LOW-CONTRAST VISION UNDER MESOPIC AND PHOTOPIC ILLUMINATION

T. W. Forbes and F. E. Vanosdall, Michigan State University

The objective of this research was to obtain normative data for 3 measures of visual ability under simulated night-driving luminance (mesopic) and ordinary lighting (photopic) conditions, to compare the performance of different age groups, and to compare results with those of a previous study. A total of 371 subjects aged 16 to over 60 were given the Titmus standard acuity test and a Titmus low-contrast test at photopic (34 ft-L) and mesopic (0.4 ft-L) background luminance, the latter simulating night-driving conditions. They were also given the Allen night vision performance test with a 10 percent contrast target at 10 and 0.2 ft-L. Comparisons were made with a previous study in which the NVPT target was 50 to 60 percent. Average scores (thresholds) were higher (poorer) on the Allen test with the 10 percent contrast target than with the 50 to 60 percent, but lower contrast targets were seen on the low-contrast Titmus test. The results seem to indicate that the Allen test with a 10 percent contrast target measured ability to see low-contrast targets against glare in both photopic and mesopic luminance and the Titmus low-contrast test measured low-contrast vision of a different type. Average low-contrast visual discrimination decreased with age. However, some subjects in all age groups exhibited poorer visual performance than most of their own and other age groups, and performance by most older subjects was as good as that of a large proportion of younger subjects.

•VISION of drivers under night-driving conditions is a problem that has concerned a number of investigators. Night driving often presents drivers with difficult conditions of vision because of low illumination and because of low-contrast targets on the highway. For example, pedestrians' clothing, vehicles, or other objects may be of such texture and color that they present relatively little contrast with the background. This problem is of special importance because visibility distances at night are all too limited for present-day driving speeds even under the best seeing conditions.

Low-contrast seeing tasks in daylight driving also may require similar visual discrimination, e.g., seeing one or more vehicles ahead in a snowstorm, especially when the vehicles are overtaken on a snowy road.

A key question is whether low-contrast seeing is mainly a problem for people in older age groups only, as some studies suggest, or whether some drivers in all age groups may show difficulty with low-contrast vision. Normative data are needed to answer this and related questions.

OBJECTIVES OF THE RESEARCH

The objectives of the research were to determine normative score distributions for drivers in 10-year age groups on 3 tests under 2 levels of surround lighting. The tests were the Allen night vision performance test (NVPT) with a 10 percent contrast target, the Titmus standard acuity test (TSAT), and a Titmus low-contrast test (TLCT), a special test slide using broken-circle test objects forming a graded scale of contrast.

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The two conditions of lighting were a 10 ft-L level representing ordinary room lighting conditions and a room lighting level of about 0.2 ft-L simulating night-driving conditions. For the TSAT and the TLCT, photopic and mesopic backgrounds were 34 and 0.4 ft-L respectively.

PREVIOUS STUDIES BY OTHER INVESTIGATORS

Pease and Allen (3) and Richards (5) noted a loss in visual efficiency of older age groups at low illumination levels similar to those of night driving indicated by Richards to be about 0.2 to 0.4 ft-L. Allen and Lyle (2) reported results on a small number of subjects in tests that used targets with contrast as low as 10 percent and filters to simulate visual characteristics of older people. Those results indicated that older subjects would have special difficulty in seeing low-contrast targets.

EARLIER STUDY AT MICHIGAN STATE UNIVERSITY

Forbes et al. (6) reported a study in which the NVPT and TSAT were used. The target letters supplied were intended to present 20 percent contrast, but our measurements with a Pritchard photometer showed that the letter contrast was actually in the 50 to 60 percent range.

The results of that study showed that some subjects in the age 60 and over group and some in younger age groups had difficulty in discriminating the NVPT targets. These subjects also tended toward poor acuity scores in the TSAT at photopic and even more at mesopic illumination levels.

When NVPT scores were correlated with TSAT scores at full brightness (about 34 ft-L) representing photopic vision, correlations of 0.50 to 0.65 or higher were obtained.

