FACTORS AFFECTING THE PERCEPTION OF RELATIVE MOTION AND DISTANCE BETWEEN VEHICLES AT NIGHT

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SYNOPSIS

It has long been known that accidents and fatalities closely parallel the number of hours of darkness per day. Accident Facts for 1950 shows almost three times the fatalities by night as by day when mileage is held constant.

Other sources indicate hazards from rear-end collision are not only much greater with respect to frequency but also with respect to severity, particularly on high speed thoroughfares and in sections where hills and grades pull down the speed of heavily loaded vehicles.

That self-illuminated, reflectorized, or high reflecting surfaces, are more visible at night is axiomatic. However, no quantitative data were previously available which could be used in evaluating the problem or for instructional and training purposes. Some of the more subtle aspects, such as the perception of distance and change in distance when overtaking a visible object and ease of seeing and judging spatial relationships, have not been properly considered.

In this study three sets of experiments were carried out, two under highway conditions and one using a laboratory device simulating roadway conditions. Variations in headlight beams, both impinging and opposing, were introduced in the laboratory study. Comparisons of the two show similar relative results for laboratory and road studies when distances set for experimental study are taken into account.

Visibility of a lead vehicle was varied by using different sizes and intensities of tail-gate treatment with one and two tail lights used as a standard of reference.

Surfaces having high-reflection characteristics were found to decrease the time and difficulty for the discrimination of relative speeds between vehicles. The higher intensities also did not show as great an increase in time and difficulty when

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the size of the tail-gate surface was decreased. Certain other beneficial effects of high-contrast treatment are shown when variations of opposing and impinging headlight beams were used.

Night driving accidents are known to be far out of proportion to the number of vehicles being driven and the mileage traveled. Available estimates show that 60 percent of all automobile accidents occur while 75 percent of the vehicles are in the garage. Correction for mileage driven during the hours of darkness further emphasizes the need for greater visibility of all objects of potential contact to a moving vehicle at night.

One of the most dangerous types of night-driving accidents is the rear-end collision. With higher speeds it is becoming even more serious in highway transportation. Motor carriers are much interested in reducing accidents of this type on super-highways.

The crux of the problem lies in the ability of a driver to see and accurately discriminate the relative motion and distance of an object or vehicle ahead. Psychologists refer to this phenomenon as perception of relative motion and distance. The effect may be produced in one of two ways: (1) both vehicles or objects may be moving in the same direction at different speeds, or (2) one may be stationary and the other moving.

Since available accident statistics do not include a classification for inadequate perception or judgment of relative motion and distance, it is not possible to determine the exact frequency of such accidents. However, the frequency and severity of reported accidents of this type were deemed sufficient to warrant the studies being reported. While the problem is generally recognized, no quantitative data have been introduced which might be used to reduce this hazard on the highways.

The purpose of these experiments was to measure a driver's perception or judgment time to various degrees of visibility of a vehicle ahead under normal roadway conditions. The basic psycho-physical method of judgment time was used. The general hypothesis set up for experimental investigation was that increasing visibility of the lead vehicle will (1) decrease the time for determining the direction of the speed differential, (2) decrease the difficulty of perception or judgment of the speed differential, and (3) decrease the distance the vehicle is judged to be away.

It is assumed, for the present, that measurements under ideal conditions of atmosphere, etc., will give relative indices of comparison. Further studies are being planned to measure the effects of such factors as smoke, fog, rain, and other contributing variables. Other assumptions made were:

1. The normal variations in fixation and reaction time of an observer constituted a negligible source of error between the various experimental conditions.

2. The relative discrimination efficiency for the various experimental conditions would not be materially affected by actual driving performance.

3. Variation in abilities of the observers affected all the experimental conditions the same.

4. Each observer was motivated to do his best on each observation.

As a criterion of visibility, the four factors listed by Luckiesh (3) were used. These factors are (1) time for perception, (2) size of the visual task in visual angle, (3) amount of over-all illumination, and (4) the contrast between the visual task and background. In the experiment, perception time or judgment time was considered as the dependent

variable. The other three criteria of visibility as they affect perception time were treated as independent variables.

The three series of experiments were: Series I in which contrast ratios were varied in actual highway conditions, II in which the size and contrast ratio were varied, and III in which a repetition of I was made under laboratory conditions with certain lighting changes.

Apparatus and Procedure for Actual Roadway Experiments

In Series I of these studies two vehicles were used on the highway for the experimental observations. These consisted of an Oldsmobile sedan and a panel truck equipped with suitable apparatus as shown in Figure 1.

