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Studies in Night Visibility

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STUDIES IN NIGHT VISIBILITY

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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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/1 Study made possible through a research grant from the Minnesota Mining and Manufacturing Co. to the Driving Laboratory, Industrial Science Research Institute, Iowa State College, Ames, Iowa.

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.

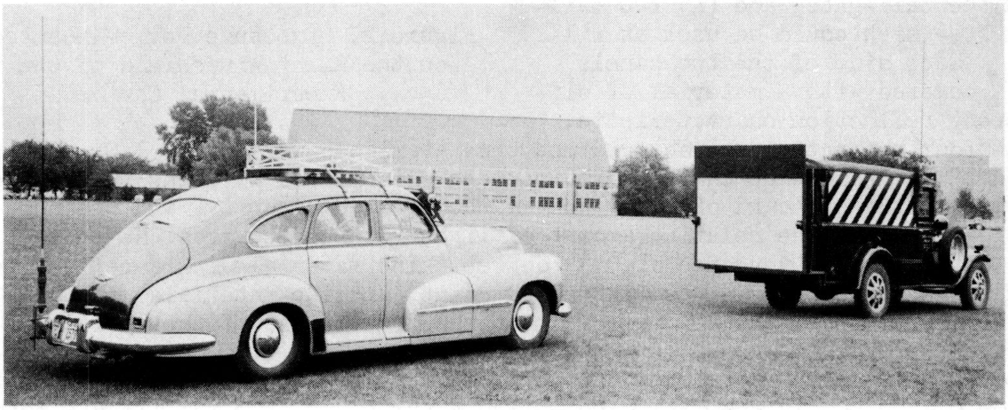

Figure 1. Car and Truck Used in the Experiment, Showing External Equipment on Car, and Panel Rack on the Back of the Truck

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.

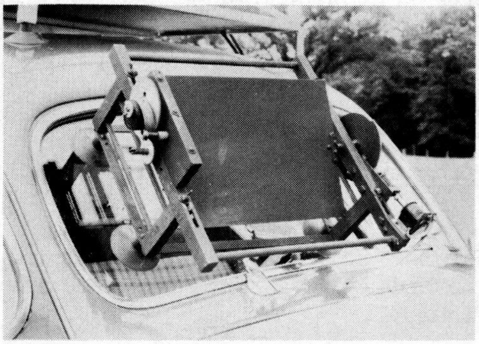

Figure 2. Exposure Device Mounted on the Right Windshield of the Experimental Car

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,

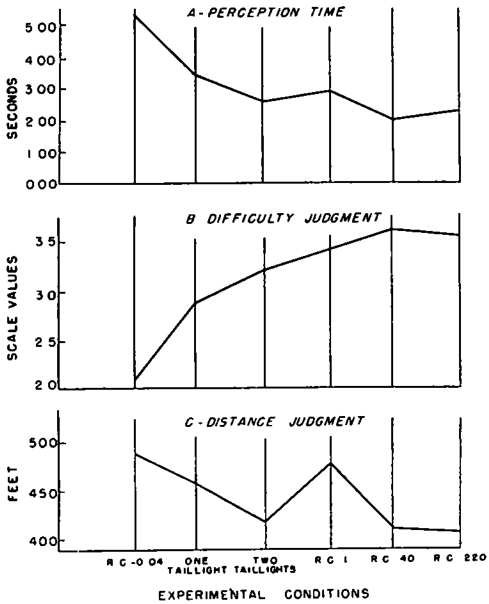

Figure 3. Mean Values for Series I

/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.

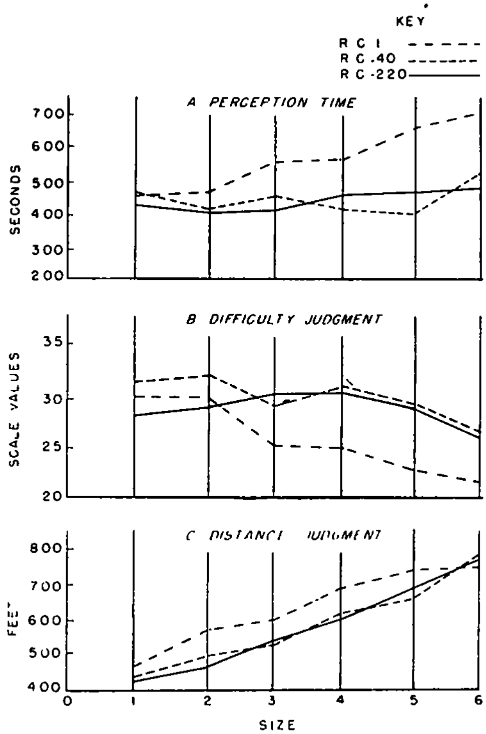

Figure 4. Mean Values for Series II.

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.

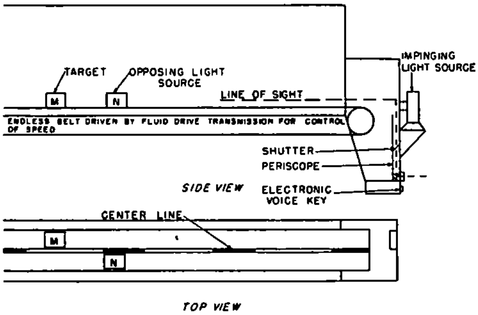

Figure 5. Laboratory Apparatus Scotometer

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.

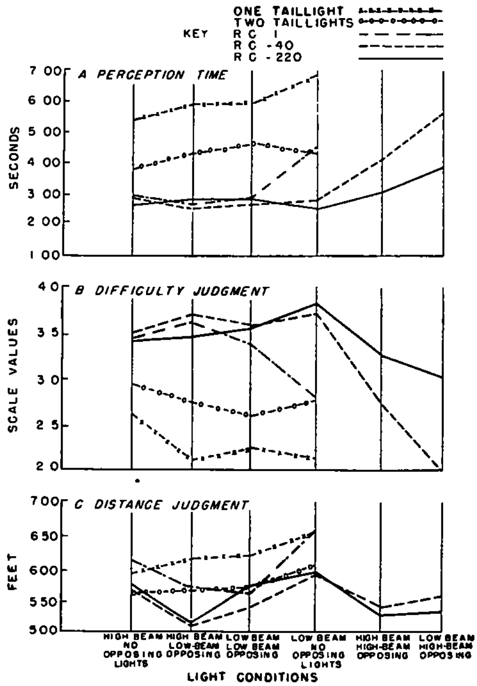

Figure 6. Mean Values for Series III

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.

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[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

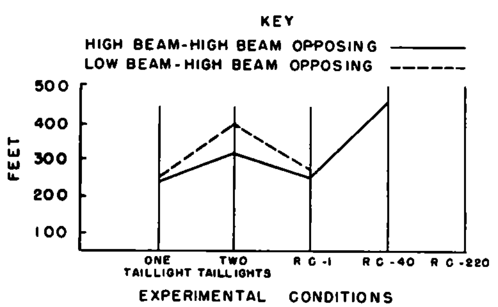

Figure 7. Mean Threshold Distances for Series III

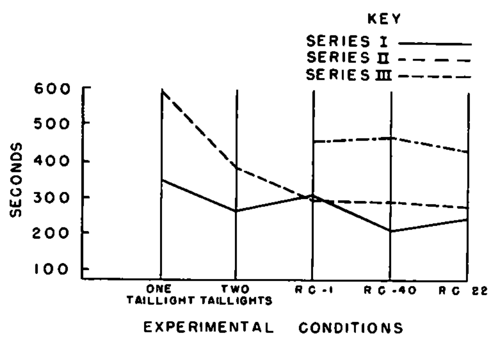

Figure 8. Comparison between Perception Times for Series I, II and III

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.

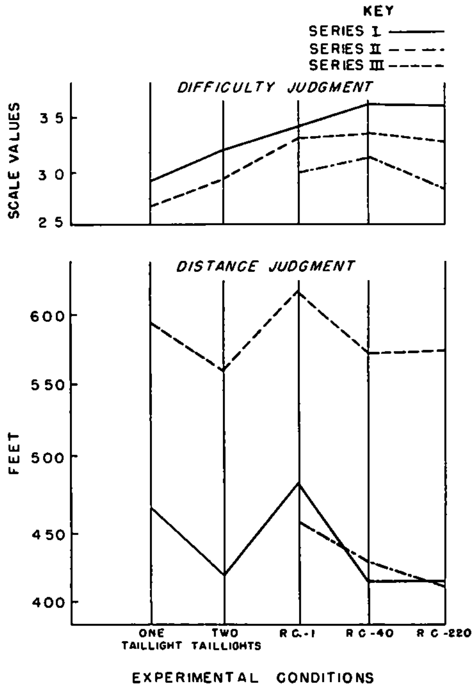

Figure 9. Comparison between Difficulty and Distance Judgments for Series I, II and III

Comparison between On-the-Road and Laboratory Experiments

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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A STUDY OF THE RELATIONSHIP BETWEEN PHOTOPIC AND SCOTOPIC VISUAL ACUITY

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(The opinions presented in this paper are those of the authors and do not necessarily reflect the views of the Department of the Army.)

Modern warfare requires that the individual soldier perform many of his duties at night. The degree of success of many military operations depends upon the ability of the soldier to see at night as well as during the day. The Army has long been using a measure of photopic visual acuity, employing a variation of the Snellen chart. In 1942, recognition of the need for training in seeing at night stimulated the development of the Army night vision tester. However, the relationship between day vision and night vision had not been determined. This project was designed to investigate the existence and extent of any such relationship. If the two types of visual acuity measures are highly correlated, there is no need to measure them separately. On the other hand, if the correlation between the two is low, separate measures of each function are needed.

Background of the Research Problem

No record has been found of a controlled experiment to ascertain the relationship between a measure of photopic visual acuity and a measure of scotopic visual acuity. Although the duplicity theory of retinal function (1) is frequently considered a law, nevertheless there are many cells of the retina which, it is thought, act together. Polyak (2) points out that the bipolar cells often collect impulses from several rods and cones, and rods and cones frequently deliver impulses to a number of bipolar cells; thus, neural effects arising in the rods and cones both diverge and converge in their transmission from receptor cells to ganglion cells. In other words, though rods and cones constitute two distinct types of receptor cells, their connection with bipolar cells indicates that they do not necessarily form two distinct functional systems as has been frequently assumed. In reviewing the evidence, then, there is some support for a theory of no relationship between scotopic and photopic visual acuity in the differences in function of the two types of end organ. However, there is also indication of a possible relationship between the two functions on the basis of interconnection of the neural structure and of the central and cortical function and in the complexity of the transmission of neural impulse. In addition, of course, one must consider behavior of the total human organism, including central and cortical functions, which could account for indications of relationship between photopic and scotopic visual acuity.

The hypothesis to be tested in this study, then, was that there is no relationship between photopic and scotopic visual acuity. In this study the limits of brightness for photopic vision were 9.5 and 10.5 log micromicro-lamberts. The limits for scotopic vision were set as 3 and 6 log micromicro-lamberts.

General Design of the Research

Selected photopic visual-acuity charts were administered to 202 subjects. These subjects were also tested with the Army Night-Vision Tester-R2X. Intercorrelations of all measures were computed using Pearson product moment correlation techniques. Correlations were also computed between the photopic and scotopic tests, correcting for attenuation in the photopic variables by utilizing reliability data from previous studies. Adequate controls with respect to test administration and other factors were maintained.

Population

Data were collected on 202 soldiers stationed at Ft. Myer, Virginia. Testing took place between May 6 and June 15, 1949. The mean age was 20.1 years with a standard deviation of 3.17 years. The age range was from 17 to 43, with only 9 cases above 25 years. Of this group 15 percent (or 31 subjects) had need of and wore glasses. For this population the mean Army General Classification Test score was 101.4 with a standard deviation of 14.86 and a range of from 56 to 140, which is fairly representative of the current Army population.