PRESENT STUDY

It seemed that measurements with a lower contrast target were needed because they might show the much greater deficiency reported for older individuals by Allen and Lyle (2).

Therefore, a 10 percent contrast target (this target was supplied through the courtesy and interest of Merrill Allen) was used in a second series of measurements on another group of subjects as reported in this paper. Also, because of interest in the low-contrast vision problem, a special target for the TSAT was supplied for this research. (R. A. Sherman and the Titmus Optical Company made this special target available for use in this research.)

TEST EQUIPMENT

Two testing devices were used: the Allen night vision performance tester and the Titmus vision tester.

The Allen tester uses 20/40 dark letters presented against a luminous background. The background illumination is raised gradually until the subject is able to read 4 out of 5 test letters. The device consists of 11- by 12-in. white translucent opal glass transilluminated by four 40-W incandescent bulbs. Three rows of reversible letters on photographic film are mounted on the opal glass screen. Two neutral density filters mounted 90 deg to each other form a V in front of the stimulus field; the vertex is toward the subjects to reduce effects of room illumination. The field and filters are enclosed in a black box. An intensity control and light-intensity measurement meter are mounted in a remote-control box. A black card was hinged to cover the front of the device so that the experimenter could cover test letters while the readout meter stabilized and also during recording of the meter reading. The subject viewed the test at a distance of 10 ft.

The Titmus tester is a binocular optical device for screening visual performance. It uses, for acuity measurements, slides bearing targets composed of Landholt rings of about 90 percent contrast and varying acuity steps from 20/13 to 20/100 and 20/200. Targets are transilluminated from the rear by tungsten bulbs. The targets are enclosed in a housing, which prevents outside light from entering. This instrument may be used

for measuring acuity of both eyes simultaneously, for the right eye or the left eye separately, and for other visual measurements.

In this study, the standard visual acuity tests and specially prepared graded contrast targets were used, both binocularly.

The standard acuity targets were presented at about 34 ft-L (photopic) and 0.4 ft-L (mesopic) luminance levels as were the graded-contrast targets. Each graded-contrast target presents 20/40 Landholt broken circles in a graded contrast series.

As in the earlier study, the mesopic level of lighting simulating night-driving conditions was obtained by use of 2 gooseneck lamps pointed at 45 deg to the rear of the room behind the subject and placed to produce about 0.2 ft-L on a white card on the front of the test equipment.

To simulate ordinary room lighting conditions that might be met if tests were administered in connection with driver licensing (called photopic in this report), luminance on the card was adjusted to give 10.0 ft-L. That level of room lighting was obtained with 2 banks of fluorescent-tube ceiling lights in diffusing fixtures slightly behind the subject. Similar lights in front of the subject were turned off to avoid possible glare from those sources.

Figure 1 shows a diagram of the layout of the test location in East Lansing. The testing room setup in the State Office Building in Lansing was very similar. All of the lighting conditions were checked photometrically and adjusted to be as nearly the same as possible.

SUBJECTS

A total of 397 subjects ranging in age from 16 to 70 were each given 3 different tests, each under mesopic and under photopic conditions. The number of subjects in each age group is given in Table 1. Because of incomplete records, the total number of subjects dwindled to 371 as shown below:

Age	Number
15-19	28
20-29	119
30-39	60
40-49	83
50-59	49
60+	32
Total	371

The first group of 309 subjects was obtained from new driver license applicants, from parents escorting them, and from renewal license applicants at the East Lansing office of the state driver licensing authority. Additional subjects were obtained through the courtesy of several state offices in Lansing. The latter group included a larger number of subjects in the older age groups.

PROCEDURE

The procedure was similar to that of the preceding study (6). All subjects wore glasses if they reported using them while driving at night. Each subject entered the experimental room and took a seat facing away from the lights in the back of the room and facing the NVPT instrument. The subject was "dark adapted" for approximately 5 min while the experimenter explained that the purpose of the project was to find out what most people can see under simulated night-driving conditions as compared to higher illumination conditions. The subject was told that the scores would be confidential and would not affect his or her driving record. Vision test records were identified only by number.

