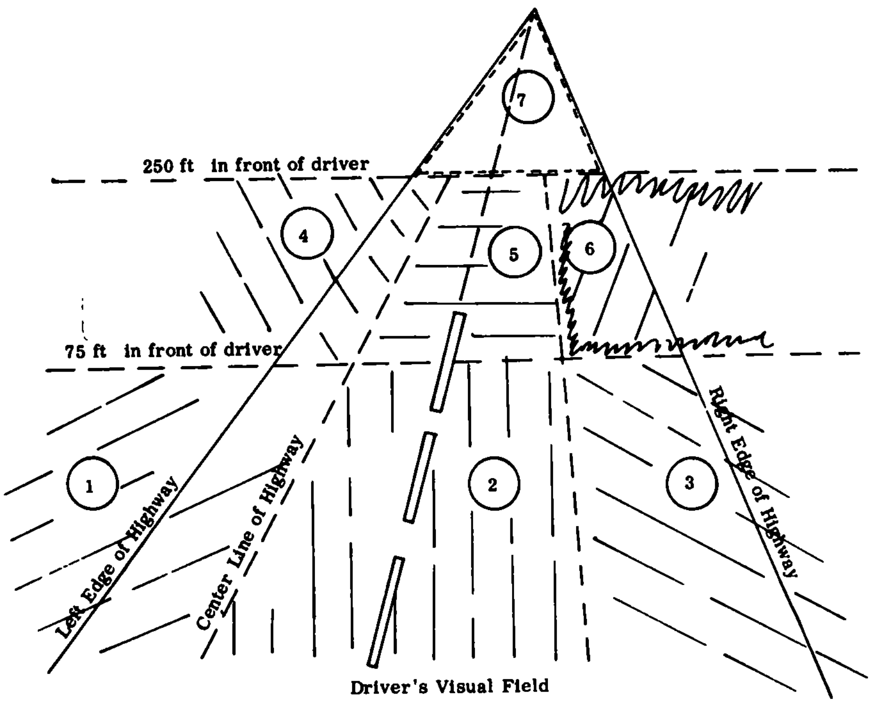


Figure 30 The seven areas used in data analysis

Procedure

Three subjects were initially run but acceptable data were obtained from only the last two. (Eye movement calibration was lost for one subject.) To familiarize the subjects with the equipment, they were asked to drive the vehicles to the test site while wearing the head gear. On reaching the first test site, the eyespot was adjusted. It was readjusted prior to each subsequent trial. Prior to beginning the runs, each subject was instructed to drive the car normally, obeying all speed and traffic laws, with no passing or lane changing allowed.

For each trial, in addition to the photographic record of eye movements, oscillographic records were obtained for steering-wheel movement, brake- and gas-pedal move-

TABLE 6

PERCENTAGE OF TIME DRIVER'S EYES FOCUSED OR SEARCHING IN THE VISUAL AREAS SPECIFIED IN FIGURE 30 (DRIVER C.O)

	Highway Test Condition	Replication	Area of Visual Field 1	2	3	4	5	6	7	Other
Daytime Driving	Rural Straight	1	0	0	0	0	1 7	25 8	67 8	5 6
		2	0	0	0	1 3	16 8	0	74 3	7 1
	Rural "S" Curve	1	0	0	0	0	0	13 2	46 8	39 7
		2	0	0	0	20 0	10 4	10 7	12 8	46 1
	Four Lane Divided	1	0	0	0	0	0	2 4	78 4	19 2
		2	0	0	0	0	0	0	80 2	19 7
Night Driving	Rural Straight	1	0	0	2 0	0	0 4	61 6	5 7	29 4
		2	No Eye Spot							
	Rural "S" Curve	1	0	0	1 8	0	0	54 2	4 0	40 0
		2	0	0	0	0 3	5 0	16 2	45 3	33 2
	Four Lane Divided	1	0	0	0	0 3	2 1	0 3	29 3	68 0
		2	0	0	0	0	7 6	20 0	11 1	62 0

TABLE 7

PERCENTAGE OF TIME DRIVER'S EYES FOCUSED OR SEARCHING IN THE VISUAL AREAS SPECIFIED IN FIGURE 30 (DRIVER D K.)

	Highway Test Condition	Replication	Area of Visual Field 1	2	3	4	5	6	7	Other
Daytime Driving	Rural Straight	1	0	0	0	0	2 6	17 2	62 0	18 0
		2	0	0	0	0	0	17 5	59 5	23 0
	Rural S" Curve	1	0	0	9 1	0	0	7 2	0	83 7
		2	0	0	0	0	0	0	19 7	80 3
	Four Lane Divided	1	0	0	0	0	0	0	0	100
		2	0	0	0	5 4	0 7	0 7	47 0	46 1
	40 mph 60 mph	1	0	0	0	0	0	0	0	100
		2	0	0	0	5 0	0	0	63 1	31 9
Night Driving	Rural Straight	1	0	0 5	0	0	3 75	1 9	88 7	5 2
		2	0	0	0	0	1 0	73 1	17 3	8 6
	Rural 'S Curve	1	0	0	1 6	4 5	11 7	27 3	33 4	21 5
		2	0	0	0	0 6	5 3	5 0	58 1	31 0
	Four Lane Divided	1	0	10 6	25 4	0 3	27 7	20 5	0 5	15 0
		2	0	0	0	0	0 1	15 9	67 5	16 5
	40 mph 60 mph	1	0	3 0	4 5	0	6 7	60 8	0	20
		2	0	0	0	0	0	21 7	41 6	36 7

ment, and vehicle speed. A stimulus button was used to mark oscillographic traces and the camera film simultaneously A small light attached to the eye-movement scene lens and actuated by the recorded stimulus button permitted simultaneous marking of both film and oscillographic traces.

In the actual conduct of the experiment, one experimenter sat in the front passenger seat and one sat in the rear seat. The front man's duty was to operate the camera, monitor the camera viewfinder, and assist the driver when necessary. The rear man's responsibilities were to operate the oscillographic recorder and to mark the film and recorder traces by signaling the beginning and end of trials.

RESULTS

Tables 6 and 7 give the percentage of time the driver's eyes were in the seven designated areas shown in Figure 30. The column headed "Other" includes the percentage of time that the eyespot was either not visible or outside the seven primary areas.

In scanning this "Other" column, it is apparent that, under certain circumstances, a large percentage of the film frames either contained no eyespot, or the eyespot was not in one of the seven areas. For example, in the "rural S curve" as contrasted to the "rural straight" test section the eyespot was lost a great deal more for both drivers.

There is considerable driver variability from one replication to the next on the same test section of highway. Thus, to illustrate, driver C.O. in daytime driving on "rural straight" road kept his eyes in Area 7 about 68 percent of the time and in Area 6 26 percent of the time on his first trip, but the second time around it was 74 percent in Area 7, 0 percent in Area 6, and 17 percent in Area 5. In terms of highway features, the first time around the driver concentrated mainly on the converging road at distances beyond 250 ft, with numerous visual excursions to the near right edge of the highway. On the second trip around, although his main focus was still on the distant road, the excursions were mainly into Area 5, the section including the highway center line between 75 and 250 ft in front of the car. Similar examples of driver variability can be seen for the night-driving data and for the second subject.