In order to enable further analysis of control factors, if desired, the following descriptive data were gathered on each subject:

1. Name
2. Army serial number
3. Age
4. Whether wore glasses
5. Army General Classification Test score
6. Seat position in ANVT-R2X testing
7. Date of tests
8. Hour of tests
9. General subjective feeling of health or well-being
10. Amount of sleep previous night

In studying the relationship between photopic and scotopic visual capacity, the problem arises of the effects of refractive correction for each of these functions. It is obvious that in the case of photopic visual acuity, sizable correction can result from refraction. In regard to scotopic visual acuity, little is known about the amount of correction effected through the use of lenses. This experiment was designed to provide a frame of reference which would render the results applicable to the military situation and more specifically to the Army situation. Consideration was given to conditions under which military subjects are likely to be tested and classified for specific duty assignments and under which those subjects would actually use their eyes in functioning in a military situation. For example, it may be assumed that very few soldiers are at present provided with special corrections for night myopia. Furthermore, it is unlikely that soldiers, even under daylight conditions, will be wearing corrections for the minor amounts of hyperopia, myopia, or astigmatism which are compatible with 20/20 uncorrected vision. Also, it is reasonable to assume that for the present the corrections that they normally "wear" will be used under conditions of night operations. Hence, research in this project was restricted to conditions which approximated the operational situation. It was decided that subjects who usually wear glasses should wear them while being tested. The findings, therefore, are limited. They do not attempt to explain the effect of refractive error on the relationship between scotopic and photopic vision. They do indicate whether the ANVT-R2X, a measure of scotopic visual acuity, is related to measures of photopic visual acuity. However, it is recognized that any relationship found may not be the same as that between uncorrected photopic visual acuity and uncorrected scotopic visual acuity.

Test Variables

The Army night vision tester, ANVT-R2X, was the measure of scotopic visual acuity used in this study. This instrument is an improved form of the ANVT-15, utilizing a radium plaque rather than a lamp as a source of illumination. The ANVT-15 has been shown to have a test-retest reliability in the mid-eighties and its validity has been determined in a previous study (3) to be about .50.

The Army Night Vision Tester-R2X is a large, metal, box-type tester utilizing eight levels of illumination. (See Fig. 1). It presents a black, two-degree Landolt Ring at 20 feet on a 4 degree background of transilluminated tracing cloth. The illumination is supplied by a self-luminous radium plaque in a diffusion box. The intensity of illumination

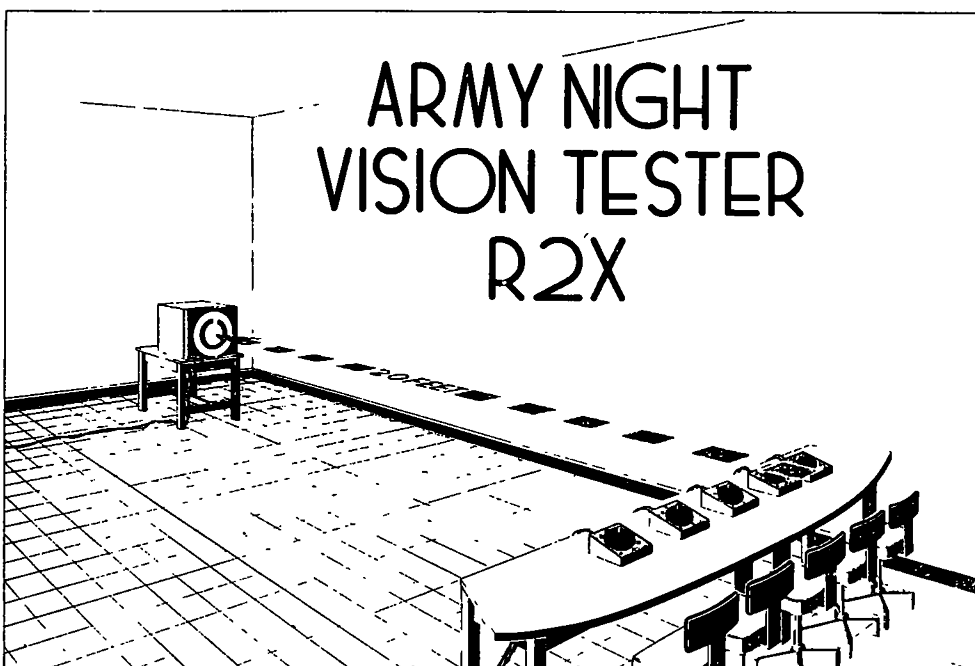

Figure 1. Scotopic Booth of the PRS Vision Laboratory

is varied by placing masking shields over the plaque; there are eight shields, each containing a circular aperture of a different size. In this way eight different levels of brightness are produced. The tracing cloth used was standard Air Force supply cloth (specification cc-c-531c). Dark-adapter subjects were seated behind their respective units at 20 ft. from the tester. An examiner presented the predetermined random settings of the Landolt Ring by turning the opening to any one of eight positions. Brightness was decreased in steps by placing the graded shields before the radium plaque.

The Taylor Low-brightness Illuminometer was used to check the brightness of the target of the Army night-vision tester. In Table 1 are given the levels of illumination in foot-lamberts and in log micromicro-lamberts of apparent brightness as used in the present investigation. (See Fig. 2).

Table 1

LEVELS OF ILLUMINATION OF THE ANVT-R2X (TEST FOR SCOTOPIC VISION)

Level	Foot-lambert	Log micromicro-lamberts
1	.00017	5.26
2	.000085	4.96
3	.000047	4.70
4	.000040	4.63
5	.000017	4.26
6	.000014	4.17
7	.000008	3.93
8	.000003	3.51

The score on the night vision test was the number of correct responses to 64 test positions as scored by the recorder.

Some investigators may question the use of the term scotopic visual acuity for the measure secured with ANVT-R2X, and may prefer the terms scotopic vision or night vision. The latter terms may be favored by investigators who feel that the variation in angular size at a specific brightness level is a more acceptable measure of acuity than the variation in brightness level holding target-size constant. It has been shown that "the relationship between visual acuity and the logarithm of illumination is sigmoid"(4). Taking this fact into account, Alphonse Chapanis increased the size of the test character from 37.5 min. to 2 deg. when accompanied by decrease in the

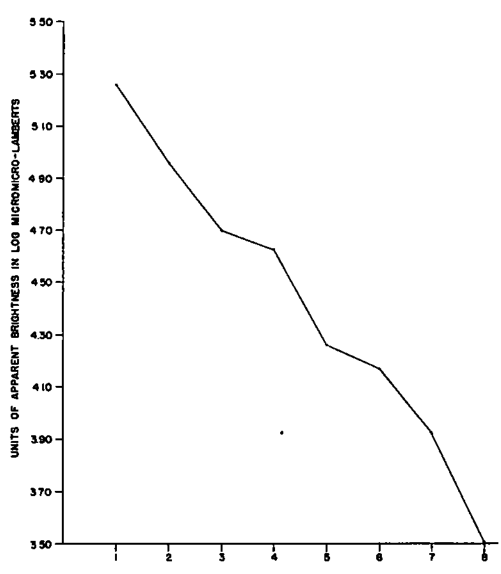

Figure 2. Illumination Levels of ANVT-R2X

general level of illumination (from 3.6 to 0.7 log micromicro-lamberts) in order to make proper threshold measures (5), and concluded that "for practical night vision testing, the size appears to make but little difference," since the relative position of subjects remains relatively stable. In addition, the RCAF Biophysics Laboratory felt that "in any test one may keep illumination constant and vary the size of the tests, or vice versa"(6).

Six variables were used to measure photopic visual acuity:

1. The Army Snellen chart was selected as a traditional measure of visual acuity, irrespective of factor-loading content.

2. The checkerboard variable grid, a wall-chart test of "retinal resolution" had been developed for a previous PRS study. It was included in the present study in order to examine possible differences in relationship that may result from differences in visual-factor content. In the factor analysis reported (7), "retinal resolution" was identified as the factor which accounted for the greatest portion of the variance on a number of tests. Of these tests, the variable grid was the one with the greatest "purity" on the retinal resolution factor.

3. Included was a measure of photopic brightness discrimination. Some investigators (8) believe that the type of scotopic measure used in this project involves a fairly heavy loading on a "brightness discrimination" factor. Hence, a measure of photopic brightness discrimination was included to determine its relationship with the scotopic measure used. Since there is no reasonably pure test of photopic brightness discrimination available, the technique of measuring this factor reported in PRS Report 763 was used (9). This technique involves use of the line resolution test and the checkerboard variable grid test. The latter is used for partialling out the resolution factor from the line resolution test which measures both resolution and brightness. The derived brightness discrimination score in the present investigation is a weighted composite of the line resolution test score and checkerboard variable grid test score. This score was obtained for the present population using the procedure developed in the earlier study (10).

The following formula for combination was adopted:

$$Z_B = \left(\frac{1}{\sqrt{1 - r^2_{RC}}}\right) Z_C - \left(\frac{r_{RC}}{\sqrt{1 - r^2_{RC}}}\right) Z_R$$

R represents a "resolution" test
C represents a test measuring "brightness" and "resolution"
B represents the derived brightness discrimination measure

In this case R represents the Checkerboard Variable Grid and C represents the Line Resolution Test. In the present study the correlation between these tests (r_{RC}) is .65. Substituting this value for r_{RC} yields the following equation: $Z_B = 1.32\ Z_C - .86\ Z_R$ which equals in terms of raw scores $X_B = .21\ X_C - .16\ X_R$. These scores were used to prepare a scatter plot of derived brightness scores against ANVT scores to check by inspection for linearity of the correlation.

4. The measure of brightness discrimination obtained with the line resolution test was compared to that obtained with two other measures which have been shown to have heavy loadings on the brightness discrimination factor. These measures were the quadrant variable-contrast and the dot variable-contrast wall-chart tests.

5. Since the Landolt ring is used as the target in ANVT-R2X, a photopic visual acuity measure with a comparable target was employed. The modified Landolt ring wall-chart was used for this purpose.

6. The Bausch and Lomb orthorater acuity tests, utilizing standard checkerboard targets, were also administered.

The Macbeth illuminometer was used to check the apparent brightness of illumination on the test charts and floor and walls of the photopic booth. The chart had the highest illumination (10.5 foot-candles), and the surroundings had no less than 6 nor more than 10.5 foot-candles. Table 2 gives the results of the illumination survey for the photopic vision booth.

Test Procedures

All tests were administered in the vision laboratory of the Personnel Research Section, AGO, in the Pentagon, Room 1C 912. This laboratory has been standardized in conformity with the specifications set by the Armed Forces National Research Council Vision Committee. (Fig. 3 and 4).