The Allen night vision performance test was given first, then the Titmus low-contrast test set for low illumination, and then the Titmus standard acuity (high-contrast) test, also under low illumination. Following this, the lights were turned up to the photopic room condition, and the tests were given again in the same sequence.

The graded series of contrast values for the TLCT are shown in Figure 2. The contrast values for the target letters of the NVPT and the broken-circle test objects of the TLC test were checked by measurements with a Pritchard photometer.

ANALYSIS OF THE DATA

The data were plotted as distributions by 10-year age groups. The scores of the different tests were coded and keypunched. Means, standard deviations, and product moment correlation coefficients were calculated by electronic computer. The entire group and the downtown and the East Lansing groups of subjects were analyzed together and separetely. Finally, the scores on each test were ordered, the poorest 20 percent were located, and sequential sorts were carried out to determine the number of those subjects common to each pair of tests.

RESULTS

Figures 3 to 8 show for each age group the percentage scoring at the levels indicated. Mean values are indicated by an X, and brackets to each side indicate the standard deviation of each distribution.

Figures 3 and 4 show the TSAT photopic and mesopic scores. As expected, the average scores increased with age. Mean photopic scores ranged from about 0.8 to 1.3 min of visual angle, and mesopic average acuities ranged from about 1.1 to 2.0 min of arc. The group means (Fig. 12) were similar to those of the group of subjects tested in the earlier study (6). Some subjects in each age group exhibited visual acuity scores considerably poorer than average for their age group. There were more of those in the mesopic than in the photopic acuity scores.

NVPT scores are shown in Figure 5 for photopic room lighting and in Figure 6 for mesopic or simulated night-driving room illumination. Mean NVPT scores for young to older age groups represented background luminances of about 4.0 to 40 ft-L for the photopic and about 7.0 to 55 ft-L for the mesopic scores. Each age group showed some extreme cases of poor visual discrimination. The deviant scores were much higher (indicating poorer discrimination) in this study than in the previous study. Average NVPT scores in the previous study ranged from about 0.5 to 1.6 ft-L. They also showed in each age group some subjects with much poorer scores than the rest of the group (Fig. 13).

Figures 7 and 8 show the photopic and mesopic score distributions on the Titmus low-contrast test. The average photopic scores for age groups varied from 2 to 8 percent contrast, and mesopic average scores for different age groups varied from 4 to 18 percent contrast. Again, a few cases in each age group exhibited much poorer scores than the remainder of the age group.

Figures 9, 10, and 11 show the proportion of subjects in the poorest 20 percent of each of the test score total distributions common to each pair of tests under photopic or mesopic conditions. The results of sequential sorting of the poorest 20 percent indicate that from 50 to 75 percent of the subjects in the poorest 20 percent were the same people, but the highest commonality occurred for the NVPT under the 2 lighting conditions.

Table 2 gives correlations for each combination of test scores at photopic and mesopic luminance levels. Considerable commonality is demonstrated among the scores on the different tests, but correlation coefficients indicate that the tests did not measure exactly the same visual ability. Correlations were highest between scores of the same test at photopic and mesopic levels. The NVPT was highest with a correlation of 0.867; the TSAT was next with 0.621. The TLCT showed the lowest self correlation of 0.468. Correlations between NVPT and TLCT involving low-contrast targets ranged from 0.36 to 0.50. Correlations within the subgroups and within age groups were also run and were quite similar.

DISCUSSION OF RESEARCH

Figure 12 shows that average TSAT scores of the 371 subjects in this study were very similar to those of the 396 subjects in the earlier study (6) for both the photopic

Figure 1. Layout of test equipment and lights.