TABLE 8

PERCENTAGE OF TIME THE EYES WERE IN TRANSIT BETWEEN THE VISUAL AREAS SPECIFIED IN FIGURE 30 (DRIVER C.O.)

	Highway Test Condition	Replication	Visual Area Links								
			3-6	4-5	4-6	4-7	5-6	5-7	6-7	Total between the seven areas	Total excursions (to and from outside the seven areas)
Daytime Driving	Rural Straight	1	0	0	0	0	0 4	0 4	6 4	7 3	9 9
		2	0	0 4	0	0	0	4 4	0 9	5 7	10 2
	Rural "S" Curve	1	0	0	0	0	0	0	1 6	1 6	7 0
		2	0	1 3	0 3	0 5	0 8	0 5	1 3	4 7	13 1
	Four Lane Divided	1	0	0	0	0	0	0	1 3	1 3	8 7
		2	0	0	0	0	0	0	0	0	9 5
Night Driving	Rural Straight	1	2 5	0	0	0	0	0	0	5 3	13 5
		2	No Eye Spot								
	Rural "S" Curve	1	1 3	0	0	0	0	0	1 8	3 1	8 2
		2	0	0 3	0	0	0 5	0 8	2 6	4 2	14 9
	Four Lane Divided	1	0	0 15	0	0 15	0	0 7	0	1 0	9 0
		2	0	0	0	0	1 0	0 5	0 6	2 2	10 8

(Data are expressed in terms of the percent of total frames in a trial)

TABLE 9

PERCENTAGE OF TIME THE EYES WERE IN TRANSIT BETWEEN THE VISUAL AREAS SPECIFIED IN FIGURE 30 (DRIVER D.K)

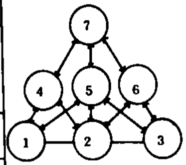
	Highway Test Condition	Replication	Visual Area Links												
			2-3	2-5	2-6	3-4	3-5	3-6	4-5	4-7	5-6	5-7	6-7	Total between the seven areas	Total excursions (to and from outside the seven areas)
Daytime Driving	Rural Straight	1	0	0	0	0	0	0	0	0	0 5	1 0	1 6	3 1	12 0
		2	0	0	0	0	0	0	0	0	0	0	5 5	5 5	13 0
	Rural 'S" Curve	1	0	0	0	0	0	0 3	0	0	0	0	0	0 3	b 5 1
		2	0	0	0	0	0	0	0	0	0	0	0	0	4 8
	Four Lane Divided	1	0	0	0	0	0	0	0	0	0	0	0	0	0 5
		2	0	0	0	0	0	0	0	1 7	0 2	0 2	0 5	2 6	10 1
	40 mph 60 mph	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		2	0	0	0	0	0	0	0	1 8	0	0	0	1 8	8 1
Night Driving	Rural Straight	1	0	0 5	0	0	0	0	0	0	0 5	0 9	3 3	5 2	8 0
		2	0	0	0	0	0	0	0	0	0	0 5	2 0	2 5	7 1
	Rural "S" Curve	1	0	0	0	0	0	0 3	0 3	0 3	0 5	2 6	2 9	6 9	11 4
		2	0	0	0	0	0	0	0	0 6	0	2 8	1 1	4 5	10 9
	Four Lane Divided	1	1 9	0 6	0 2	0 2	1 4	0 8	0	0	2 2	0 3	0	7 5	14 4
		2	0	0	0	0	0	0	0	0	0	0 1	1 9	2 0	7 3
	40 mph 60 mph	1	0 4	0 6	1 1	0	0 4	1 3	0	0	0 2	0	0	4 1	10 3
		2	0	0	0	0	0	0	0	0	0	0	1 7	1 7	6 8

(Data are expressed in terms of the percent of total frames in a trial)

TABLE 10

LINK TABLE SHOWING EYE TRANSIT BETWEEN THE SEVEN AREAS OF FIGURE 30 AS A PERCENT, WHEN TOTAL EYE TRANSIT WITHIN THE SEVEN AREAS IS TAKEN AS 100 PERCENT (DRIVER C O)

	Highway Test Conditions	Replication	2-3	2-5	2-6	3-4	3-5	3-6	4-5	4-6	4-7	5-6	5-7	6-7	Percent of total frames in a trial
			Links Between Areas												
Daytime Driving	Rural Straight	1	0	0	0	0	0	0	0	0	0	5 5	5 5	89 0	7 3
		2	0	0	0	0	0	0	7 0	0	0	0	77 0	16 0	5 7
	Rural "S" Curve	1	0	0	0	0	0	0	0	0	0	0	0	100	1 6
		2	0	0	0	0	0	0	27 8	6 4	10 5	17 0	10 5	27 8	4 7
	Four Lane Divided	1	0	0	0	0	0	0	0	0	0	0	0	100	1 3
		2	0	0	0	0	0	0	0	0	0	0	0	0	0
Night Driving	Rural Straight	1	0	0	0	0	0	47 0	0	0	0	0	6 0	47 0	5 3
		2	No Eye Spot												
	Rural S' Curve	1	0	0	0	0	0	42 0	0	0	0	0	0	58 0	3 1
		2	0	0	0	0	0	0	7 1	0	0	11 9	19 0	62 0	4 2
	Four Lane Divided	1	0	0	0	0	0	0	14 0	0	14 0	0	72 0	0	1 0
		2	0	0	0	0	0	0	0	0	0	45 5	25 0	29 5	2 2



Schematic of Visual Areas with Links

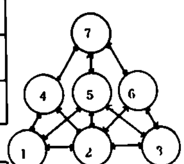
Comparing and contrasting the results for the two drivers indicates substantial differences in visual behavior. For example, in some trials, such as the first replication for driver D.K. on daylight four-lane divided highway (Table 7), the fixation point (eyespot) appeared in the sky just above the horizon line. Thus, 100 percent of his visual focus is recorded in the "Other" category. Driver C.O. much less often drove with fixation in the sky area above the horizon line. It appears that D.K.'s visual behavior pattern might be one whereby under low task demands such as on the four-lane highway he picks up more essential information through peripheral vision than does driver C O.