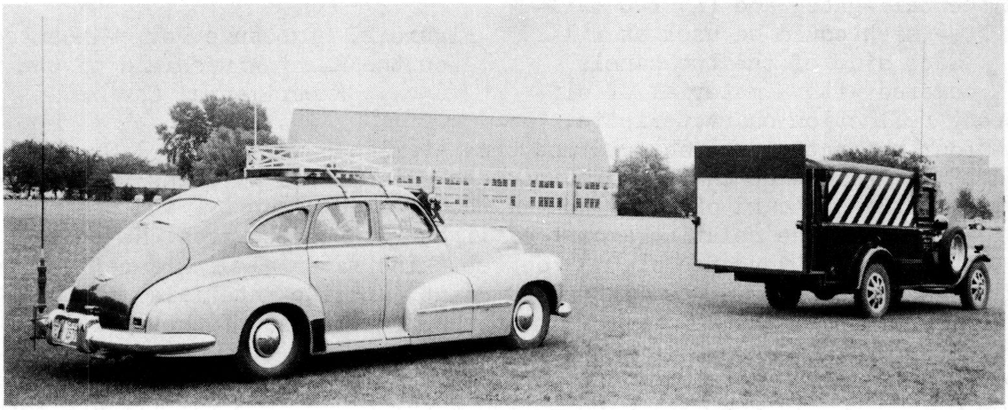

Figure 1. Car and Truck Used in the Experiment, Showing External Equipment on Car, and Panel Rack on the Back of the Truck

The essential units of the apparatus in the test car for the road experiments were: (1) an exposure device which restricted the vision of the subject until a certain instant when exposure was desired, (2) a timing device registering in hundredths of a second was started when the observer had the first clear view ahead, (3) an electronic voice key which made it possible for a verbal response to stop the timing unit, (4) a radio receiver and transmitter for communication with the other vehicle, and (5) the standard headlights for illumination of various stimuli presented. A more detailed description of the apparatus used was made by Kjerland and Lauer (1).

The exposure device (Figure 2) consisted of a rotating shutter mounted on the right-front window of the test car. With the shutter in the vertical position, the observer's vision was restricted by directing him to fixate on a white target just below the lower edge of the shutter at an object 150 feet away. A soft ball painted white was used for this purpose. This permitted the observer's eyes to be adapted to the illumination level produced by light reflected from the roadway and to be accommodated for distance as they would be when driving. (Accommodation over 20 ft. is considered infinity.) The observer had unrestricted vision ahead when the shutter was in the horizontal position. Power to rotate the shutter was supplied by a spring and the release controlled by a solenoid-operated lever which meshed with a ratchet wheel. A micro-switch which opened the shutter also started the Springfield time clock. When

the observer responded into the voice key the timer was stopped and the shutter closed.

The headlights of the test car were measured at the "hot spot" of the upper beam and were found to have approximately 75,000 b.c.p. in the visible spectrum.

Equipment for the truck consisted of: (1) two-way radio as in the test car, (2) two 48- by 68-in. plywood-target or tail-gate panels, (3) a rack for holding the panels on the tail-gate, and (4) two tail-lights which could be used at will.

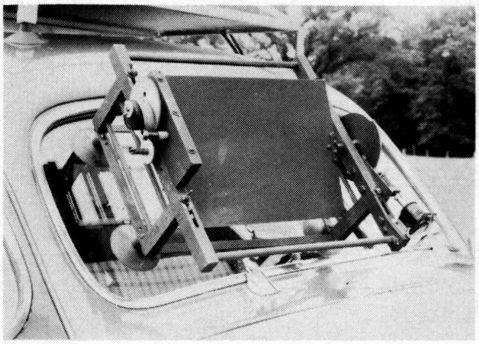

Figure 2. Exposure Device Mounted on the Right Windshield of the Experimental Car

Each side of the two panels was covered with a material of different reflection characteristic. The four reflection characteristics thus available were 0.04, 1.0, 40, and 220. Reflection characteristics were established by using flat white paint as the standard of reference and designated as unity, and the numbers represent the relative amount of light returned towards the source at an angle of divergence of 0.33 degree. The material with a reflection characteristic of 0.04 was flat-black paint, and the materials with characteristics of 40 and 220 were reflectorized materials of the reflex-reflector type.

A tail light was mounted at vertical center of the panel on each side of the panel rack. With both lights turned on, the tail lights were found to give approximately 2.6 b.c.p. in the visible spectrum. The headlights of the truck were turned off during the experimental trials to eliminate any lateral cues. The rack on the back of the truck held the panels securely in a vertical position with detachable clamps to make changes possible in the minimum of time, which was of the order of one minute.

A level gravel road was selected as the site for the experimental trials. The road was seldom traveled and no trials were made when there were other vehicles in the vicinity. The procedure required that the test car be stationary and the truck either backed towards or driven away from the test car. The observer sat in the right-front seat of the test car and was instructed to determine as quickly as possible the direction of movement of the vehicle ahead after the shutter opened. He was directed to call out "faster" if the vehicle was going away, and "slower" if the distance between the vehicles was decreasing. Each observer was given a short training period on the laboratory apparatus to facilitate the speed and accuracy of response. The transceiver was used by the operator in the truck to indicate when the truck was in the proper position for the trial to begin and by the experimenter in the car to signal when the trial was completed.