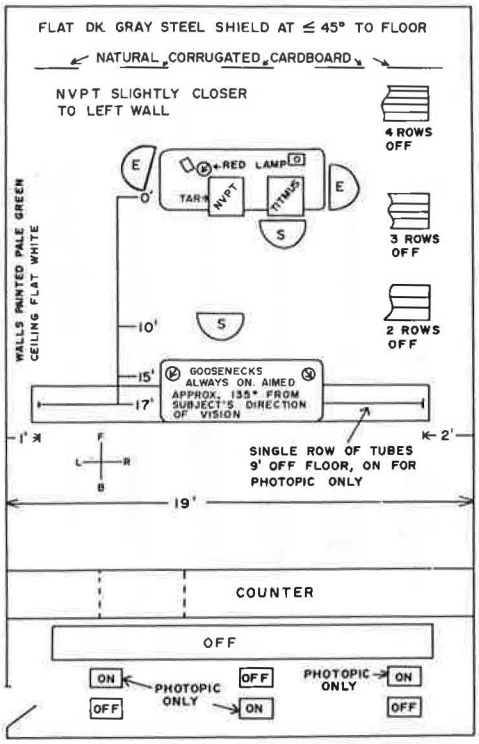


Table 1. Subjects in each age group.

Age	Males	Females	Total
16-20	18	19	37
21-25	44	38	82
26-30	26	11	37
31-35	19	12	31
36-40	25	17	42
41-45	22	25	47
46-50	27	19	46
51-55	16	10	26
56-60	18	4	22
61-65	13	3	16
66-69	6	0	6
70+	3	2	5
Total	237	160	397

Figure 2. Values used for TLCT target.

	1	2	3	4	5
A	.69	.61	.54	.48	.43
B	.38	.34	.31	.28	.25
C	.23	.20	.18	.15	.12
D	.09	.06	.04	.01	.01

BRIGHTNESS CONTRAST SCORE $(1-\frac{B_T}{B_B})$ FROM SMOOTHED CURVE.

Figure 3. Titmus standard acuity test, photopic condition.

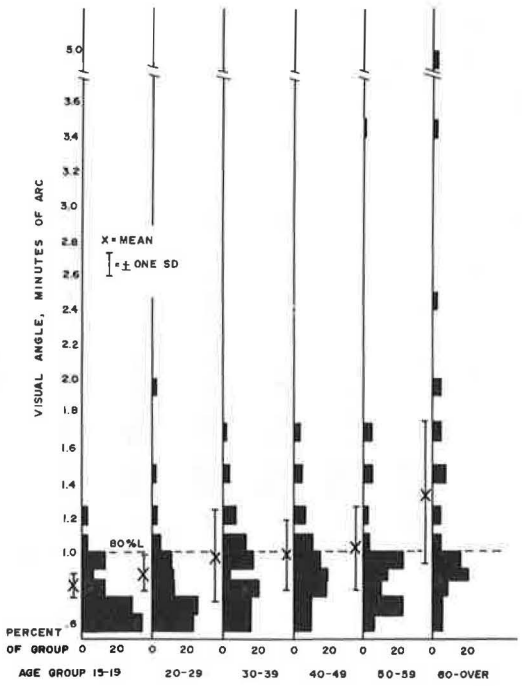


Figure 4. Titmus standard acuity test, mesopic condition.

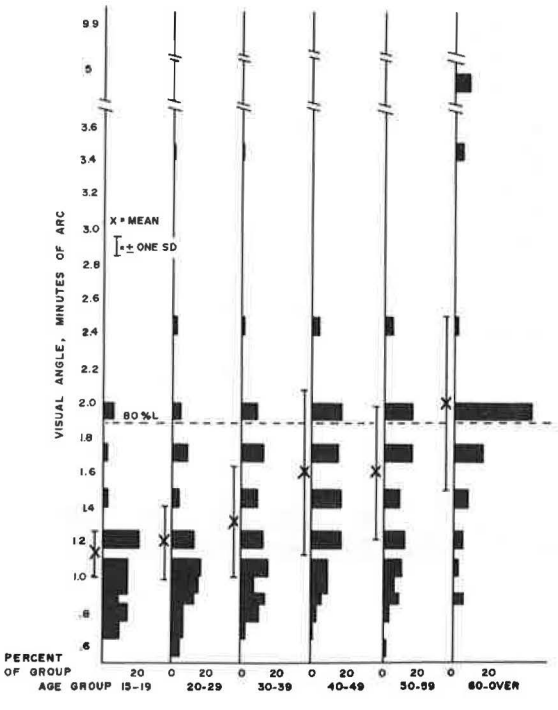


Figure 5. Allen night vision performance test, photopic condition.