Data in Tables 6 and 7 indicate in general that, for both drivers, the area of fixation tends to move down, closer in toward the car, for night driving than is the case in daytime driving over the same highway section. It can be seen that the right edge of the highway between 75 and 250 ft in front of the car (Area 6) had a larger percentage of fixation times under night than day conditions. The triangle formed by the converging road beyond 250 ft

TABLE 11

LINK TABLE SHOWING EYE TRANSIT BETWEEN THE SEVEN AREAS OF FIGURE 30 AS A PERCENT, WHEN TOTAL EYE TRANSIT WITHIN THE SEVEN AREAS IS TAKEN AS 100 PERCENT (DRIVER D.K)

	Highway Test Conditions	Replication	2-3	2-5	2-6	3-4	3-5	3-6	4-5	4-6	4-7	5-6	5-7	6-7	Percent of total frames in a trial
			Links Between Areas												
Daytime Driving	Rural Straight	1	0	0	0	0	0	0	0	0	0	16 1	32 3	51 6	3 1
		2	0	0	0	0	0	0	0	0	0	0	0	100	5 5
	Rural "S ' Curve	1	0	0	0	0	0	100	0	0	0	0	0	0	0 3
		2	0	0	0	0	0	0	0	0	0	0	0	0	0
	Four Lane Divided	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		2	0	0	0	0	0	0	0	0	65 4	7 7	7 7	19 7	2 6
	40 mph	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	60 mph	2	0	0	0	0	0	0	0	0	100	0	0	0	1 8
Night Driving	Rural Straight	1	0	9 6	0	0	0	0	0	0	0	9 6	17 3	63 5	5 2
		2	0	0	0	0	0	0	0	0	0	0	20 0	80 0	2 5
	Rural "S ' Curve	1	0	0	0	0	0	4 4	4 4	0	4 2	7 3	37 6	42 1	6 9
		2	0	0	0	0	0	0	0	0	13 3	0	62 3	24 4	4 5
	Four Lane Divided	1	25 2	8 0	2 5	2 5	18 6	10 2	0	0	0	29 0	4 0	0	7 5
		2	0	0	0	0	0	0	0	0	0	0	5 0	95 0	2 0
	40 mph	1	10 0	15 0	27 5	0	10 0	32 5	0	0	0	5	0	0	4 1
	60 mph	2	0	0	0	0	0	0	0	0	0	0	0	100	1 7



Schematic of Visual Areas with Links

(Area 7) contained a larger portion of focus time during day than it did during night driving.

Rural two-lane straight highway requires more driver focus time closer to the car than does four-lane divided highway. In Table 6, driver C O in the rural straight daylight trials focused in Area 7 (beyond 250 ft) approximately 70 percent of the time and in Areas 5 and 6 (between 75 and 250 ft) approximately 20 percent of the time On straight four-lane divided highway, he was in Area 7 about 80 percent, and hardly ever in Areas 5 and 6. He was also in the "Other" category about 20 percent of the time, a substantial portion of which was focused beyond the 250-ft line but to the right or left of the triangular Area 7.

Tables 6 and 7 show (as one would expect), for both drivers and for day and night conditions, that the focus area pattern differs for the S curve as contrasted to straight road There are periods of fixation on the left edge of the road Area 4 and also some close in (less than 75 ft in front of the car) on the right edge Area 3.

To give some insight into the nature of the scan patterns in these studies, film frames were counted during which the eyes were in definite transit from one region to the next, as regions are defined in Figure 30. Such information was recorded in Tables 8 and 9. Data were further abstracted from Tables 8 and 9 and are given in Tables 10 and 11 so as to give a better picture of the magnitude of link bonds between the seven primary areas of the field.

It is important in studying Tables 8 and 9 to note that entries are in terms of percentages of total frames counted for a trial. This enables one to gain some insight as to the significance of major eye movements as a function of experimental and subject variables

The total percentage of major eye excursions between the seven areas is given in the next-to-the-right-most column in Tables 8 and 9. The right column indicates total excursions, including those when the eyespot was departing to a lost condition or returning after being lost. A small portion of these "to and from" lost excursions are the result of blinking by the subject A blink usually appears as a flip of the eyespot up and out of the scene

In studying the data in Tables 10 and 11 a number of interestingly different observations can be made Intra- and intersubject differences appear, as was evident in the discussion of these data in Tables 6 and 7. The general search and scan patterns, as here abstracted, indicate differences between visual behavior on different highway test sections. Thus, with driver C.O. in day driving on the "rural straight" section, on his first trip, his scan pattern was confined to the triangle linking Areas 5, 6, and 7, with the majority of the movements between 6 and 7. In his second trip on the S curve, his pattern included the entire road, far and near, encompassed by Areas 4, 5, 6, and 7.

Day-night differences in visual scan patterns are perhaps more vividly portrayed with the data in Tables 10 and 11 than in Tables 6 and 7—at least for some of the highway geometry conditions Thus, in Table 10 for day driving on rural straight roads, most of the visual behavior was confined to Areas 5, 6, and 7; but for this same driver at night almost half of his major eye excursions dipped into Area 3 This is interesting to note in view of the fact that Table 6 indicates the driver spent only 2.0 percent of his total time in Area 3 Thus, one sees the driver under night conditions making about half his visual excursions (within the seven areas) quickly down in front of the car in the region of the right edge of the highway. He apparently samples briefly in this region but does not focus for any great length of time there Different scan patterns also with day-night contrasts can be seen in Table 11 for driver D.K

DISCUSSION

These studies, in which a research technique has been developed and preliminary eye movement results have been obtained, have a number of implications for the design of highway marking and lighting systems and for the design of vehicular lighting systems. Further research under more controlled conditions (such as might be possible on a test track) is needed to point to specifically desirable design alternatives.

This research has indicated that driver visual behavior (eye movements) is different in day than it is in night driving Given the present vehicular lighting schemes, the data suggest that highway marking systems (such as center and edge markings) are used differently by drivers in day than in night conditions At night, more use is made of the right edge marking or road edge contrast and at distances closer to the vehicle than is the case in daylight driving. Thus, that which is desirable for one condition might not be as desirable for the other. Additional research is suggested with the eye-movement camera to evaluate under both day and night and various highway night illumination conditions the effect of different color, luminance, placement, and pattern of road edge, center, and lane markings. Attempts should be made to explore the relative contributions of foveal and peripheral vision under these conditions. Additional research should be done to assess the driver's visual behavior as a function of vehicle speed and road curvature in relation to highway marking systems

SUMMARY

This chapter presents an outline of experimental methods and the results of experiments in which driver eye movements were studied using corneo-reflective methods of recording.

The effects of illumination levels (day vs night), various highway geometry patterns, and vehicle speed on eye movements were studied in exploratory fashion. Because the major effort on this phase of the total project deals with the development of research techniques with the eye-movement camera, actual research results must be viewed as only suggestive

The eye movements for two drivers were recorded and data were extracted from the film records by frame count to determine (1) the percentage of time the eyespot was in a given segment of the visual scene, and (2) the magnitude of the major eye movements between these segments of the visual scene (link type analysis).

The visual scene in the longitudinal dimension as seen by the driver was divided into three segments—less than 75 ft in front of the driver, between 75 and 250 ft in front, and beyond 250 ft. The visual scene was also segmented laterally into three elements—that including the left edge of the road, the road center section, and that including the right edge of the road.

Brief analysis of the data for the two subjects yielded the following observations.