Table 2

TABLE OF ILLUMINATION OF PHOTOPIC WALL-CHARTS

Location	Illumination Ft. Candles
Front Wall	
Chart (center)	10.5
Top	10.5
Bottom	9.5
Center 1 1/2 ft. above	10.5
Center 1 1/2 ft. below	9.5
Center 1 1/2 ft. left	9.0
Center 1 1/2 ft. right	9.0
Center 3 ft. left	8.5
Center 3 ft. right	8.5
Left Wall	
3 1/2 ft. from front wall	8.2
12 1/2 ft. from front wall	7.0
20 ft. from front wall	6.3
Right Wall	
3 1/2 ft. from front wall	7.2
12 1/2 ft. from front wall	6.5
20 ft. from front wall	6.3
Floor Center	
3 1/2 ft. from front wall	8.0
12 1/2 ft. from front wall	8.0
20 ft. from front wall	6.7

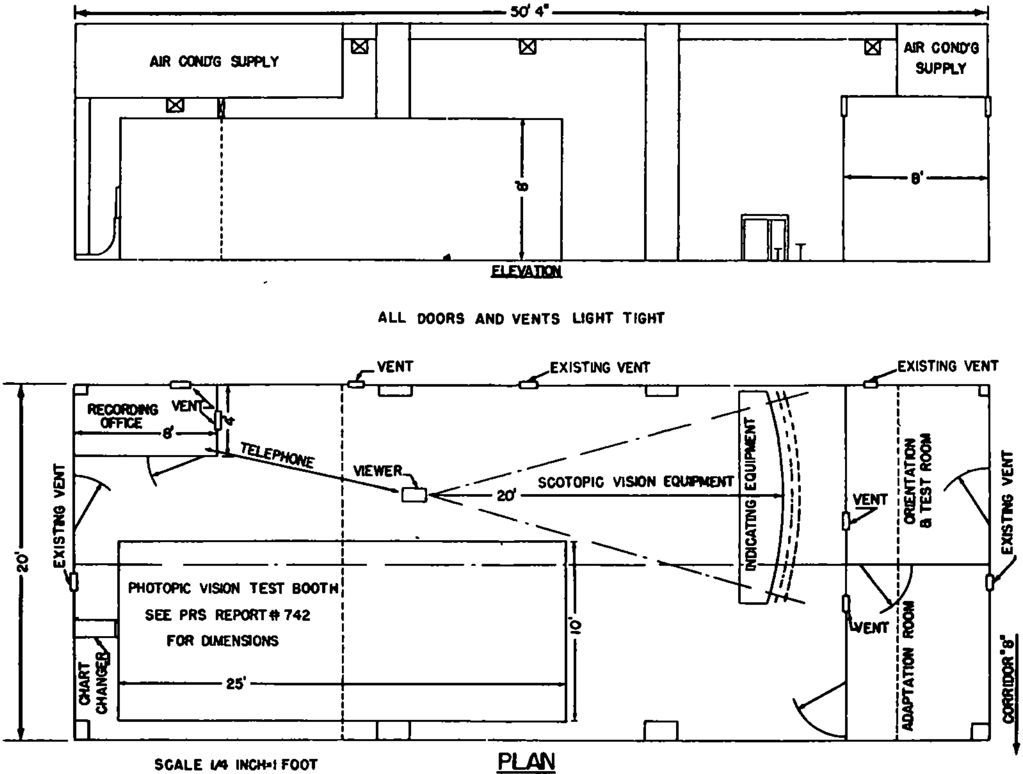

Figure 3. Layout for Vision Laboratory, Personnel Research Section, AGO

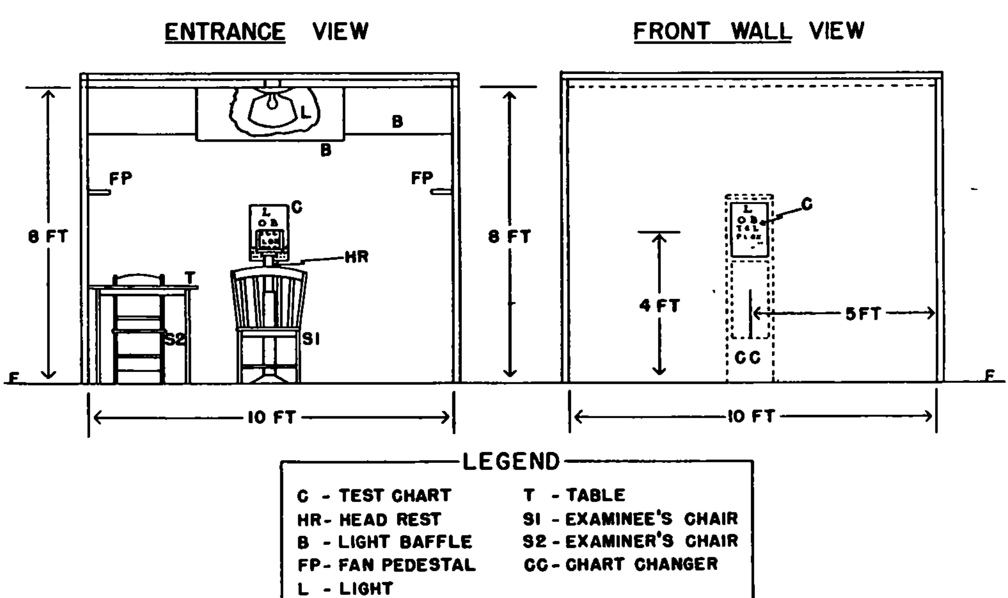

Figure 4. Construction Plan for Photopic Vision Booth of the PRS Vision Laboratory

The ANVT-R2X was administered before the photopic vision tests. Testing was scheduled for two sessions each working day, one at 8:45 a.m. and one at 1:15 p.m. Five subjects were tested at each session. The scotopic tests were administered in the light-proofed rooms of the PRS vision laboratory. The photopic tests were administered in the laboratory's photopic-vision booth.

All tests were administered for binocular vision with the refractive correction customarily used by the subject. Specific directions for administration of the tests are presented in the standard operating procedures on file in the Personnel Research Section, AGO. Subjects spent 30 min. becoming dark adapted. In groups of five, they first spent 20 min. in the adaptation room, illuminated by a low intensity (25 watts; 120 volts) frosted red lamp. This was followed by 10 min. in the light-proofed testing room. During the adaptation time, the subjects were oriented in the principles of night seeing: off-center viewing, scanning, and avoidance of fixation. They were also instructed in the test procedure and informed of the method of recording responses and scoring.

Subjects were tested for eight positions of the break in the Landolt ring at each of eight intensities of illumination, making 64 trials in all. The eight trials at the first and highest level of illumination were practice items. Duration of each trial was 10 seconds. The recording and timing were accomplished in a recording room adjacent to the scotopic vision room; communication between experimenter and recorder was effected by a small handset field telephone.

The order of presentation of individual wall-chart tests and instrument tests (refer to Figure 5 for sample items) was (1) modified Landolt ring, (2) Army Snellen, (3) quadrant variable contrast, (4) dot variable contrast, (5) line resolution, (6) checkerboard variable grid, (7) Bausch and Lomb orthorater (far), and (8) Bausch and Lomb orthorater (near). The subject was seated 20 ft. from the wall-chart in the photopic booth. A headrest was used. He was shown a sample hand-chart and given standard directions. The standard procedure provided in the Bausch and Lomb orthorater test manual was used for the Bausch and Lomb orthorater tests.

The method of scoring the wall-chart tests was that shown to be the most reliable method in the studies reported in PRS Report No. 742 (10). For the modified Landolt ring, the Army Snellen, and the line resolution and checkerboard variable grid tests, the score was the number of correct responses given by the subject up to the point where he had made three consecutive errors. For the dot variable contrast and quadrant variable contrast tests, the

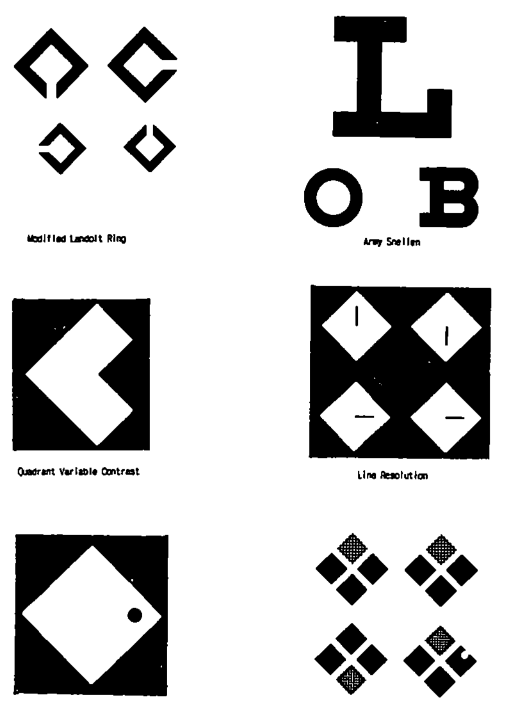

Figure 5. Photopic Visual Acuity Test

score was the number of correct responses up to the first miss. The scoring directions given in the Bausch and Lomb orthorater test manual were followed in the case of the orthorater tests.

Reliability of the ANVT-R2X

Based on the 202 subjects used in this study, the Army Night Vision Tester-R2X was found to have an odd-even reliability coefficient of .94 after correction with the Spearman-Brown formula. This measure of reliability is fairly consistent with findings on the ANVT-15, previously mentioned in this report, and it is reasonable to expect that the test-retest reliability of ANVT-R2X is as high as, or higher than, that of the ANVT-15. Hence the ANVT-R2X can be considered a reliable instrument.

Based on research by the School of Aviation Medicine (11) and also on our own analysis of the data gathered for this study, a "hot spot" /1 has been suspected on the screen of the ANVT. Using the information gathered in this study, the question as to whether a hot spot affects the reliability of the scotopic visual acuity measures obtained with the ANVT has been examined.

Table 3 indicates that seat variation for the total test is not significant and hence the hot spot does not influence total scores when the frequency of the target positions used is balanced, as they were in this study. The F test has not been computed because the variance within groups exceeds that between groups.

Table 3

MEANS, STANDARD DEVIATION, AND ANALYSIS OF VARIANCE DUE TO GROUP (SEATS) AND DUE TO WITHIN GROUP (SEATS) VARIATION

Seat	1	2	3	4	5	Total
M	49.2	49.7	50.9	48.8	48.7	49.5
σ	9.9	8.8	8.1	10.3	10.7	9.6
N	41	40	41	41	39	202

Source of Variation	Sum of Squares	d.f.	Variance
Between groups (seats)	134	4	33.50
Within groups (seats)	18538	197	94.10
Total	18672	201	

/1 The "hot spot" of ANVT-R2X may be created by the fact that there is a small area of illumination behind the larger target screen. This condition possibly results in greater illumination along the visual line of regard on certain portions of the target screen when these areas coincide with the opening in the Landolt ring and may result in an easier or in a more difficult item, depending on the line of regard from the seat position to the target position.

Reliability of the Photopic Test

Reliabilities of the photopic visual-acuity measures were not computed on the populations used in this study but secured from a previous study (12). The test-retest reliabilities of the six wall-chart photopic visual-acuity tests are given in Table 4. Reliability estimates for the two photopic visual-acuity tests from the Bausch and Lomb orthorater instrument were also secured from the previous study, PRS Report 742, and are also given in Table 4. The reliability estimate on the derived measure for brightness discrimination is .55.

Table 4

CORRELATIONS OF THE SCOTOPIC VARIABLE WITH THE PHOTOPIC VARIABLES, CORRECTED FOR ATTENUATION OF THE PHOTOPIC VARIABLES

Photopic Variables	Correlation with ANVT-R2X	Correlation with ANVT-R2X, Corrected for Attenuation	Coefficient of Reliability, Test-Retest
Modified Landolt ring	.35	.39	.80
Army Snellen chart	.38	.40	.88
Line resolution	.39	.42	.85
Quadrant variable contrast	.21	.28	.57
Dot variable contrast	.19	.29	.43
Checkerboard variable grid	.29	.32	.81
B and L Orthorater (far)	.27	.29	.87
B and L Orthorater (near)	.25	.27	.82

Relationship between Scotopic and Photopic Measures of Visual Acuity

In Table 5 are presented the intercorrelation of the scotopic measure, the nine photopic-acuity tests, the derived brightness-discrimination measure, and the Army General Classification Test score. The relationship between the scotopic visual-acuity measure, ANVT-R2X, and the nine photopic-acuity measures ranges from .19 to .39. Since the population consisted of 202 cases, and the standard error of a correlation coefficient of zero for a sample this size is .07, it may then be concluded that these correlations are significantly different from zero at the 1 percent level of significance. Furthermore, it may be seen that the correlation between the ANVT-R2X and the line resolution test, and the correlation between the ANVT-R2X and the Army Snellen test, are the two highest correlations, .39 and .38 respectively, among the comparisons between photopic and scotopic acuity measures. It is to be noted that these two photopic measures have the highest test-retest reliability, .85 and .88, respectively (Table 4). The correlations between ANVT-R2X and the checkerboard variable grid and between ANVT-R2X and the modified Landolt ring are relatively high, .29 and .35, respectively, and their reliabilities are .81 and .80, respectively. The correlations between ANVT-R2X and quadrant variable contrast and between ANVT-R2X and dot variable contrast are lower, .21 and .19, respectively, the reliabilities being .57 and .43, respectively. Thus we see the order of magnitude of the correlation between

TABLE 5

INTERCORRELATIONS OF PHOTOPIC AND SCOTOPIC VISUAL ACUITY VARIABLES

N=202 Enlisted Men at Ft. Myer, Va.