After each trial was completed the perception, or judgment, time was recorded and the subject asked if it had been very easy, easy, of average difficulty, difficult, or very difficult to perceive the direction of movement. After the series of trials on each experimental condition he was again asked to estimate the distance as well as speed differential in miles per hour between the two vehicles. In all cases the distance and

speed differentials were as nearly the same as possible, since it was desired to determine whether one experimental condition was judged consistently different from another under such conditions. The difference in distances at about 500 feet would produce changes considered to be less than the j.n.d. (just noticeable difference).

Results for Series I

For Series I the truck was exposed at a distance of 500 feet and was moving at a speed of 5 mi. per hr., either towards or away from the observer in the test car.

The six experimental conditions presented to 24 subjects for a total of 576 observations were: (1) A panel with reflection characteristic of 0.04 and no tail lights; (2) The same panel with one tail light on the left side; (3) The same panel with two tail lights, one on each side; (4) A panel with R.C./2 of 1 with no tail lights; (5) No tail lights and a panel with R.C. of 40; (6) R.C. of 220 with no tail lights.

Each experimental condition was exposed four times to each subject, twice with the distance increasing and twice with it decreasing. The order of presentation was systematically rotated in an effort to cancel out such factors as practice and fatigue. The observers for all three series were males and held driver licenses.

In this series of experiments, size and contrast were used to vary the visibility of the truck. The flat-black represented minimum visibility. The condition using one tail light was the minimum highly defined visual angle used. Two tail lights provided a horizontal visual angle of a magnitude about 20 times greater, while the three panels with the higher reflection characteristics offered a horizontal angle about the same as that of the two tail lights and a vertical angle as discrimination cues. (There are eight or nine psychological cues for discriminating distance which cannot be reviewed here.)

Variations in contrast were achieved through the use of the panels with different reflection characteristics as already described. Over-all illumination was kept constant in this series by using only the high beam of the headlights on the test car with the motor running at a speed to insure charging of battery by the generator.

The mean perception times,

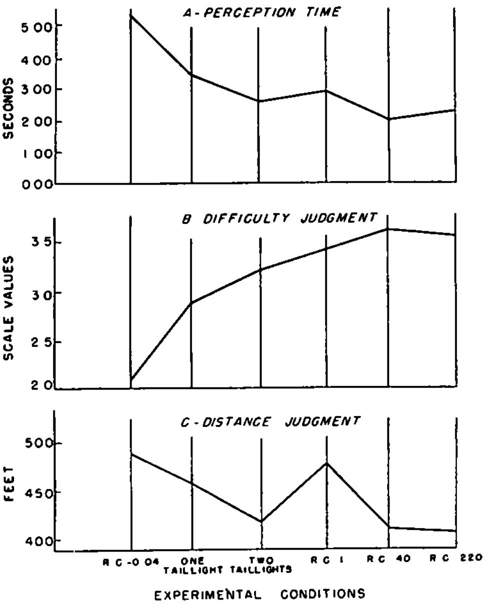

Figure 3. Mean Values for Series I

/2 Throughout the discussion of results reflection characteristics will be designated as R.C. and the relation to flat-white as 1. The other surfaces will be designated as 0.04, 40 or 220.

difficulty judgments, and distance judgments are shown in Figure 3, A, B, and C. Because of greater pragmatic value and limitation of space, only data for the distance decreasing between the vehicles are presented here, and since there were no statistically significant differences in the speed judgments these data are also not included.

The data were subjected to the T-test to determine if mean differences obtained were statistically reliable. In all cases where differences are indicated as significant in the remainder of this paper they are significant at the 5 percent level or higher unless otherwise stated, this being the accepted level for the acceptance or rejection of a hypothesis being tested.

Statistically significant differences found in Series I were:

A. Perception time. (Note values on the graph).

1. The mean times for one tail light, two tail lights, R.C. 1, R.C. 40, and R.C. 220 were all significantly less than the mean time for R.C. 0.04.

2. The time for two tail lights was significantly less than for one tail light.

3. The times for R.C. 40 and R.C. 220 were significantly less than the time for either one or two tail lights.

4. Since one subject contributed heavily to the mean differences between R.C. 1 and R.C. 40 and R.C. 220 they were not statistically reliable, even though the mean differences were greater than in the case of two tail lights.

B. Difficulty judgments. For statistical treatment, scale values of 1 to 5 were assigned the levels in the difficulty scale: 1, very difficult; 2, difficult; 3, average difficulty; 4, easy; and 5, very easy.