There was considerable variability in each driver's eye movements from one replication to the next on the same test section of highway and under similar illumination conditions. Individual drivers appear to exhibit quite different visual patterns on the same highway test section and under similar illumination conditions. Part of this variability and, in general, the variability in results of these experiments might well be attributed to lack of control of external variables such as traffic on the highway.

In general, it appeared that for both drivers the eyespot was in an area closer to the vehicle (between 75 and 250 ft) and more on the right edge of the road at night than was the case in day driving when the spot tended more toward the apex of the visual scene of the highway beyond 250 ft.

Different tendencies appeared between day and night conditions relative to major eye excursions between sectors of the visual scene using link analysis concepts. In day driving on rural straight road, the majority of the large eye excursions took place between visual scene segments beyond 75 ft in front of the car. There were no major excursions into the region less than 75 ft ahead of the car. At night, however, on the same highway test section the eyespot did frequently dip into the region close in front of the car. In the case of one driver, about half of the major eye excursions at night were into the "close-in" region (less than 75 ft) at the right edge of the highway. This is interesting because the spot spent only about 2 percent of the total time in this "close-in" region. Apparently this driver at night frequently visually sampled briefly close in front of the car but did not focus there for any appreciable time.

There were differences in visual search and scan patterns with different highway geometry conditions but, because of such limited data, no clear-cut patterns were really apparent. In the S curve, as one might suspect, the eyespot spends more time in the visual field segments, including the left edge of the road.

Because of recognized uncontrolled environmental variables—and the fact that there were data for only one subject—nothing can be inferred from the test runs made to study the eyespot as a function of vehicle speed.

This research has interesting implications for the designer of highway systems. Results indicate that the driver, using foveal vision as inferred from eyespot focus, makes use of different aspects of highway features and road-marking systems in daylight as contrasted to night driving. More research is needed to establish useful design criteria.

ADDENDUM

This preliminary investigation of driver's eye movements revealed the need to determine the calibration accuracy of the eye-marker system, and to ascertain the effects of head movements and driving on calibration accuracy. In particular, the head unit support of the Polymetric system caused driver discomfort, and limited the length of time the apparatus could be worn. A new stabilization unit (Fig. 31) was designed by the research agency. In addition to being comfortable, the unit also allows the driver to communicate verbally.

A calibration experiment was designed to investigate the accuracy of the Polymetric camera in connection with the new stabilization unit. The independent variables were head movements (calibration before vs calibration after), distance (30 ft vs 60 ft), and sessions (day 1 vs day 2). In a second phase of the experiment, calibration accuracy was measured before and after driving an automobile.

The experiment was conducted by placing a target array on a blank wall of a building. The array consisted of six targets placed in a 2 ft by 3 ft matrix. The vertical and horizontal distances between the center of the targets spanned an angle of 8° 30″. Seven male college students served as subjects. A vision examination determined that all subjects had normal eye physiology.

Each calibration data collection session started by placing the apparatus on the subject in the laboratory. After the eyespot was located, the system was calibrated by using a matrix placed on the wall of the laboratory. The subject then drove the vehicle to the test site, positioned the car at 30 or 60 ft, and lined up his right eye with the center target in the bottom row of the matrix. Data were then collected while the subject traced the matrix twice. The subject then went through a series of head movements and data were collected while the subject traced the matrix twice again. The same procedure was repeated at the other distance. The subject then drove the vehicle for 0.2 mile, and positioned it at 30 ft. Data were collected while the subject traced the matrix two times. The total procedure was repeated on another day.

Error was defined as the vertical and horizontal components of the distance from the center of the target to the center of the eyespot. A product moment correlation was computed between the vertical and horizontal errors. The correlation coefficient was only 0.04. Thus, the vertical and horizontal errors are uncorrelated, and, therefore, may be analyzed separately.

Table 12 gives the means of the horizontal errors. As can be seen, the horizontal errors in the eye marker system were extremely small. Analysis of variance showed no significant effects.

The means of the vertical errors are given in Table 13. Analysis of variance showed no significant effects. As can be seen, the vertical errors are larger than the horizontal errors. This result is typical of eye-marker systems and may be due to the curvature of the cornea being greater in the vertical direction than in the horizontal direction. The magnitude of both the vertical and horizontal errors is well within the $\pm 1°$ accuracy of the system that is stated

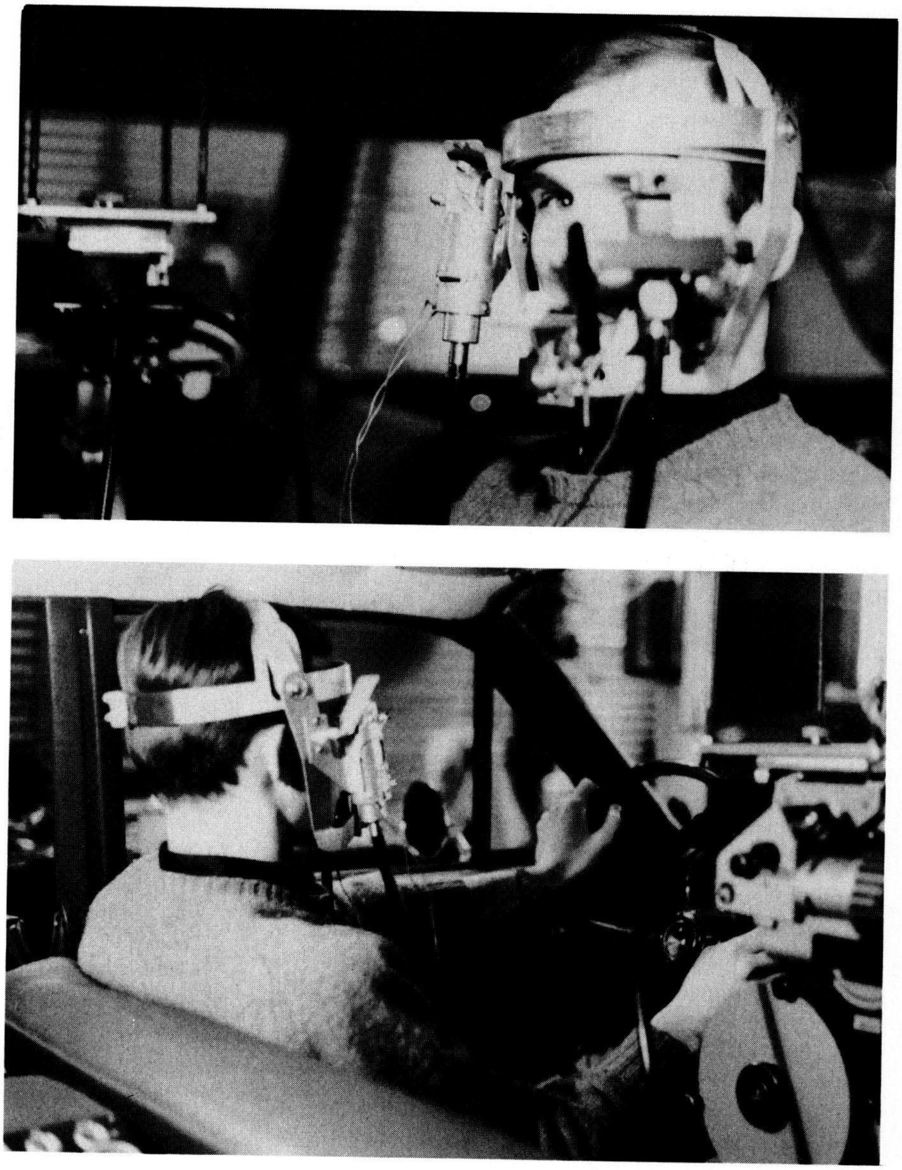


Figure 31. A new stabilization unit.

by the manufacturer. The small calibration errors may be attributed partially to the stabilization unit designed by the research agency.