Mean	Standard Deviation	Description of Variables		1	2	3	4	5	6	7	8	9	10
49.42	9.60	Army Night Vision Tester	1										
27.77	3.71	Modified Landolt	2	.35									
34.89	5.59	Army Snellen	3	.38	.69								
5.18	1.10	Quadrant Contrast	4	.21	.30	.25							
42.51	6.18	Line Resolution	5	.39	.68	.68	.34						
3.51	.99	Dot Variable Contrast	6	.19	.42	.43	.30	.45					
19.74	5.52	Checkerboard Variable Grid	7	.29	.57	.56	.13	.65	.38				
11.24	1.68	Bausch and Lomb Orthorater (far)	8	.27	.50	.60	.17	.59	.33	.58			
10.64	1.57	Bausch and Lomb Orthorater (near)	9	.25	.53	.62	.10	.49	.27	.53	.58		
5.79*	1.03*	Derived Brightness Discrimination Score	10	.25	.38	.38	.31	.72	.25	-.01	.25	.18	
101.35	14.86	Army General Classification Test Score	11	.12	.08	.06	.04	.08	-.10	.07	.02	.04	.05

* Brightness Discrimination = .21 Line Resolution - .16 Checkerboard Variable Grid

the ANVT-R2X and the several photopic-acuity tests is related to some extent to the rank order of the reliability of the photopic-acuity variables.

Further inspection of the intercorrelations shows that the derived photopic brightness-discrimination measure[2] correlates about as well with the ANVT-R2X measure as does the checkerboard variable grid (.25 and .29, respectively). Thus, one may conclude that approximately an equal amount of photopic brightness discrimination variance and photopic "pure" retinal resolution variance is contained in the scotopic-acuity measure used in this study. In Table 6 are presented the upper and lower limits of the correlations shown in Table 5 at the 1/2 percent level of significance. The coefficients shown in the upper-right triangle of Table 6 are the minimum values, and the coefficients shown in the lower-left triangle of Table 6 are the maximum values which can be expected as often as 1 case in 200 respectively. The probability for both limits together represents a 1 percent test of significance. As further interpretation of the values presented in this table, an example is offered: In this study the correlation found between the scotopic visual-acuity measure ANVT-R2X and the Army Snellen test was .38. However, this is a fallible measure. That is, if the "true" correlation coefficient is .22, only one correlation coefficient in 200 for similar samples under similar conditions would be as high as .38. Similarly, if the true correlation happens to be .53, only 1 of 200 correlation coefficients computed on similar samples would be as low as .38.

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[2] One may assume that this derived brightness measure is a pure measure of brightness discrimination. It should be noted that the correlation between this derived brightness-discrimination measure and the checkerboard variable grid scores is -.01, indicating that, on a computational basis, there is some evidence for the plausibility of this assumption.

TABLE 6

THE LIMITS OF THE VALUES OF THE CORRELATION COEFFICIENTS OF TABLE II AT THE 1% LEVEL OF SIGNIFICANCE

		1	2	3	4	5	6	7	8	9	10	11
Army Night Vision Tester (ANVT)	1		.18	.22	.03	.23	.01	.12	.09	.07	.07	-.06
Modified Landolt Ring	2	.50		.58	.12	.57	.26	.43	.35	.38	.21	-.11
Army Snellen	3	.53	.77		.07	.57	.27	.43	.46	.50	.22	-.13
Quadrant Contrast	4	.37	.45	.41		.17	.13	-.05	-.01	.08	.13	-.15
Line Resolution	5	.53	.77	.77	.49		.30	.53	.46	.34	.61	-.10
Dot Variable Contrast	6	.36	.56	.56	.46	.59		.22	.15	.09	.07	-.28
Checkerboard Variable Grid	7	.45	.68	.68	.30	.74	.53		.45	.39	-.19	-.11
Bausch and Lomb Orthorater (far)	8	.43	.63	.70	.34	.70	.48	.69		.44	.08	-.16
Bausch and Lomb Orthorater (near)	9	.41	.65	.72	.28	.61	.43	.65	.69		.01	-.14
Derived Brightness Discrimination Score	10	.41	.52	.53	.46	.79	.41	.17	.42	.35		-.13
Army General Classification Test	11	.30	.25	.23	.21	.26	.08	.25	.20	.22	.23	

Table 4 presents for comparison purposes the correlations between the above-mentioned eight photopic measures and the scotopic measure, together with the corresponding correlations corrected for attenuation of the photopic variables. The reader is cautioned to remember that these reliabilities are based on a different population sample from that of the present study, having been taken from PRS Report 742. The examination of the corrected coefficients reveals that the increase in relationship when the photopic-acuity measures are corrected for attenuation is negligible.

An additional point of interest is the relationship between AGCT and the acuity measures, which ranges from -.10 to .12. Considering the standard error of a zero coefficient of correlation for a sample of the size used here, it becomes apparent that correlation of the Army General Classification Test score with the measures of visual acuity is not significantly different from zero at the 5-percent level of significance. Thus, "general learning ability" does not account for the relationship between scotopic and photopic visual acuity.

In summary, it may be said that there is a positive correlation, exceeding expectation in the light of general accepted theory, between the measures of photopic and scotopic acuity, under the conditions used in this study. However, this relationship is still not high enough for predicting one variable from the other for the range of value in this study.

With regard to the practical significance of the above conclusion, if selection procedures must provide instruments appropriate to measuring photopic, scotopic, or both types of vision, at least one instrument of each type would need to be used for the present. There should be a scotopic visual-acuity test as well as a photopic visual-acuity test, since correlation between the two variables is not sufficiently high to permit scores from the measure of one of these abilities to represent the other.

A further interesting interpretation is possible when one examines the table of intercorrelations and the appropriate scatter plots among the vision variables. Selecting one of the best predictors, one finds the correlation between the Army Snellen and the ANVT-R2X to be .38. An examination of that scatter plot (Table 7) shows that if the top 28 cases

TABLE 7

4074-07-02 SCATTER PLOT OF ARMY NIGHT VISION TESTER vs ARMY SNELLEN

ARMY SNELLEN	ANVT-R2X SCORES													
Scores	14-17	18-21	22-25	26-29	30-33	34-37	38-41	42-45	46-49	50-53	54-57	58-61	62-65	fy
44-45										1	1	2		4
42-43								2	5	3	7	5	2	24
40-41						1		2	3	1	4	6		17
38-39				1	1		1		2	3	2	1		11
36-37	1		1	1			1	7	2	11	6	6	3	39
34-35				2	1	2	3	4	4	7	12	9	3	47
32-33					1	1	1	2	4	7	6	1		23
30-31							1	3	1	3	3	1		12
28-29							1		1		1			3
26-27				2	1		2	2		1				8
24-25		1									1			2
22-23								1	2		1			4
20-21				1			1		1			1		4
18-19				1										1
16-17	1	1							1					3
fx	2	2	1	8	4	4	11	23	26	37	44	32	8	202

are selected on the photopic variable, the mean of those 28 cases on the scotopic variable is 54.1 as compared with the mean of 49.4 for the total group. No case among the 28 would fall more than .66 below the mean for the total group. Hence, the interesting possibility presents itself that if prediction were necessary only in the extremes for a population, particularly on the upper extreme, it may be possible to predict scotopic vision in terms of the photopic-vision variables. Furthermore, the population used in this study has been quite restricted in range on the photopic variables. More specifically, this population, which was tested with corrected refraction and which had better photopic visual acuity than the population used in PRS Study 742, obtained a sigma on the Army Snellen Test 59 percent as large as the population utilized in the study reported in PRS Report 742. Hence, the relationships reported are underestimates as compared to the relationships likely in a population similar to that used in the previous study. Furthermore, it is also recognized that one would want to examine the relationship between photopic predictors and night-vision validity criteria before accepting the predictability of scotopic vision from photopic measures.

Since a positive correlation was found between photopic visual acuity at the usual level of illumination (approximately 10 f.c.) and scotopic visual acuity at very low levels illumination (3.5 to 5.5 log micromicrolamberts) further research is indicated to explore relationships at various intermediate levels of illumination. This research project would test the hypothesis that there are higher degrees of relationships between photopic visual acuity at intermediate levels of illumination and scotopic visual acuity.

Summary

The problem was to determine the relationship between photopic (day) and scotopic (night) visual acuity. A further objective was to ascertain whether the two types of visual acuity can both be measured by the same instrument or whether two types of visual-acuity tests are required. The information is applicable in selection procedures.

Two hundred and two soldiers between the ages of 17 to 43 were tested with the Army night-vision tester, ANVT-R2X, the modified Landolt ring, the Army Snellen, the quadrant variable contrast chart, the dot variable contrast chart, the checkerboard variable grid chart, the line resolution chart, and the Bausch and Lomb Orthorater. A derived brightness-discrimination score was also computed. All subjects used both eyes in taking the tests and were permitted to wear glasses if correction was necessary to their everyday vision. Thirty-one subjects or 15 percent wore glasses. All of the tests were administered in the vision laboratory of the Personnel Research Section, AGO. This laboratory has been standardized in conformity with the specifications set by the Armed Forces National Research Council Vision Committee. The light under scotopic conditions varied between 3.51 and 5.26 log micromicro-lamberts in 8 approximately equal steps. The light under photopic conditions was 10.5 foot-candles on the charts and no more than 10.5 nor less than 6 foot-candles in the booth.

All subjects were dark adapted for 30 min. and instructed in night-seeing principles: off-center viewing, scanning the target, and avoidance of fixation. With regard to the photopic tests, all subjects viewed the wall-charts from a distance of 20 ft. with binocular vision. The photopic measures correlated with the scotopic measure in a range from .19 to .39. There was no appreciable correlation between these tests and intelligence as measured by the Army General Classification Test. The report concludes that there is a positive correlation between the measures of photopic and scotopic visual acuity under conditions of this study and for the population used, and that this correlation somewhat exceeds expectations in the light of generally accepted theory.

The above findings are of practical significance in considering possible use of selection measures of photopic or scotopic visual acuity, or both, in the case of a population similar to that in the study. For the present, it is felt that at least one instrument of each type should be employed, inasmuch as the correlation between the two measures is not sufficiently high for the scores on one measure to be used as representative of the other. Nevertheless, data secured in this study indicate that further research may provide a means of identifying, by use of photopic wall-charts, a portion of a given population (probably 10 to 15 percent) whose night-vision score would tend to be considerably above the mean of the total population.

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FIELD AND LABORATORY EVALUATION OF ROADSIDE SIGN SURFACING MATERIALS

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SYNOPSIS

Physical and optical characteristics of sign materials and design and application of a reflectometer devised by the Kentucky Department of Highways are discussed. Accelerated weathering procedures and specification standards are described.

Field studies paralleling laboratory work and a possible correlation between the two are described. The field work included several thousand individual observations covering 30 different sign-surface types under actual conditions on a night-visibility driving-course. Most of the major types of surfaces available were represented.

In addition to using ordinary sealed-beam headlamps, field observations were made using polarized headlamps and viewers.