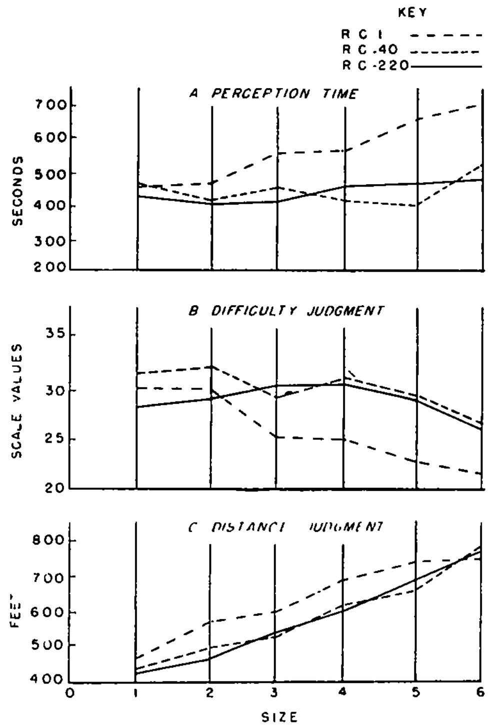

Figure 4. Mean Values for Series II.

1. Statistically reliable differences for the judgment of difficulty were in the same comparisons as for the perception time, except in two cases which were not significant:

a. The difference between one and two tail lights.

b. The difference between R.C. 220 and two tail lights.

C. Distance judgments.

1. Two tail lights, R.C. 40, and R.C. 220 were judged significantly closer than were the experimental conditions of R.C. 0.04 and R.C. 1.

As two trials were given for each subject on each experimental condition for the perception times and difficulty judgments, it was possible to obtain reliability coefficients for the method by correlating the results from the first trial with the second. The Spearman-Brown formula was applied to the obtained correlations to estimate the reliability of the combined trials. Reliability coefficients obtained are shown in Table 1.

Table 1

Reliabilities for Perception Time and Judgment of Difficulty for Series I Experiment.

Experimental Condition	Reliability Coefficients	
	Perception Time	Difficulty Judgment
R.C. 0.04	0.792	0.562
One tail light	0.932	0.726
Two tail lights	0.875	0.567
R.C. 1	0.915	0.715
R.C. 40	0.790	0.600
R.C. 220	0.942	0.882

Results for Series II - Roadway Experiment

For Series II the same general conditions were used as for Series I except that the truck was exposed at a distance of 700 feet. In this series size and contrast were the independent variables set for experimental study. Six different sizes of the panels with reflection characteristics of 1, 40, and 220 were exposed to 24 observers. Two trials were given to each observer with the distance decreasing, but to reduce the total number of trials there was no standard number of trials for the distance increasing since their observations were considered to be secondary. Only enough trials with the truck traveling faster were included to insure that a choice situation was maintained. A total of 54 trials was given to each subject, making a total of 1,296 separate presentations. The order of presentation was rotated to cancel out any methodological errors.

Each size of the stimulus panels exposed was 70 percent of the next larger size to give proper psychophysical discriminative units. The six sizes used were:

(1) 46.2- by 67-in.
(2) 41- by 53-in.
(3) 32.3- by 46.9-in.
(4) 27- by 39.3-in.
(5) 22.6- by 32.9-in.
(6) 18.9- by 27.5-in.

Size of the panels was varied by attaching a flat-black roll-type window curtain on each side of the panel rack on the truck. Each curtain was pulled into the center and hooked to frame the sizes smaller than the original panels. This made possible the use of the same stimulus surface for all sizes and also saved some time in making changes. Results obtained for Series II are shown in Figure 4, A, B, and C.

The statistically significant differences for this series were:

A. Perception time.

1. For size 3 (see sizes listed above) the time for R.C. 220 was significantly less than for R.C. 1.
2. In the case of size 5, the times for R.C. 40 and R.C. 220 were significantly less than for R.C. 1.
3. For size 6, the time for R.C. 220 was significantly less than for R.C. 1. The difference between R.C. 40 and R.C. 1 was statistically reliable at the 10 percent level.

4. For R.C. 1, there was a significant increase in the times as the size decreased, i.e., between size 1 and sizes 5 and 6.

B. Difficulty judgments.
1. For sizes 4, 5, and 6, R.C. 1 was judged significantly more difficult (lower scale value) than were the conditions of R.C. 40 and R.C. 220.
2. In the case of R.C. 1, sizes 1 and 2 were judged significantly easier than sizes 3, 4, 5, and 6.
3. For R.C. 40, sizes 1, 2, and 4 were judged significantly easier than size 6.
4. In the case of R.C. 220, sizes 3 and 4 were judged significantly easier than size 6.

C. Distance judgments.
1. R.C. 40 was judged significantly closer than R.C. 1 for sizes 3, 4, and 5.
2. R.C. 220 was judged significantly closer than R.C. 1 on size 4.
3. In the case of all three, R.C. 1, R.C. 40, and R.C. 220, there were significant increases in the distance judgments as the size was decreased.