TABLE 12

MEAN HORIZONTAL ERRORS

VARIABLE	LEVEL	ERROR (°)
Head movements	Before	0.31
	After	0.26
Distance	30 ft	0.26
	60 ft	0.32
Session	Day 1	0.29
	Day 2	0.28
Driving	Before	0.26
	After	0.44

TABLE 13

MEAN VERTICAL ERRORS

VARIABLE	LEVEL	ERROR (°)
Head movements	Before	0.51
	After	0.59
Distance	30 ft	0.57
	60 ft	0.53
Session	Day 1	0.52
	Day 2	0.59
Driving	Before	0.63
	After	0.96

CHAPTER SIX

A SELECTIVE VISUAL FIELD ATTENUATOR

The research and development effort was an attempt to instrument a research vehicle to be used in a study to determine the visual information needed by the driver at night.

The objective was to control the visual input of a driver while the driver maneuvers the research vehicle in a real-world environment. Thus, one requirement of the system was that it would be fail-safe and impose the least hindrance to the driver.

DEVELOPMENT

Visibility, per se, depends mainly on the following:

1. Target contrast with the background.
2. Luminance value of the visual field (background + target).
3. Exposure time of visual target
4. Luminance distribution within the visual field.

The research for which this selective visual field attenuator (SVFA) was designed pertained to finding a correlation between the driver's performance and his visual information. Consequently, an absolute measure of the visual performance was not required.

The general strategy for this research was to engage a number of subjects as drivers who would perform some driving task. During the performance of this task the visual input of the subjects would be manipulated in a controlled and predetermined manner.

The Illuminating Engineering Society has been using the visual performance characteristics as described by Blackwell (*1*), and it seemed logical to follow this practice These visual performance characteristics correlate the interdependency of target contrast and luminous background for discrete exposure times and target sizes A family of revised performance curves with sufficient field factors is shown in Figure 32.

It was expected that, in the course of the actual driver performance, the factors of exposure time and target size, as experienced by each driver, could be ignored as a significant variable The significant variables in this research would then be the target contrast and the luminance distribution within the visual field.

In order to retain the same state of adaptation, the luminous value of the visual field should remain constant Devices with these characteristics have been described by Finch (*3*) and by Blackwell, Pritchard, and Schwab (*2*), however, these monocular devices would impair binocular vision

The intent of this research and development was to devise a system by which it would be possible to illuminate the outside world of an automobile driver selectively, simultaneously introducing the possibility of degrading this visual field in a controlled manner.

This system would be used under real traffic conditions by subjects not necessarily initiated and familiar with the device. The latter condition implied equipment that would introduce the least encumbrance for the subjects. Adequate and instantaneous safety procedures available would also have to be included.

It seemed obvious to use a luminance substitution method to achieve the objectives Consequently, the following preliminary experiment was executed A 5-ft-diameter hemisphere was set up to function as a nondescript visual field in the laboratory (Fig. 33). The hemisphere was closed off by means of a vertical screen in which a square hole of 2×2 ft was made. The center of this hole was on axis with the hemisphere This axis was also the viewing direction of an observer into the visual field. Along the circumference of the screen, incandescent lamps illuminated the interior of the hemisphere. In the square opening of the screen a piece of plate glass was mounted under different angles, culminating in an angle of approximately 50° with the horizontal. This glass plate was illuminated by a light box mounted under the glass plate. The glass plate reflected part of the flux of the light box into the eye of the observer while the observer still could see straight through the glass plate into the visual field (the sphere wall). The effect obtained is similar to that experienced when driving with the sun in zenith and a newspaper on the dashboard, where the newspaper itself is invisible through its foreshortening, but its reflection, due to the slant of the windshield, is interposed between the eye and the outside world

In the laboratory experiment, the observer was replaced by a photometer to ascertain if the independent manipulation of the luminous field and the light box would produce unwanted optical interference Some cross feeding was caused by the sphere luminance, but after extending the distance between the sphere and board approximately 3 ft this effect was eliminated. This experiment indicated that clear glass could be used between the driver and the visual field rather than a half mirror, which would have impaired the driver's vision in an emergency.

It was possible to manipulate the background luminance, which is one constituting factor in the contrast of a target, commonly expressed as follows:

$$C = \frac{Bb - Bt}{Bb} \qquad \text{(A-1)}$$

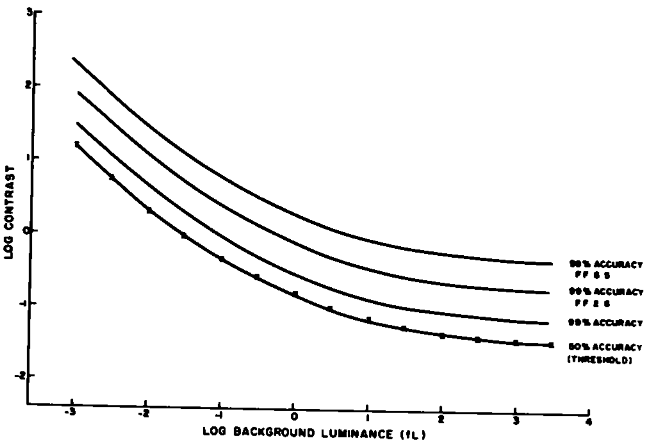


Figure 32 Revised possible performance curves

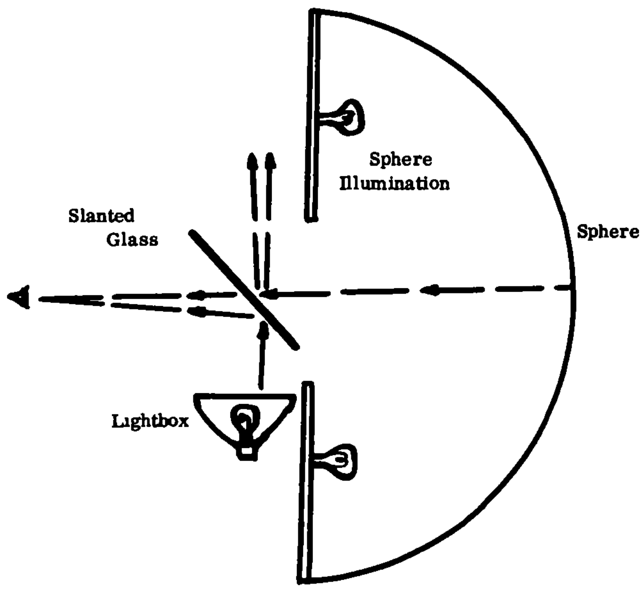


Figure 33 Veiling luminance laboratory setup.

in which

Bb = background luminance;

Bt = target luminance; and

C = contrast.