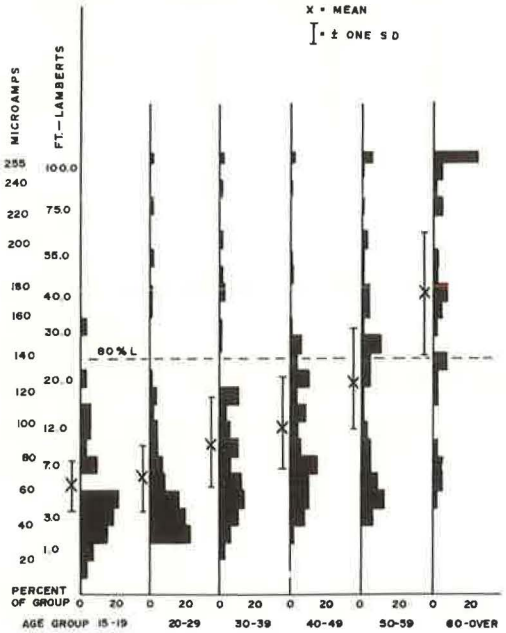


Figure 6. Allen night vision performance test, mesopic conditions.

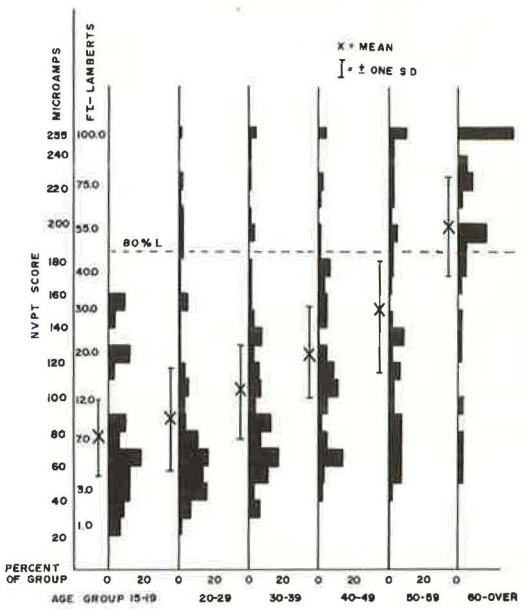


Figure 7. Titmus low-contrast test, photopic condition.

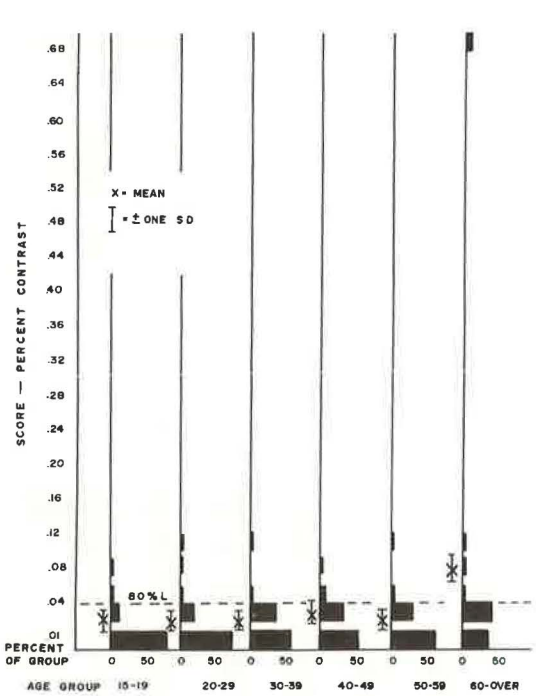
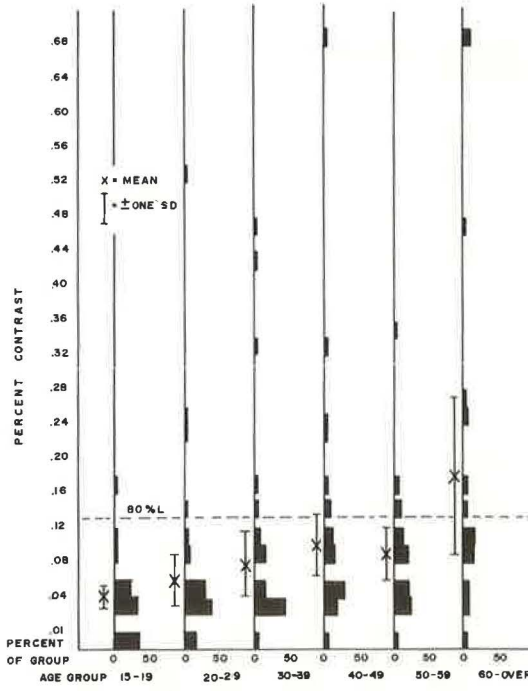