Reliability coefficients were obtained for each different reflection characteristic on all six sizes and are shown in Table 2.

Table 2

Reliabilities for Perception Time and Judgment of Difficulty in Series II Experiment.

Reflection Characteristics	Reliability Coefficients: Perception Time	Reliability Coefficients: Difficulty Judgment
R.C. 1	0.921	0.635
R.C. 40	0.870	0.771
R.C. 220	0.805	0.723

Apparatus and Procedure for Laboratory Experiments.

Actual road experiments are costly and time consuming. In addition there are many limiting factors such as weather, night time observations, moonlight, difficulty of obtaining observers, etc. Consequently an endeavor was made to design an apparatus that would simulate highway situations as nearly as possible. The apparatus, shown in Figure 5, was built to the scale of ½ inch to 1 foot.

Two endless belts, driven by an electric motor through fluid-drive transmissions, were mounted in a dark tunnel 43 ft. long. On the right belt (right lane) a box, simulating a truck, was attached for carrying the various stimuli. The travel of this belt was set for an equivalent speed of 10 m.p.h. in either direction, and was controlled within an error of plus or minus 1 m.p.h. A set of opposing lights was designed for placement

on the left belt at an equivalent distance of 500 feet. This belt was kept stationary for the experiments herein reported.

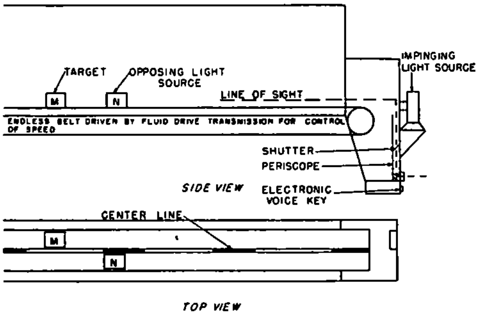

Figure 5. Laboratory Apparatus Scotometer

The subject viewed the situation through a periscope as shown in Figure 5. The line of sight was adjusted in such a manner as to prevent the subject from obtaining cues with respect to direction of travel of the target by watching the belt. A shutter was mounted in the periscope for occluding the stimulus until the desired instant of exposure. Each observer was dark adapted to approximately the night-driving level by placing him in the observation booth for 5 min. before beginning the experimental runs. Complete adaptation was not desirable for the present purposes. Two lights were placed in the periscope for approximate reproduction of the illumination produced by reflect.

The light intensities from both the high and low beams of the car used for the actual road experiments were measured at various distances. The impinging light source and the opposing lights of the apparatus were calibrated to furnish the same amount of light at the same scale distance.[3] The amount of light obtained was approximately equal to that obtained on the road with 75,000 effective b.c.p. on the upper beam and 21,000 effective b.c.p. on the lower beam. The word effective is used to indicate the power of the lights as calculated from the formula

$$\text{b.c.p.} = (\text{foot candles})(\text{distance in feet})^2$$

when the foot candles were measured at a point directly in front of the car.[4]

In the box used for carrying the stimuli a system of dry cells, variable resistance, milliameter, and two red lights was designed for reproduction of the tail lights on the truck used for the road experiments. The calibration of the tail lights was not possible with the equipment used for calibrating the headlights. Therefore it was necessary to develop a subjective method:

The truck used was placed at 600 feet, and the box with the tail lights at a scale-distance of 600 feet. Through successive adjustments of the rheostat, four observers judged when the tail lights of the laboratory apparatus were equivalent to the intensity of the tail lights on the truck. Readings on the milliameter were recorded and averaged to obtain a standard setting for the tail light intensity obtained.

In addition to the calibrations of the various lights, subjective judgments of the lights in the apparatus were obtained from several observers. They all reported that the intensity of the lights closely approximated that of situations which they had met on the highway at night.

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[3] The equipment used for calibrating the lights was a Viscor corrected Weston Photronic cell, and a portable Leeds and Northrup d'Arsonval galvanometer.

[4] This formula has been found to hold very closely for headlights beyond the distance of 60-75 feet directly in front of a car.

When the box carrying stimuli passed the point of 600 feet scale-distance, it closed a switch which opened the shutter and started the timer. The same timer and other apparatus as described in Series I were used. The decision to place the opposing lights at 500 feet and expose the stimuli at 600 feet was based upon Roper's (4) findings, that the minimum visibility is obtained when the opposing lights were between the observer and the target. (Further study of the phenomenon is being made with the scotometer.) The subject was instructed to respond with "faster" or "slower," spoken briskly into the microphone of the voice key as on the road experiments. The response of the observer closed the shutter and stopped the timer with the minimum of error. There was a slight lag of from .08 to .12 seconds which was constant for all conditions. The observer was also asked to make difficulty and distance judgments as in Series I and II. As no significant differences had been found for the speed estimations in the preceding road experiments, this factor was eliminated from the laboratory procedure.