Current night-driving habits practiced by the driving public are characterized by a series of assumptions. There is a tendency for drivers to assume their roadway is clear and unobstructed unless forewarned of an approaching hazard, such as a hazard beyond the crest of a vertical curve, a break in the pavement, an intersection, or a congested area. Glaring headlights of approaching vehicles present equally dangerous hazards of a mobile nature. Drivers must rely upon blind faith when passing approaching vehicles: Faith that the vehicle is operating correctly, well over in its proper lane; faith that the roadway does not alter in character or direction immediately beyond the oncoming lights; faith that there is not a pedestrian or stalled car in the roadway immediately behind the glaring lights. Considering the number of people who travel the highways by night, no effort should be spared in providing the best night-driving aides to increase the comfort and safety of the traveling public.

About 1939, the use of minute glass beads for reflectorization of highway signs and markers was introduced. However, the advent of World War II prevented their widespread use until about 1945. During the war several states used all of the material not taken by the armed forces to begin reflectorization of the signs in their highway systems. This conversion was slow and went generally undetected by the public.

Early in 1947, a comprehensive study of the optical and physical properties of reflectorized sign-surfacing materials was instituted by Kentucky. At that time there was no published detailed information available pertaining to these materials, so it was necessary to develop a general knowledge of these materials and their inherent properties.

One of the first forms of reflectorization encountered in this investigation was a type in which the paint-like binder was applied to sign-stock and beads were dusted onto the wet paint-film. This was classified as a Type II surface, Type I being reserved for older, non-reflectorized, enamel surfaces. Prefabricated sheet materials, extending the classification in order of ascending reflectances, were assigned to Category III. Sub-classifications III-A and III-B were used to further differentiate between materials having a clear-plastic matrix and materials having a pigmented-plastic matrix respectively. These Kentucky Department of Highways classifications are used throughout this paper to facilitate description.

Refractive Index

Ordinary glasses possess refractive indices in the range of 1.52 to 1.65. Special glasses may have indices in the order of 1.90. Optically speaking, the higher the refractive index the shorter is the focal length of a spherical lens. Assuming a refractive index of 2.0, the focal length of a spherical lens is equal to the radius of the sphere. Assuming a refractive index of 1.5, the focal length is 3/2 the radius measured from the center of the sphere. Regardless of the size of the sphere, when $n = 2.0$, the focus is at the axial center of the trailing surface, but when $n = 1.5$, the greater the size of the sphere the farther the focal point is removed from the axial center of the trailing surface. These hypothetical cases are illustrated graphically in Figure 1.

(For the sake of these analogies, the incident light is assumed to be a parallel beam. Actually, light from a headlamp is slightly divergent. Also, the illustration for Type III-A neglects the refractive index of the clear matrix. Where the index of the matrix is approximately equal to that of the bead, the focal length of the system is twice the radius of the bead, measured from the center of the sphere.)

Light entering a Type II surface having a refractive index of 1.5 never reaches a focal point. It illuminates a large area on the reflecting surface which, if considered a battery of point-radiating sources, returns diverging light in the general direction of the original source. When light enters a Type III-A surface, also having a bead index of refraction of 1.5, the light is focused at the reflecting surface by the properly-spaced beads when the illumination is normal to the surface. At other angles the reflecting surface is beyond the focal point and diverging light is reflected. At normal and near normal angles of incidence this surface exhibits high reflectances. For this reason it may be highly efficient under long-viewing conditions where small angles of incidence and divergence are encountered.

The Type III-B surface is shown by the illustration to be an optically-idealized condition favorable to reflex reflection. With a refractive index of 2.0, the focal point is fixed at the axial center of the trailing surface and is otherwise independent of the size of the sphere. Not only does this feature eliminate the necessity for precise spacing of the beads, but it permits the use of graded beads (within limitations). It further permits the use of a more durable binder material. Although pigmented binders are used almost exclusively, it is not inconceivable that a lustrous metal binder may eventually be produced which would furnish additional permanence to a finished sign.

Measurement of Refractive Indices

Glass spheres are ideal specimens for refractive indices measurements by the Becke line method (1). The procedure is simple and may be completed

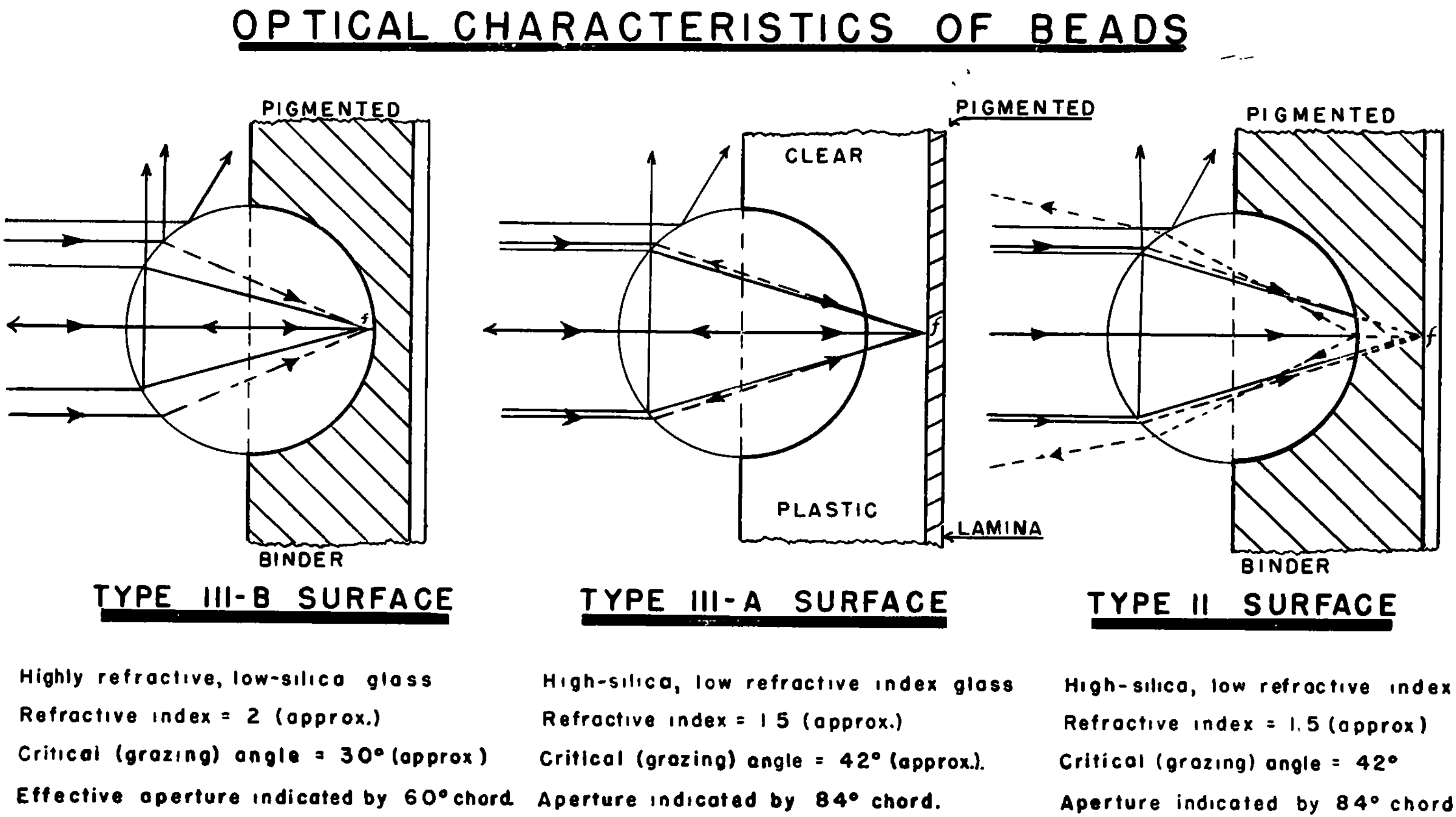

Figure 1. Optical Characteristics of Beaded Reflecting Surfaces

in 5 or 10 minutes. The determination requires a simple microscope having a small aperture objective and a stage with accommodations for transmitted light. The additional equipment consists of a set of refractive-index immersion liquids, range 1.50 to 2.00, which may be purchased from any of the scientific supply companies; and standard biological glass slides and coverglasses.

A few of the beads are dusted lightly onto the slide and covered with a drop of the trial immersion oil and the coverglass placed over the oil droplet; the beads are then observed with the microscope using transmitted light. The concentric lines move toward the medium having the higher refractive index when the objective is raised. When the indices of the glass and immersion liquid are exactly matched the bead cannot be seen at all. It suffices to define the indices as being between the two closest immersion liquids. Care should be taken to avoid misleading observations on air bubbles that may have been occluded by the immersion liquid.

Durability

The two components of the surface, glass and binder, are considered separately:

1. Glass beads - Glasses are formulated much in the same manner as any other chemical compounds. The usual components are silica, calcium oxide, lead oxide, boron, barium, and potassium oxides. Glasses differ equally as much in optical properties, hardness, chemical stability, and refractive index as they do in chemical composition. Hardness and stability are achieved in low refractive-index glasses by virtue of a high-silica content. The preservation of stability in highly refractive glasses is difficult. As shown in Figure 2 (Series 3) a soft, chemically-unstable bead has shown deterioration under both artificial and natural weathering.

Figure 2 is a group of photomicrographs illustrating the types of materials considered in this study and their appearances after subjection to both artificial and natural weathering. The area shown in each view is roughly one millimeter square. Series 1 horizontally shows specification Type II; at the left, unweathered; in the center, weathered artificially; on the right, weathered by horizontal outdoor roof-exposure. In the same order, Series 2 shows Type III-A material, while Series 3 and Series 4 show Type III-B material, with an unsound bead and with a more stable bead respectively. In each case the artificial weathering was 1000 hours in a carbon-arc weathering chamber, and the natural weathering was 21 months of horizontal roof exposure. Note the similarity in effects of the two types of exposure. The weathered samples are in very similar stages, with the exception that the outdoor samples are darker due to an accumulation of soot and stain from their exposure to the elements, conditions which were not encountered by the samples exposed to accelerated weathering in the laboratory.

Soft, unstable beads may be easily detected by crushing them with a blade or placing a drop of concentrated hydrochloric acid on the surface and observing the results after 5 or 10 minutes under a microscope. A stable glass will remain virtually unaffected while an unstable sample will show etching or complete solution. The acid will have no apparent effect on resinous binders. A Missouri Department of Highways report on traffic paints (2) showed unstable beads to suffer deterioration under simple wetting and drying. Like any other lens, the surface must retain