By superimposing a veiling luminance (Bv) this equation transforms as follows:

$$C_1 = \frac{(Bb + Bv) - (Bt + Bv)}{(Bb + Bv)} = \frac{Bb - Bt}{Bb + Bv} \qquad \text{(A-2)}$$

The subject observes this veiling luminance as reflected in the slanted glass (emanating from the light box) superimposed on the luminances of the outside world. In the experimental setup this outside world was the hemisphere. The luminance distribution of the hemisphere was homogeneous. In a real-world situation the luminance distribution would be nonhomogeneous and discontinuous The discontinuity of the visual field in essence is the visual information.

The visual information of the driver could be grouped in the recurrent (or repetitive) kind and the nonrepetitive. The repetitive kind would include pavement striping, edges between road and shoulder, shoulder and berm, etc. The nonrepetitive information would include signs, curves, bridges, and other off-roadway developments.

In a free-field experiment the location and geometry relative to the driver of the nonrepetitive visual information is unpredictable and it was assumed not to contribute to the information needed to control the motor vehicle.

The repetitive type of visual cues for straightaway driving remains constant relative to the driver.

The manipulation of the luminances of this repetitive occurring visual information was desired to selectively weigh the relevance of these cues.

This balancing of field luminance against veiling luminance can be done in an analog fashion by manipulating the perceived contrast, while maintaining a constant retinal illumination. Thus, the subject could drive through the same environment, while outside information was made available to him in a controlled manner.

The selective visual field attenuator (SVFA) is shown in Figure 14. It consists of the veiling luminance device (VLD) and the multi-lamp rack (MLR). From left to right, the subject looks through the VLD at the target which is illuminated by the light sources mounted on the MLR on the same vehicle that he is driving. The slanted glass makes it possible to interpose a luminous field between the subject and the target. Both the MLR and the VLD are energized and controlled from within the vehicle.

DESCRIPTION

Veiling Luminance Device

The VLD (Fig. 15) consisted of a shallow box in which three fluorescent lamps of 20 watts (nominal) were mounted. The light colors of these tubes were cool white deluxe. The box was closed off on top by a plastic lid which contained, in a sandwich fashion, Kodak Wratten filters #86 to lower the color temperature of the light source, so that it would match the multi-lamp rack's incandescent sources used for the selective illumination of the outside world. The power supply for this VLD was made versatile enough to produce a source brightness varying from 5 to 3,000 ft-lamberts, with lower levels to be achieved by neutral density filters. This meant that, at the low level, arc stability in the tubes would be precarious, whereas the high end would suffer from overload. Both conditions could be met by a proper adjustment of the cathode emission. This power supply and control circuit, as shown in Figure 34, contains a constant voltage transformer which supplies energy through a variable transformer and some stepdown transformers to the cathode of the three fluorescent lamps in a parallel fashion; the tubes proper are connected in series. This array makes it possible to vary the thermionic emission of the cathodes.

The arc current through the tubes is identical for all tubes, and is governed by a ballasting device with variable impedance. A coarse control for the large variations in flux is obtained by changing the impressed voltage on the series system of tubes and ballast. Within such a setting of this coarse control, the variable impedance ballast allows a

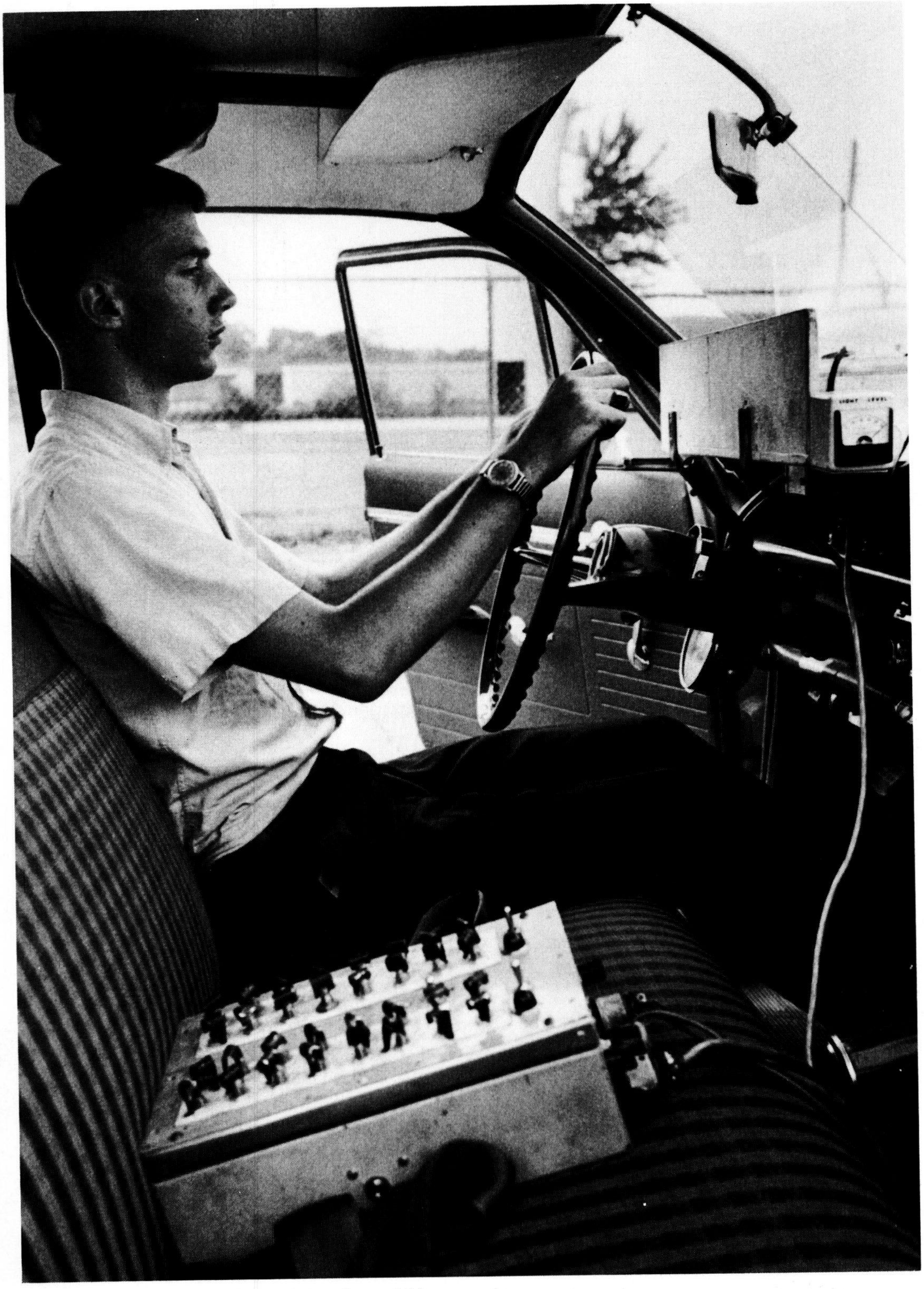


Figure 34. Master control panel for the multi-lamp rack.