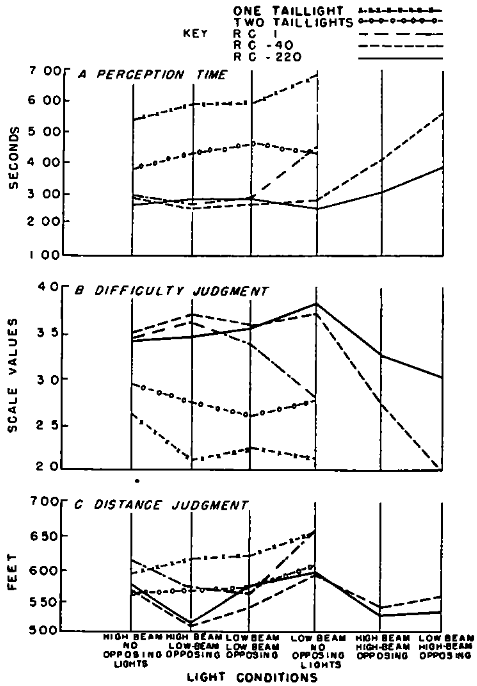

Figure 6. Mean Values for Series III

Experimental conditions/5 exposed were one tail light, two tail lights, and panels of R.C. 1, R.C. 40, and R.C. 220 of a scale size equivalent to the large-size panels used for the road experiments. These five conditions were exposed under variations of the light source and opposing lights, graduating from most favorable to the most unfavorable conditions for making the observations:

	Test Car	Oncoming Car Near Target
(1)	High beam	no opposing lights
(2)	Low beam	no opposing lights
(3)	High beam	low-beam opposing lights
(4)	Low beam	low-beam opposing lights
(5)	High beam	high-beam opposing lights
(6)	Low beam	high-beam opposing lights

For each condition two trials with the distance decreasing were given to 30 subjects, and enough trials with the distance increasing were interspersed to insure that a choice situation was maintained. It was planned to give each subject 84 trials, but in some cases the subjects were unable to see the stimuli at the scale distance of 600 feet. There was a total of approximately 2,400 observations. The order of presentation was rotated systematically.

/5 Laboratory duplication of Series I with modification.

Results for Series III

The results obtained for Series III are shown in Figure 6. The independent variables were size, contrast and over-all illumination. In some cases no points on the graphs are shown for certain conditions. It was in these cases that so few subjects could perceive the stimulus that a reliable mean measurement could not be obtained as the opposing lights completely masked the tail lights. This point is of considerable significance as an incidental observation.

The significance of the differences found in Series III are:

A. Perception time.
   1. The time for one tail light was significantly longer than for all the other conditions, except in the case of two tail lights with low beam with low-beam opposing lights.
   2. Times for either of the three panels of different reflection characteristics were significantly less than the times for two tail lights in all cases, except in the case of R.C. 1 and low beam with no opposing lights.
   3. For the light conditions of low beam with no opposing lights, there were significant differences between R.C. 1 and the conditions of R.C. 40 and R.C. 220.
   4. There was a significant difference between R.C. 40 and R.C. 220 for the conditions of high beam with high-beam opposing lights.
   5. Although only 11 subjects perceived R.C. 40 for the conditions of low beam with high-beam opposing, the difference between it and R.C. 220 was statistically reliable at the 10 percent level.

B. Judgment of difficulty.
   1. The significant differences for judgment of difficulty were in the same comparisons as for perception time, except the difference between one and two tail lights for high beam with no opposing lights was not significant.

C. Distance judgment.
   1. For the light conditions of high beam with no opposing lights, two tail lights, R.C. 40 and R.C. 220 were judged significantly closer than were R.C. 1.
   2. With high beam with low beam opposing, all conditions were judged significantly closer than one tail light. R.C. 40 and R.C. 220 were significantly less than two tail lights and R.C. 1.
   3. All the conditions were judged significantly closer than one tail light for low beam with low-beam opposing.
   4. One tail light and R.C. 1 were judged significantly farther away than the other three conditions for low beam with no opposing lights.

For the variations in the amount of over-all illumination, the main significant differences were:

A. Perception time. One tail light and R.C. 1 were significantly less with high beam with no opposing, than on low beam with no opposing lights.

B. Difficulty judgment. One tail light and R.C. 1 were judged significantly more difficult on low beam with no opposing, than on high beam with no opposing.

C. Distance judgment. One tail light and R.C. 1 were judged significantly closer on high beam with no opposing, than on low beam with no opposing lights.

The main significant differences for the variations in opposing lights were the increases in time and difficulty for R.C. 40 and R.C. 220, and the decrease in perception distance for the other experimental conditions when high-beam opposing lights were used. The reliabilities for the experimental conditions are shown in Table 3.