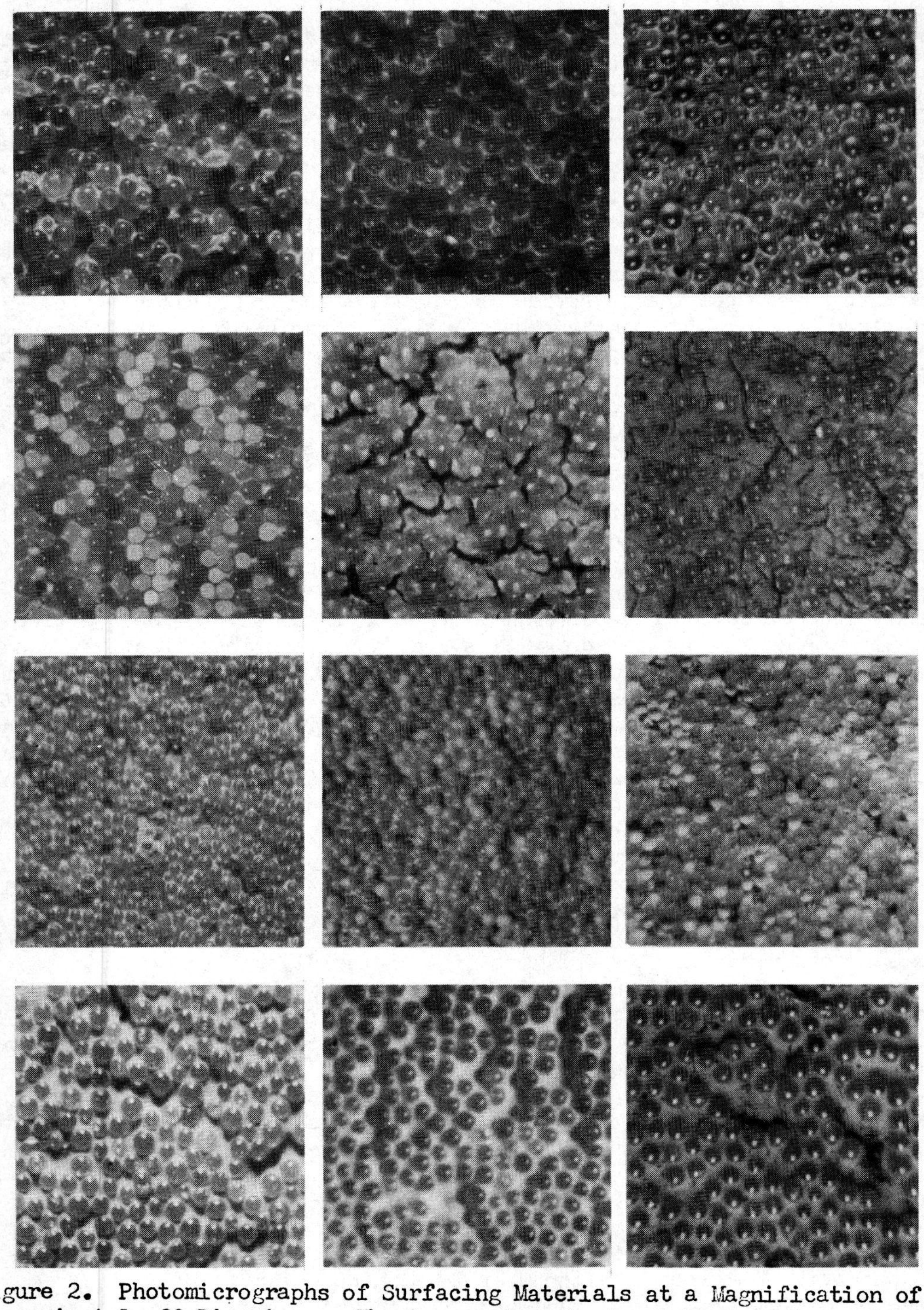

Figure 2. Photomicrographs of Surfacing Materials at a Magnification of Approximately 30 Diameters. The top series, horizontally, is Type II; the second series is Type III-A; the third series is Type III-B with soft beads, and the bottom series is Type III-B with hard beads. Left to right in each series shows unweathered, artificially weathered, and naturally weathered samples.

a high degree of gloss, since otherwise it acts only as a diffuse reflecting surface and is no better than paint.

2. Binder - A pigmented binder is comparable in most respects to a resinous paint. Weathering tests suffice mostly to assure stability of the pigment against bleaching, cracking of the resin, and blistering or peeling due to absorption of moisture. Both Series 1 and Series 4 of Figure 2 have survived severe weathering tests without sustaining any apparent damage. In Series 3 the loss of beads is attributable more to weathering of the glass itself than to the deterioration of the binder material.

In Series 2 of Figure 2, Type III-A, the binder is a clear plastic resin backed up by a pigmented lamina. Here the bead loss is attributable solely to a deterioration of the binder. Failure resulted from shrinkage and drying of the matrix through the loss of plasticiser, and the rate of this loss was probably determined more by heat than other factors of weathering.

Prefabricated materials must be flexible and tough during application to prevent breaking and tearing in handling and subsequent impression over embossed sign stock. Some sheets tend to become brittle after extended storage in a warm, dry atmosphere.

Type III-A and III-B sheets are secured to treated and primed signstock by the manufacturer's adhesives. Adhesives are of two general types: thermo-plastic and solvent-activated. Thus far, the evaluation of adhesives has been considered outside the scope of this research. It will suffice to say that failures or peeling of the surface from the signstock have been rare. If there is any peeling it generally occurs at the prime-metal interface due to corrosion of the metal itself.

Bead Size

Bead sizes may be measured very accurately by drawing a straight pencil line on a section of the surface or sheet and measuring about 100 beads along the line with the aid of a microscope equipped with a micrometer eye-piece (previously calibrated against a stage micrometer). By this method the percentages corresponding to standard sieve sizes can be calculated. Of course, when beads and binder are obtained separately sieve analysis may be obtained directly.

The samples of Type II materials observed thus far have generally had larger beads than the prefabricated sheets. Over 95 percent fell within the range from 0.10-mm. to 0.20-mm. and averaged about 0.15-mm. Type III-A materials are limited to greater uniformity in bead sizes ranging from about 0.10-mm. to 0.15-mm. and averaging about 0.12-mm. Since Type III-B materials are not so restricted with regard to bead sizes, averages for small-bead samples may be in the order of 0.05-mm., while for large-bead samples the average bead size may be as large as 0.15-mm. to 0.20-mm. No significant relation has yet been shown between average bead sizes and reflectances for Type III-B materials.

Reflectance Measurements

In addition to an evaluation on the basis of durability, it was necessary to devise a system for measuring the reflectivity of these materials under angles and conditions actually encountered in service on the road. Preliminary studies of commercially available instruments revealed that

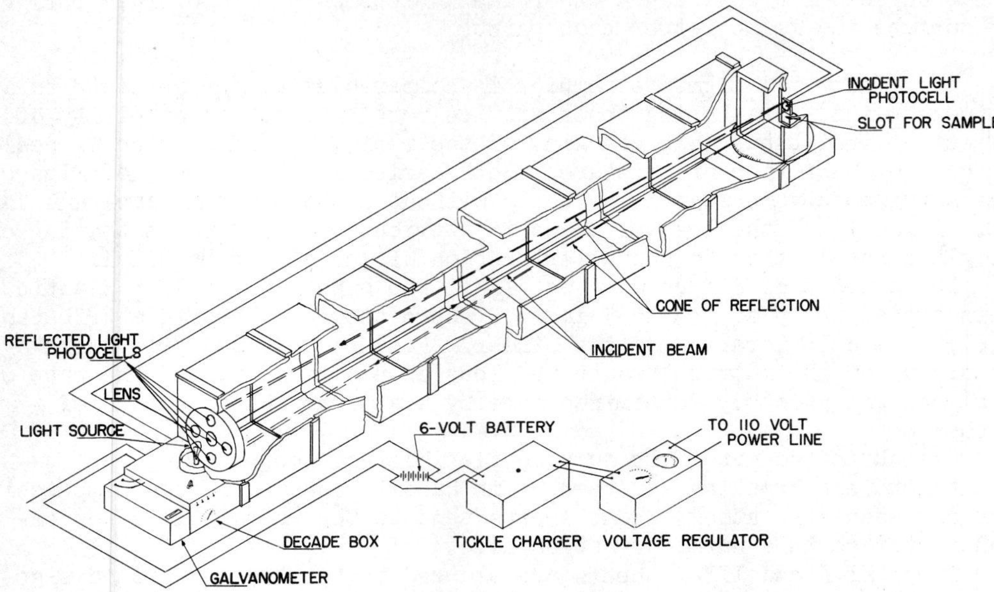

Figure 3. Pictorial and Schematic Diagram of the Reflectometer.

none was directly adaptable to the requirements. Of course, it was apparent that such an instrument would necessarily be of a photoelectric type. With due recognition of the limitations inherent in any photoelectric device, the reflectometer, diagrammed in Figure 3 and shown in Figure 4, was designed and built.

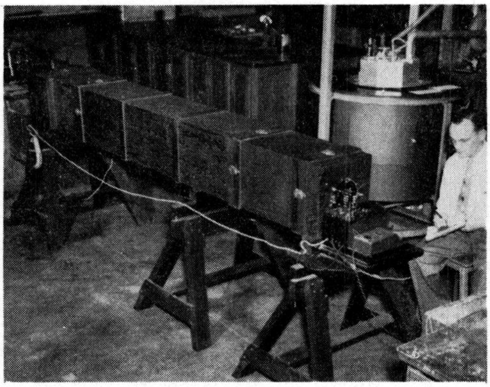

Figure 4. The Reflectometer Assembled for Measurements of Reflectance at 1 Deg. Divergence and 2 Deg. Incidence.

Briefly, this instrument utilizes a parallel beam of light from a standard, 50-candlepower, 6-volt headlamp bulb projected by a lens system onto a 2 in. diameter area of the sample. A photocell is provided at the specimen end of the instrument for measuring the amount of light incident on that area. Four photocells are mounted around the perimeter of the light-projecting lens to measure the intensity of light reflected in a cone representing the cone of vision. This intensity of reflected light, expressed as a percentage of the incident light, is taken as a measure of the reflective efficiency of the specimen. The specimen holder is pivoted and provided with a goniometer scale by which the angles of incidence can be varied from 0 to 30 deg. The angle of divergence of the reflected cone is varied by interchangeable tunnels of length appropriate to provide angles of $\frac{1}{2}$, 1, $2\frac{1}{2}$, and $4\frac{1}{2}$ deg., simulating distances from about 50 to over 400 ft. on the road.

The photocell output is indicated on a suspension galvanometer provided with a decade-box shunt-resistance system for changing the sensitivity of the galvanometer. The photocells were individually calibrated against a Weston standard foot-candle meter, and the galvanometer was similarly calibrated against a Weston standard micro-ammeter.

These four factors: optics, refractive indices, durability, and reflectance, served as the basic criteria in the establishment of a specification for the materials.

Field Evaluations

In order to determine what laboratory tests meant in terms of field performance, a field-testing project was instituted to determine: (1) the relationship between reflectance and average effective sight distance, (2) the relationship of target size to average effective sight distance, and (3) how reflex-reflector materials perform under polarized headlights with polarizing viewers.

Field Procedures

Considerable thought was given to the choice of a field location for the night-driving course. An access-road to a military installation was chosen because it was reasonably close and of good concrete construction with modern grade and alignment providing good pavement, shoulder, and right-of-way viewing conditions. Since it was not a through highway traffic was extremely light, except when workers were leaving or reporting. Those times were conveniently avoided so far as night observations were concerned. The road was about 2-miles long, and with signs located on both sides of the road its effective length was 4 miles. Two sets of 12 signs were used on the road, one for each direction.

Another convenient feature of this road was the fact that the joint-spacing was 20 feet, which facilitated distance determinations. Because of this feature, it was deemed adequate to mark off the 100-ft. distances in front of each sign and use the joints to determine the intermediate distances. Thus the roadway approaching each sign had large numerals painted on the surface in the middle of the right-hand lane indicating hundreds of feet up to 800. Approximately the same technique as used by Forbes and Holmes in 1938 (2) was used to determine effective sight distances, except that in this case the course was driven at night with the driver acting as the observer and with distances painted on the road surface.

After all of the signs were placed and the distances marked off, liberal numbers of observers were obtained through the cooperation of the College of Engineering of the University of Kentucky. Three or four complete sets of observations were made each night for an average of about three nights a week at random intervals for about a year. This large number of observers was used in order to assure true averages for the group and to prevent unique individual differences from affecting the results. The average age of the observers, however, was about 20 years, so therefore their eyesight may have averaged somewhat better than that of the average driver.

Three identical models of the same make of automobile were used in the field work. One was used with its standard, sealed-beam lights while the other two (shown in Fig. 5) were equipped with polarized lights in the place of the sealed-beam lamps in the regular fender mounts and PAR-46 traffic lamps mounted inboard and connected to serve as the low, or deflected, beam for the car. Each of these two cars was equipped with a necessarily larger generator and with two polarizing viewing filters, one for each of the front-seat passengers.

Aside from the sign evaluation, it was of interest to see how effectively the Polaroid headlighting system eliminated the mobile glare hazard. Figure 6 is a photograph representative of the condition now universally prevalent in night driving.

Figure 5. Two of the Cars Used in the Field-Testing Program. Both were equipped with polarized headlights, PAR-46 traffic lights, and polarizing viewers.