variation of flux output of approximately 1 through 10. The fine control ballasting as depicted is in essence a self-contained magnetic amplifier. Another version of this fine control was a split self-inductance, which could be saturated by means of a direct current from another source. This would make it possible to tie in electronically with the control circuit for the MLR. For the run of this experiment, however, it was decided to use manual settings, and the megamp control system was selected as having a lesser electrical burden.

For safety reasons the slanted glass reflector from the laboratory experiment was replaced in the vehicular-mounted equipment with a piece of acrylic plastic. The refractive indexes of glass and acrylic plastic are close enough to warrant the substitution.

Multi-Lamp Rack

The MLR (Fig 7) was mounted at the front of the vehicle and consisted of two carrier bars, including an electric busbar system for carrying the heavy current which, in case of full load, could be as high as 150 amperes. To achieve ultimate versatility as well as luminance efficiency, sealed-beam reflector lamps with various beam spreads, as follows, were used:

ITEM	WATTS	VOLTS	HORIZONTAL (°)	VERTICAL (°)
GE par 36 #4303	40	6.4	8	6
GE par 36 #4601	30	6.0	50	25
GE par 36 #4009	30	6 0	80	30

Each sealed beam was mounted individually with its own power control and a mechanical mount, making rotation around its axis possible. These sealed-beam reflector lamps have electrical characteristics that vary between 30 and 40 watts each, with designed voltages of 6.0 to 6 4 volts To modulate the beam intensity it was necessary to control the energy to the lamp directly at the location of the lamp rather than a full-current remote control which would have introduced an exorbitant mass of heavy cables A simple transistor circuit was designed in which the two parallel transistors function as an on and off gate as well as a modulating control, the signal of which has been obtained from a third transistor in order to reduce the control current to a minimum of 5 milliamperes. A number of individual controls can be varied at will and overridden by one master control. This master control allowed overriding, not only for experimental purposes, but also for panic situations where either driver or experimenter could make as many as 20 high-intensity headlamps available (Fig. 34). The master control and individual controls were energized from some large dry batteries independent of the vehicular generating system Subsequently, the transistor circuit not only modulatd but maintained constant voltage at the light sources independent of large voltage fluctuations in the vehicular generating system The vehicular generating system had a total capacity of approximately 200 amperes This burden was so high that it would function as an electrical brake on the vehicle. Sufficient buffering capacity was introduced by installing 10 large heavy-duty 12-volt batteries in the trunk of the vehicle.

OPERATION OF THE SVFA

The subject seated in the driver's position has an interposed veiling luminance which affected a lateral width of approximately 35° and a vertical width of approximately 15° of his visual field The diffuse top panel of the VLD was in a horizontal position and, as such, formed a horizontal table, on top of which opaque or transparent cutouts could be placed to vary the shape or luminous gradient of the driver's visual field. The experimenter, at will, could decrease the outside illumination, simultaneously increasing the veiling luminance and by doing so maintain the same adaptation brightness for the subject. The experimenter was seated adjacent to the driver and had a full view of the roadway ahead of him. The controls were conveniently housed in a flat box held on the lap of the experimenter

SAFETY OF THE SVFA

The combination of the MLR and the VLD includes the following precautions.

The outside world was illuminated at a higher level than normal, using the MLR. The increased visibility was then degenerated by interposing a veiling luminance optically between the driver and his outside world

None of the devices made physical contact with the driver.

The controlling experimenter had unobstructed view and he not only could null the veiling luminance (VLD) in front of him, but also could make more external illumination available by switching on more lamps on the MLR

FUTURE RESEARCH

The selective visual field attenuator developed for this project has shown a greater potential in a dynamic evaluation of the visual field in correlation with driver performance. This SVFA should be regarded as a tool rather than a goal in itself, and should be used to compare laboratory and roadway visual evaluations achieved by different methods. In doing so, good cross correlation could be found between different investigating interests.

It seems highly feasible to modify and adapt the SVFA to conduct fact-finding investigation in high-accident areas. The suspected area would be surveyed by a vehicle, where not a subject driver but a trained observer is moved through the specified stretches of roadway in consecutive passes, during which passes his visual information could be attenuated in a prescribed manner. The observer could record by means of movie film and/or spoken word the available remaining visual information and the approximate size and distances of the pertinent information. At the boundary conditions where the sequence of the visual information does not seem to be forthcoming with comfortable vision, the observer would have a criterion for roadway visibility. The driver of the surveying vehicle has unimpaired driving visibility, and, consequently, surveys like this could be conducted at high speed in high traffic density conditions (with safety).

Calibration of an observer, as described, could be a valuable investigation on its own. By moving the observer through a preorganized system of visual cues of known size, and then driving at a predetermined speed and consequently known target observation time, a good correlation could be found between static laboratory visual performance measurements and dynamic situations.

The VLD also could be modified to produce pulses of luminous flux, enabling the researcher to investigate dynamically performance effects due to transient adaptation.

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APPENDIX A

SYSTEM INSTRUMENTATION

INSTRUMENTED VEHICLE AND EQUIPMENT

The instrumented vehicle used in this experimentation was a 1963 Chevrolet. This vehicle was equipped with a 50-channel oscillograph recorder (Fig. A-1) that produced continuous traces of signal inputs on 400-ft rolls of 12-in.-wide photographic paper. Sensors mounted throughout the vehicle permitted the continuous recording of driver control movements (steering wheel, gas pedal, and brake pedal), together with vehicle dynamics and position (lane position and velocity). Each of these measuring systems is described briefly in the following.

VELOCITY MEASUREMENT

Vehicle velocity was obtained by attaching a tachometer generator to the vehicle transmission and by feeding the output from this generator (which was proportional to vehicle speed) to the oscillograph recorder.

STEERING-WHEEL POSITION MEASUREMENT

A 10-turn precision potentiometer was geared to the steering column, and a regulated 10 volts of power were applied across the potentiometer. Changes in steering-wheel positions were then obtained by measuring the changes in the applied voltage.

GAS-PEDAL AND BRAKE-PEDAL POSITION MEASUREMENT

Gas-pedal movement and brake-pedal movement were obtained in a manner similar to that used to obtain steering-wheel position. Potentiometers were attached to both of these controls, and position changes were obtained by measuring changes in a constant applied voltage that was placed across the resistors.