Table 3

Reliabilities for Perception Time and Judgment of Difficulty on Series III Experiment.

Experimental Condition	Reliability Coefficients: Perception Time	Reliability Coefficients: Difficulty Judgment
One tail light	0.976	0.659
Two tail lights	0.800	0.564
R.C. 1	0.701	0.564
R.C. 40	0.924	0.846
R.C. 220	0.791	0.763

Most of the observers were unable to perceive at 600 feet some of the stimuli under the conditions of high-beam opposing lights. When a subject reported that he could not see the target, it was moved towards him until it became perceptible. The distance of the target at that point was recorded. The target was then moved away, and the subject was asked to

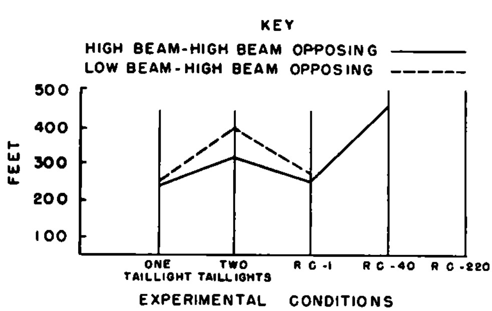

Figure 7. Mean Threshold Distances for Series III

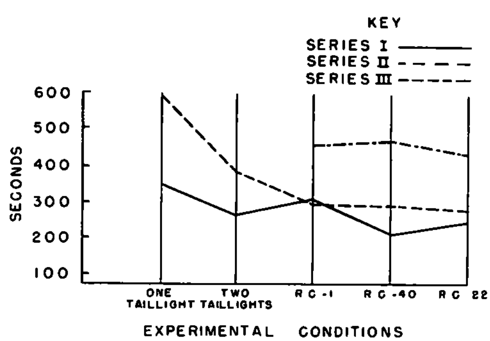

Figure 8. Comparison between Perception Times for Series I, II and III

report when he could no longer see the target. The two distances determined in this manner were averaged to determine the threshold distance. The mean threshold distances obtained are shown in Figure 7. Where there are no points on the graph, the majority of the subjects were able to perceive the target at the 600-foot experimental distance. For R.C. 40 on low beam with high-beam opposing, 19 out 30 subjects were unable to perceive it at 600 feet.

It should be recognized that the threshold distances shown are for the conditions holding only for this experiment. The distances are dependent upon such variables as intensity of headlights and tail lights, and the width of separation between the lead vehicle and the opposing lights. Width of separation appeared to be a factor because many subjects reported that they were able to perceive the right tail light first when two tail lights were used. It has been shown by Lauer and Silver (2) that the angle of declination greatly affects the tolerance of glare.

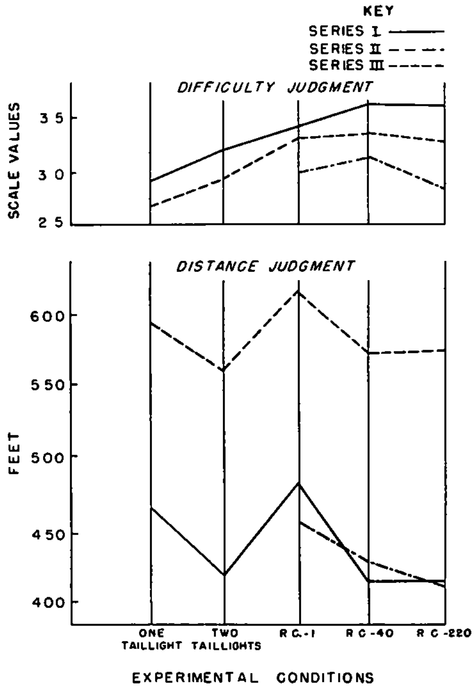

Figure 9. Comparison between Difficulty and Distance Judgments for Series I, II and III

<u>Comparison between On-the-Road and Laboratory Experiments</u>

When laboratory experiments are made there is always the question of their relationship to actual road situations. As some of the same experimental stimuli were used in both the road and laboratory experiments it was possible in this study to check the validity of the laboratory experiment. The comparison between the results for perception time, difficulty judgment, and distance judgment are shown in Figures 8 and 9.

Although the actual means varied considerably, the relationships between the conditions were maintained in most instances. The one variation between the significance of the differences was as follows:

A. Perception time. R.C. 1 was significantly less than one and two tail lights for Series III, but was not on Series I.

B. Difficulty judgment. The significant and non-significant differences occurred in the same instances for Series I, II and III.

C. Distance judgment. The significant and non-significant differences existed in the same instances for Series I, II and III.

Errors in the Judgment of Direction and Their Effect Upon the Results

Although the subjects were given definite instructions to take as much time as required to be accurate, a number of errors were made in the judgment of relative motion. The percentage of errors made for the three experiments are shown in Table 4.