In contrast, Figure 7 shows a similar encounter in which both cars are using polarized lights and viewers. The result is a great reduction in glare and an increase in viewing distance and eye comfort. These photographs were made on the night-driving course using a properly oriented filter on a view-type camera. Exposures were in the range of 3 minutes at an aperture of f/6.3 with a fast panchromatic film. Because of these long exposures it was necessary to mount the camera on a tripod outside the car away from vibrations due to the idling engine. The sign on the right and the approaching car are 200 ft. from each other while the sign visible in the background is 1000 ft. from the approaching car.

The procedure on the night-driving course was to place two persons in each car, one driving and acting as the observer and the other sitting beside him with a data sheet acting as recorder. The driver proceeded along the course at about 20 miles per hour and identified each sign as soon as he could recognize its design. The recorder then picked up the distance at that point from the pavement markings and entered it on the data sheet. After driving the full course, driver and observer changed places and repeated the procedure. At the conclusion of this second trip around the

Figure 6. Photograph of an Oncoming Vehicle Using Regular, Sealed-Beam Headlights.

Figure 7. Photograph of Vehicular Encounter Using Polarized Headlights and Viewers.

course the lighting conditions were changed and the whole process was started over again.

Each subject drove the course under five lighting conditions by using, in order: (1) Regular sealed-beam headlights, (2) Polarized headlights with no viewing filter, (3) Polarized headlights with the viewing filter, (4) PAR-46 traffic lamps without viewer, and (5) PAR-46 traffic lamps with the polarizing filter.

From this it is easy to see why only four or five observers could be used each night, since each one had to make a total of 124 observations and drive a distance of about 40 miles.

The observers were cautioned to give the signs a fair evaluation and not to guess at their identity or attempt to memorize them. A member of the staff of the research laboratory rode in the back-seat of each car to assure compliance with these regulations and to answer questions of procedure as they occurred to the observers while driving the course.

Figure 8 shows the four targets used in the field work. The first group of signs used were regulation-yellow curve-delineation signs, shown in the upper left, which differed from each other only in the direction in which the arrow pointed. The signs were selected to cover a wide range of reflex-reflective material then available. Data pertaining to this set of signs are of primary importance since this type of sign is in wide service.

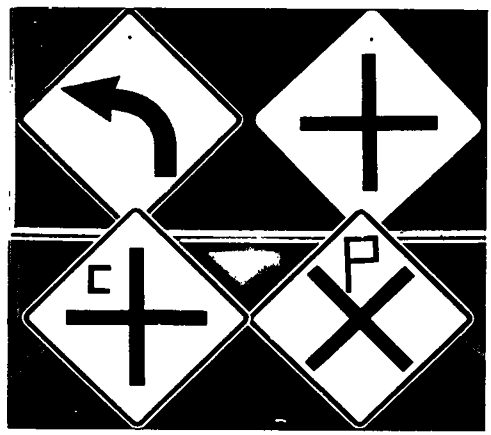

Figure 8. The Four Target Types Used in the Field Evaluations. All are on standard 24-inch by 24-inch metal sign stock.

A second set of signs placed on the course were obtained directly from the manufacturers and represented the range of materials covered in the first group plus some higher reflective types which had just been developed and were still in the experimental stages. These signs were coated by the various manufacturers on regulation steel sign-stock supplied by the Division of Traffic, Kentucky Department of Highways.

The first target used on these surfaces was presumed to be the largest possible message the signs could convey. Each sign had a large plus or X placed across its face (Fig. 8, upper right), and the observers were offered the decision as to the target identity as soon as it could be interpreted. This large target was used in an attempt to determine the maximum distance at which standard-size signs of various reflectances could convey a message.

After a suitable number of observations on the large target, a smaller, 4-in. letter of 3/4-in. masking tape was placed on the same surfacing material (Fig. 8, lower left). The C's and O's were chosen because they have the same general configuration, only the opening in the right side of the C distinguishes between the two, and the size was representative of the smallest practical letter for road signs. Then 8-in. letters of 3/4-in. width, used on the standard 24- by 24-in. stop signs, were chosen as an intermediate size (Fig. 8, lower right). This time the target letters were R's and P's, for the same reasons of similarity in configuration as explained before.

In each of the latter two cases only one of the letters was put on each sign, and the placement was at random so that the order would be difficult to memorize even subconsciously. As a result of this the decision of the observer rendered a more definite point of recognition than could otherwise have been achieved. In all, over 100 observers were used and over 12,000 observations made.

Correlation of Field and Laboratory Data

Correlation between the field and laboratory data is shown graphically in Figures 9, 10, and 11. Figure 9 shows the results for the standard curve-delineation signs for the three types of lighting with no viewing filter in use. Thus each curve represents a plot of the relationship between average effective sight-distances for one lighting condition and reflectance as measured in the laboratory by methods defined earlier. It is evident that as reflectance is increased up to about 0.20 there is a proportional increase in the effective sight-distance. Above this point, however, increasing the reflectance of the sign surface has little effect on the average effective sight-distance. Visual acuity is considered the limiting factor here, and there is evidently an optimum value of reflectance above which an increase is of no value in extending the distance at which the sign is effective.

In general, the Type I signs are represented on the curves at reflectances in the range about 0.10. Type II materials range between 0.10 and 0.15, while Type III sheeting accounts for the remainder of the high end of the curve. There is, of course, some overlapping of these ranges and no sharp point of separation can be identified.

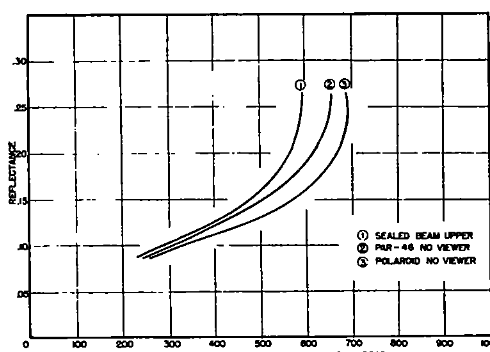

Figure 9. Relationships Between Effective Sight Distances and Reflectances of Signs under Three Different Headlighting Conditions and Without Viewing Filter.

Figure 10 shows the same data for the same set of signs except that the polarizing viewing-filter was used with the PAR-46 lamps and polarized lamps. The use of the polarizing viewer with the non-polarized PAR-46 traffic lamps results in their being slightly less effective than the sealed-beam uppers. This is as might be expected since the traffic lamps are designed to replace the sealed-beam lower or deflected beam for city driving and for passing cars not equipped with polarizing viewers as protection from the polarized headlamps.

In Figure 10 the points are shown from which the curves were drawn. This was done because the use of the filter resulted in rather erratic data as compared to the same condition without filter. Note that the points for curve No. 1, which is representative of all the curves for unfiltered viewing conditions, fall into a very smooth curve. However, when the filter is introduced the data are not so well aligned and thus it becomes necessary to average these points with a curve. This irregular performance with the filter may be attributable to differential-absorption effects of the filter toward the signs, which were of various shades of

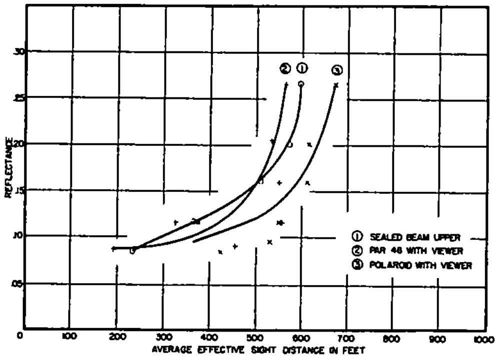

Figure 10. Relationships Between Effective Sight Distances and Reflectances of Signs under Three Different Headlighting Conditions and with Viewing Filter.

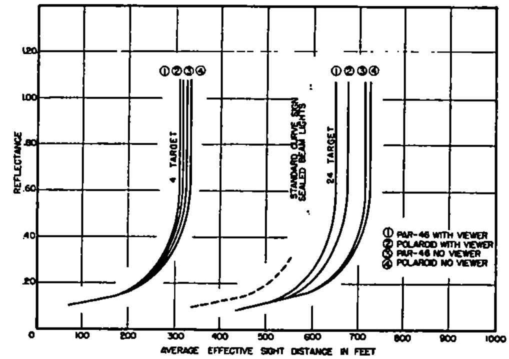

Figure 11. Graph Summarizing the Relationship Between the Laboratory-Measured Reflectances and the Field Data.

yellow.

Figure 11 is a summary of all of the data obtained from the field work. Note here that the range of reflectance has been increased by the addition of some highly-reflective surfacing materials. For this reason the scale is diminished as compared to the previous two figures. The standard curve-delineation sign under sealed-beam lighting is shown on this graph as a dashed and dotted line. The dashed portion of this curve is the same as curve No. 1 in Figures 9 and 10. The dotted portion is an extrapolation of these data into higher reflectance ranges.

A family of curves has been defined by the data for each target size and the five lighting-viewing conditions. The family of curves on the left represents the data obtained with the 4-in. letters, the smallest letters, and the family on the right results from the use of the largest design. The intermediate 8-in. letter is not shown since it fell, as might be expected, between the two extremes.

Note that the separation of the curves within a family increases with an increase in design size. This means that with larger target sizes an increase in the incident light has a larger effect on the sight distance than it does with the smaller targets. These curves again show that above reflectance values of approximately 0.20, the advantageous increase between sight-distance and reflectance is lost. This excludes the factor of prominence, or the capacity of a highly reflective surface to attract attention, even though the message may not be read. Higher reflectances may contribute to the attention factor. But they do not greatly increase the distance at which the message of the sign is effective.

Applications of the Data

So far as the use of the laboratory data and techniques is concerned, specification requirements for three general classes of materials were established in 1948. Aside from minor revisions, the need for which became apparent in the light of experience, this specification has served the Kentucky Department of Highways, Division of Traffic, quite satisfactorily in the purchase of reflectorized sign-surfacing materials since that time.

Results of the field observations at this early date have not been worked into practice so specifically. However, the significance of the results is apparent, and they do provide a basis for estimating the effectiveness of materials in the different specification classes. Conversely the field data offer a straight-forward approach to selecting the range of reflectance appropriate for any set of rural night-driving conditions.

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FILTER STUDY OF THE EFFECT OF CERTAIN TRANSMISSION FILTERS ON VISUAL ACUITY WITH AND WITHOUT GLARE

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SYNOPSIS

Practically every state in the Union has some legal standard of visual acuity for pilots, railway engineers, street-car operators, bus and commercial vehicle operators, as well as lay drivers. It is assumed that superior vision is a factor in safe driving and every effort has been made to increase the size of signs, improve legibility, and otherwise make it easy for one to observe accurately. It is axiomatic that anything which interferes with clear vision will increase the hazards of driving, particularly at night when illumination at best is inadequate.

Glare or extraneous light falling into the eyes of a driver will reduce his visual efficiency. Even turning on the dome-light will greatly confuse a driver and cause him to lose his orientation with respect to movement of his car. The high beams of an oncoming car are alleged to be particularly detrimental to vision. Experimentally this deleterious effect on semi-scotopic vision has been shown to bear a certain relationship up to about the equivalent of 1.25 foot candles of light at the eye after which no great objective effect is to be noted until the amount of light is doubled. In other words, part of this effect seems imaginary and mostly subjective. Some drivers can stand much more light than they care to stand without evidence of deterioration in visual acuity and consequent visual efficiency.

Various methods have been suggested to reduce glare, notably the use of Polaroid. But automotive industry does not seem ready to accept this solution. A few enthusiasts have proposed and actually marketed types of glass which they claim will increase visual acuity at night. The larger companies have not shared this enthusiasm, which is contrary to all the evidence concerning effective vision.

This study is based upon an experiment in which 44 varieties of glass, ranging in color from violet to deep red and having transmission coefficients of visible light from .05+ to .86+

/1 Study made possible through a grant from the American Optometric Association, Committee on Motorist Vision.