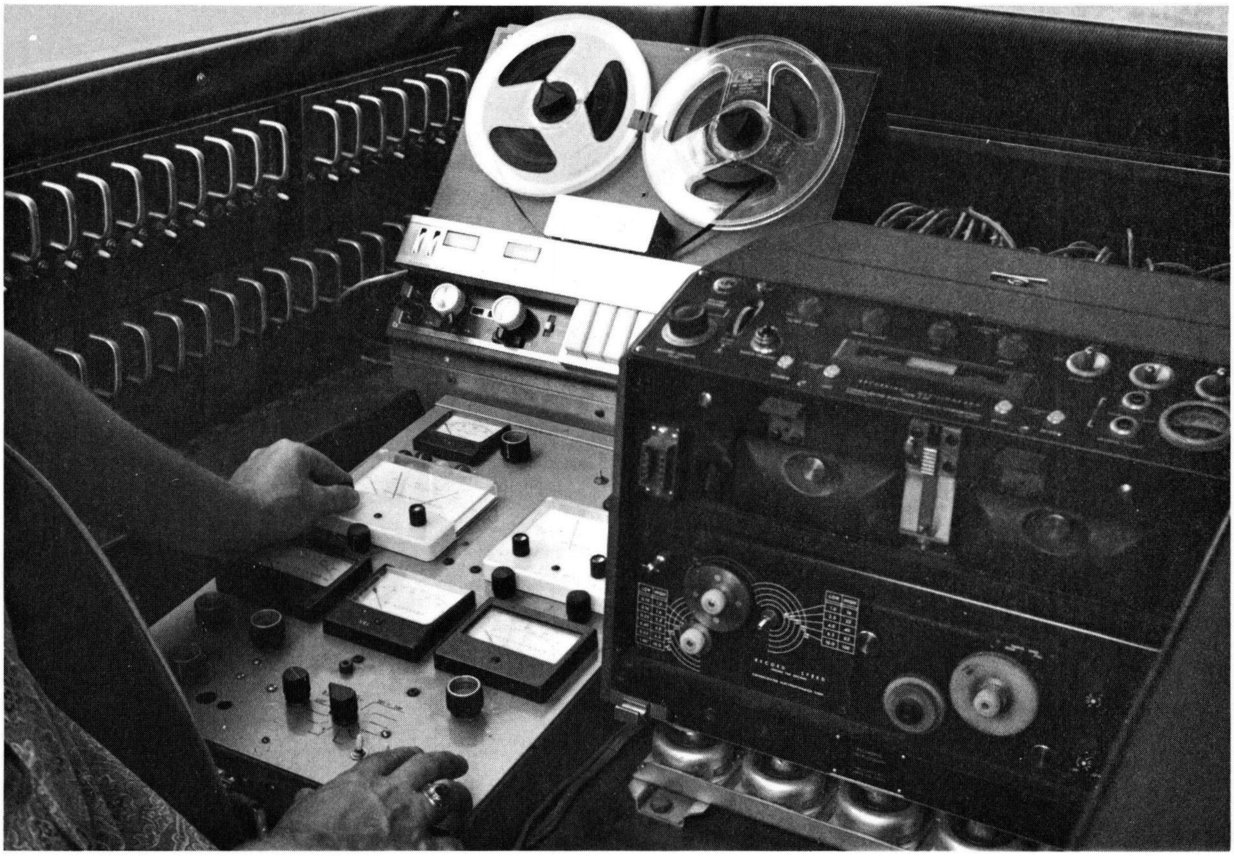

Figure A-1. The instrumented passenger vehicle.

VEHICLE LANE POSITION MEASUREMENT

The lane position measuring device shown in Figure A-2 was mounted on the right-hand side of the instrumented vehicle. In operation, the detector portion of the device rotates back and forth, scanning the ground alongside the vehicle, which was uniformly illuminated by two 40-watt 12-VDC floodlamps. With these lamps a cadmium sulfide cell was used to measure the light reflected from the pavement. The retro-reflective white line painted on the highway produced a 3-footcandle contrast with the surrounding pavement. Consequently, when the electrical resistance of the cadmium sulfide cell changed, a corresponding change occurred in the output signal from the system. By determining the point in the arc of the detector arms sweeps at which this change took place, the lateral position of the vehicle was obtained.

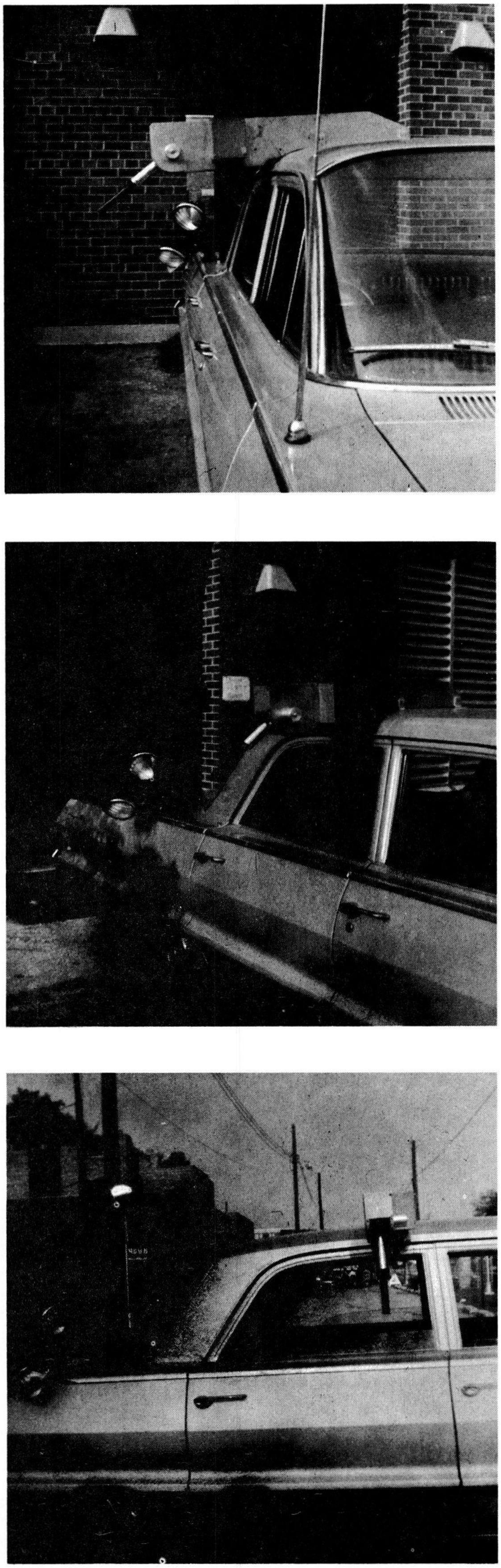

Figure A-2. Lane position measurement equipment.

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