Table 4

Percent of Errors Made on the Experimental Conditions

Experimental Condition	Percent Errors		
	Series I	Series II	Series III
R.C. 0.04	27.1	----a	----a
One tail light	18.8	----a	31.4
Two tail lights	12.5	----a	13.2
R.C. 1	0.0	16.3	1.7
R.C. 40	4.2	3.5	3.4
R.C. 220	0.0	10.0	3.1

a. No data obtained.

A hypothesis might be stated that there was no difference between the times for correct and incorrect responses. It was possible to test this hypothesis because in some cases a subject was correct on one trial and incorrect on the other for the same experimental conditions. For all three experiments the mean time for the incorrect responses was less than for the correct responses. In Series I and III, the difference was not statistically reliable, but in Series II it was. In other words, the hypothesis would be rejected for Series II.

However, rejection or non-rejection of the hypothesis would not change the interpretation of the significant differences which were found in the three experiments. As shown in Table 4, the greatest proportion of errors was made on the experimental stimuli which required the longer perception times. If the hypothesis were rejected, it could be stated that the mean times obtained for the one with a relatively high number of errors were actually underestimates of the true means. In that case the mean differences found would also be underestimates, and if the true differences were known the statistical confidence level would be higher than was actually found. If this line of reasoning is followed, there remains the possibility that there are true differences in the data which were not found statistically reliable. However, a similar possibility exists in any piece of data analyzed by statistical methods.

If the hypothesis were not rejected, that there was no difference between the times for incorrect and correct responses, then the statistically reliable differences would stand as found.

Summary and Conclusions

The purpose of this study was to obtain certain quantitative data relating to a driver's reactions to various conditions of visibility and perceptual value of a vehicle being overtaken on the road at night. Time

and difficulty for perception of the direction of speed differential and estimates of distance between the vehicles were obtained. Size, contrast, and over-all illumination were used as independent variables for changing the perceptual cues of the lead vehicle.

Two experiments employed actual road conditions and one laboratory experiment was carried out. The essential apparatus for measurement of the perception time consisted of (1) a shutter for control of the instant when the subject could first perceive the vehicle ahead, (2) a timer started at the first moment of perception, and (3) a voice key for stopping the timer with a verbal response when judgment was established. The data for the difficulty of perception and distance between the vehicles were obtained from judgment responses made by the subjects to a standard set of questions.

In light of the statistically significant differences obtained, the following general conclusions on the effects of the three major variables of visibility might be drawn.

A. Size of visual angle and contrast between vehicle and background.
   1. Increasing the horizontal visual angle, such as comparing one and two tail lights, reduced the time for perception of the direction of speed between the vehicles.
   2. With a contrast of sufficient magnitude, the use of a verticle visual angle of some magnitude, as well as a horizontal, such as comparing two tail lights with the rectangular panels having reflection characteristics of 40 and 220, reduced the time for perception of the direction of speed differential.
   3. Reducing the size of the horizontal and vertical visual angles of a low contrast, such as R.C. 1, increased the time and difficulty for perception of a speed differential.
   4. Reduction of the horizontal and vertical visual angles increased the distance estimates of the leading vehicle for various levels of contrast.
   5. Increasing the contrast from very low, R.C. 0.04, to relatively high, R.C. 40 and 220, reduced the time for perception of the speed differential.

B. Over-all illumination.
   1. A decrease in the amount of over-all illumination increased the time, and difficulty and distance judgments for conditions of relatively low visibility, i.e., one tail light and R.C. 1.

Although opposing lights was not one of the major factors of visibility listed by Luckiesh (3), it can be concluded that the high-beam opposing lights reduced the visibility from the increase in perception or judgment time for the high levels of contrast, and the decrease in threshold distances for the other experimental conditions. Under the light conditions as used in the laboratory experiment it was concluded that the conditions of horizontal and vertical visual angles of some magnitude, with relatively high contrast, offered the conditions of maximum visibility when high-beam opposing lights were used. Although several more specific conclusions could be drawn, it was the opinion of the experimenters that their pragmatic value did not warrant statement of them here.

In general, the hypotheses set forth for experimental testing were supported, and the use of materials giving greatest visibility and perceptual value at night significantly decreased the time and difficulty for discriminating speed differentials in most all cases studied.

For application of the above conclusions to actual highway situations, a basic assumption must be made that the differences found would hold over the wide variations of distances and speed differentials which exist on the highways today. Since the experimental conditions generally maintained their relative ranks for the three distances and two speeds used in the experiments, there is some justification for the assumption at present.

It must be remembered that all tests made here are of the more subtle aspects of perception, such as the discrimination of speed differentials found to operate in driving situations. It is axiomatic that visibility alone is a factor of brightness-contrast, although this might well be more specifically stated in quantitative terms. In summary, high perceptual values of vehicles and other objects on the highway establish a significant safety factor at night.

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