> percent, were measured to secure a representative set of 20 filters for design of an experiment to determine the effect of filters on visual acuity throughout the spectral range. In all cases there was a decrement in visual acuity with the introduction of a filter, regardless of color or wave length of the type used. Although some colors reduced glare, they also reduced visual acuity to the same degree. At no point in the spectral range was any significant difference found. Hence, in light of present knowledge it is concluded that any media introduced between the eye and a stimulus object or situation on the roadway as a means of reducing glare is not to be recommended for night-time or any other condition which lowers acuity when maximum visual efficiency is desired.

In recent years there have been numerous theories advanced concerning the effect of certain wave-band filters on visual acuity. Most research workers in the field do not accept the general hypothesis that it is possible to cut out light and yet retain acuity. However, it is possible that when facing a strong luminant, glare effect for certain individuals may be reduced more than acuity by filters. The loss due to glare might conceivably be greater than the loss due to the filter, thus creating a net gain in seeing efficiency.

Before this problem may be attacked directly, it is necessary to determine the relationship between acuity decrements and the density of interposed filters of known characteristics.

In a pilot study of this nature by Lauer, Fletcher, and Winston (1949), it was found that the objective measurements of acuity, with and without filters, showed only losses, both with and without opposing light. In the experiments only three lenses were used, having transmission factors of 57.9, 60.2 and 86.3. Fourteen subjects in all were used, each being partly dark adapted as expected of a driver meeting cars at night.

An attempt was made in the present experiment to extend the previous study by using more subjects, a wider range of filters, more rigid controls, and typical transmission filters throughout the spectral range of visible light.

Method and Procedure

The design of the experiment was primarily functional in nature and was set up to determine what relationship, if any, exists between the loss in acuity and density of filters and whether a differential effect may be produced between various wave-length ranges of the visible spectrum. The main hypothesis: Vision is proportionally decreased by the interposition of any type of filter according to its transmission factor of visible light. Corollary hypothesis: Visual acuity is proportionally reduced under normal conditions of seeing when a filter is placed before the eyes.

From a set of 44 available filter samples, 20 were selected according to color, percentage of light transmission, and difference in characteristic wave length to provide an adequate range of test filters. The characteristics of all the filters were not known at the time of the experiment although curves on several given by Lauer, Fletcher, and Winston were available.

Due to imperfections, one of the filters, made of plastic, proved to be very inefficient under conditions of opposing light. This filter was not considered in the final calculations.

Eleven subjects of near-normal vision were selected, and 15 separate sets of observations made, using one eye at a time. The vision of all subjects was accurately measured by the Clason acuity meter and corrections made to equate what differences may have existed before treatment of the data.

The test filters were presented in random order, so far as color and transmission coefficients were concerned. Only persons having 70 percent vision, or above, in one, or both eyes, were used in the experiment. Acuity of each eye was determined by standard methods. Half the measurements were run with the opposing light condition first, and half were run with the normal condition of vision being measured first.

An average of three readings was calculated for each setting of the acuity meter, and the mean was entered as the measure. The readings were divided by the subject's normal acuity to correct for individual ocular differences.

The order of stimulus presentation was controlled by systematic rotation to offset fatigue and practice effects.

The subjects ranged in age from 12 to 53, and all measurements were made with monocular vision to control the angular effect of the opposing light, arbitrarily set at 4 degrees declination from the optical axis of the eye. (It was established by Lauer and Silver [1945] that this angle is near the critical point when meeting a car on the roadway.) The eyes were light-adapted at approximately 8-15 foot candles of daylight illumination in this series of observations, although the observer was looking into a dark tunnel while making the determinations.

Apparatus

The measurements were made in the driving laboratory at Iowa State College, using the specially-designed darkened booth described by Lauer and Silver (1941). A Clason acuity meter was used to make all the measurements, since the test image can be gradually enlarged to the point of threshold discrimination with a reasonable degree of accuracy. Four trials were made for each separate measurement in order to obtain a more stable index of acuity. The measurements given have a reliability of approximately +.94. A Ferree and Rand acuity meter was used as the opposing light source and was set to give approximately 1-2 foot candles of light at the eye. The aperture was restricted to give a narrow beam of light. The filters had been carefully tested by means of a specially designed apparatus using a Weston photronic cell with Viscor filter, which passes only visible light.

Treatment of Results

In order to determine the effect of decreased light transmission on acuity levels, the means of all subjects for each filter were computed and plotted against the transmission coefficients shown on the X-axis of the graph (See Fig. 1.) This was done for both the normal condition and with opposing light. The curves show a non-linear relationship and a distinct difference with and without the opposing light. The total decrease in acuity was approximately 14 percent at the upper range of filter transmission for normal vision and 27 percent with the glare source of

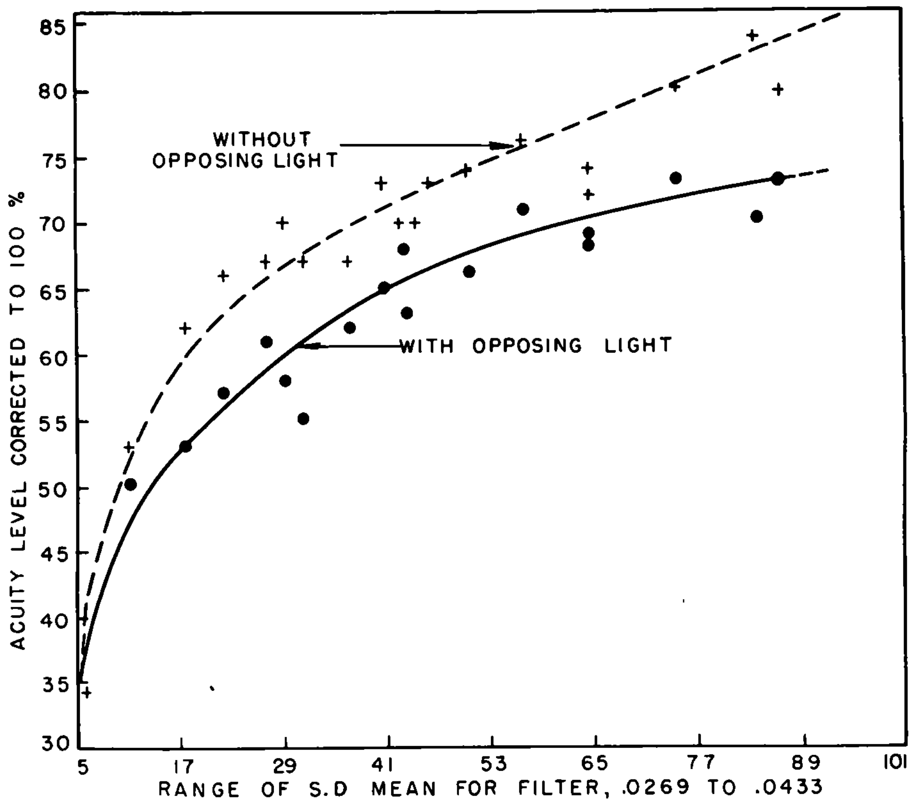

Figure 1. Percent Transmission of Filters

interference. At the lower range there was a general drop of about 65 percent with little differentiation between the two conditions set up.

After this curve was constructed it was used to set up the expected values of filter interference in order to make comparison of bands of wave-length transmission grouped according to qualitative classifications: neutral colors, violet, blue, green, yellow and orange, and red.

The ratio of expected to observed values for each filter was calculated and averaged for each group of filters, both with and without glare source. These data are shown in Tables 1 and 2. Statistical differences could not be shown between the different bands of wave lengths. Although there was an insufficient number of cases to show differences, no obvious irregularity occurred, with the exception of the green band which seems to give lower readings under both conditions, indicating somewhat poorer characteristics as a filter to be used before the eyes in low illumination.

Results and Conclusions

A study of 20 filters, representing as many specific wave bands throughout the visible spectrum, was made to determine the relationship between the filter-transmission factor and visual acuity in low illumination with the test object viewed through the filter. Fifteen sets of measurements were made of visual acuity under normal conditions, and

Table 1

Relation Between Wave Band of Filters and Visual Acuity
No Opposing Light

Spectral Groups	Filter Number	Trans-mission Factor	Acuity Actual	Acuity Expected	Ratio of Actual to Expected	Ratio[1] of Actual to Expected by Spectral Groups
	1	.222	.66	.630	1.05	
Neutral	13	.437	.70	.722	0.97	
	9	.457	.73	.725	1.05	1.020
	10	.177	.62	.600	1.04	
Purple	8	.271	.67	.660	1.02	1.030
	17	.059	.34	.350	0.97	
	2	.110	.53	.523	1.01	
Blue	5	.408	.73	.712	1.02	
	36	.572	.75	.762	0.99	0.998
	20	.309	.67	.680	0.98	
Green	3	.649	.74	.778	0.95	
	30	.506	.74	.740	1.00	0.976
	31	.644	.72	.775	0.92	
Yellow-	38	.751	.80	.800	1.00	
Orange	44	.863	.80	.821	0.97	0.963
	6	.366	.67	.700	0.96	
	21	.290	.70	.666	1.05	
Red	34	.436	.70	.724	0.97	
	40	.847	.84	.820	1.02	1.000

1. Need be 1.00 + or - .08-.10 to be significant.

fifteen were made with opposing light or glare source, for a total of 600 separate observations. Each observation was a mean of from 3-5 trials. The results from 19 filters, or 570 observations, were used as the basis of calculation to obtain the conclusions:

1. The relationship between acuity and filter transmission factor used is not linear but follows a curve of the general form

$$y = be^{+ax}.$$

2. The over-all average loss of 9.83 percent was noted with 1-2 foot candles impinging upon the light-adapted eye looking into a dark chamber. The absolute loss at the upper range was appreciably higher but bears a definite relationship throughout the range.

3. From preliminary analysis of the data there seems to be no spectral range giving significantly different results, unless it should be in the

Table 2

Relation Between Wave Band of Filters and Visual Acuity
Opposing Lights

Spectral Groups	Filter Number	Trans-mission Factor	Acuity Actual	Acuity Expected	Ratio of Actual to Expected	Ratio[1] of Actual to Expected by Spectral Groups
	1	.222	.57	.566	1.01	
Neutral	13	.437	.63	.660	0.96	
	9	.457	.66	.665	0.99	0.985
	10	.177	.53	.536	0.98	
Purple	8	.271	.61	.595	1.03	1.005
	17	.059	.35	.365	0.95	
	2	.110	.50	.475	1.05	
Blue	5	.408	.65	.650	1.00	
	36	.572	.71	.691	1.02	1.005
	20	.309	.55	.610	0.90	
Green	3	.649	.69	.708	0.97	
	30	.506	.66	.675	0.98	0.950
	31	.644	.68	.708	0.96	
Yellow-	38	.751	.73	.720	1.01	
Orange	44	.863	.73	.731	0.99	0.987
	6	.366	.62	.632	0.98	
	21	.290	.58	.601	0.96	
Red	34	.436	.68	.660	1.03	
	40	.847	.70	.730	0.96	0.983

1. Need be 1.00 + or - .08-.10 to be significant

band of wave lengths designated as green. Slightly greater losses than expected were noted in this band, although the differences are not statistically significant.

4. From this study there seems no indication that filters before the eyes can in any way aid vision at low levels of illumination. The results indicate deleterious effects in practically every instance.

5. Some earlier indications of a purely psychological, or apparent, effect of brightness of certain filters seem in evidence from subjective accounts given but are not born out by the objective data.

6. The study supports the primary hypothesis set up but not as a linear relationship.

7. The corollary hypothesis is supported in a general way but not as a linear relationship.

8. The conclusions offered are given subject to limitations of the number of subjects used and the conditions of the experiment. Consistency of results indicates a certain degree of reliability throughout the experiment, which bolsters the conclusions offered.

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