Figure 8. Titmus low-contrast test, mesopic condition.



and the mesopic levels of background luminance. The mesopic acuity correlated with the photopic about 0.62, and average acuity decreased consistently with age from about 1.0 to 2.0 min of arc. Those relations are in general agreement with results reported by Uhlaner and Drucker (7) and by Richards (5). Blackwell and Blackwell (4) report a threshold "contrast multiplier" for the 60 to 70 age group compared to the 20 to 30 age group of 2.5, which is roughly in the same range.

Table 3 and Figure 13 show that the NVPT 10 percent contrast target resulted in higher average scores (poorer discrimination) for all age groups in both photopic and mesopic conditions. Contrary to the earlier results, photopic scores (room lights on) were lower (better). Therefore, the room lighting in which the test is given is important when the 10 percent contrast target is used.

The poorest 20 percent of the subjects required more than 50 ft-L under mesopic and more than 25 ft-L under photopic room conditions. (The foot-lambert values shown in Figure 13 represent an average of mesopic and photopic readings taken with a Pritchard photometer.) Those levels were very much higher than the 1.0 to 1.6 ft-L in the previous study using a target contrast of 50 to 60 percent. That difference in score level again shows the effect of the 10 percent contrast target.

The 10 percent contrast target apparently introduced different factors into the visual performance. In fact, when viewing this target, a few of the subjects were unable to discriminate the test letters even with the highest luminance level available.

In the TLCT at photopic background luminance, most subjects discriminated 4 percent contrast targets, and all subjects discriminated targets at or below 12 percent contrast. At mesopic background luminance, the majority discriminated targets at 12 percent contrast or lower, but a few subjects in each age group required 20 percent or higher.

Although a majority of the subjects discriminated mesopic Titmus target contrast as low or lower than the NVPT target, very few discriminated the 10 percent NVPT target even at a 2 ft-L background luminance. Most required a much higher level. This suggests that the NVPT with the 10 percent contrast target measured some other factor than low-contrast discrimination alone.

Because the NVPT background luminances for discrimination were much higher than those in the previous study, it seems that the NVPT background may have been bright enough to introduce pupillary contraction and veiling glare to produce the poorer scores. Thus, the NVPT with the low-contrast target apparently served as a test of vision against glare. That interpretation is supported by comments of some subjects that the NVP test gave them trouble because of glare.

As in the previous study, the average scores for the different age groups showed a gradual decrease of acuity from the lowest to the highest 10-year age group. Some subjects in each of the age groups showed much poorer visual performance than the majority in their age group, and many in the older groups did as well as many in the younger groups.

CONCLUSIONS

1. Normative scores for 3 visual tests at both photopic and mesopic luminance levels were determined for 371 subjects divided into 10-year age groups. As expected, average visual performance decreased with age, but age-group scores overlapped greatly on the 3 tests.

2. The NVPT with 10 percent contrast target appears to measure ability to discriminate low-contrast targets against glare. A few subjects in younger as well as older age groups (except those under 20 years) showed poor performance compared to the majority of the people in that age group. Therefore, low-contrast vision in low illumination may be a problem for some drivers of all ages.

3. The TSAT (with about 90 percent target contrast) at low luminance level (0.4 ft-L) simulating night-driving vision conditions showed somewhat similar relations (i.e., gradually decreasing acuity from lowest to highest 10-year age groups). Some individuals with very poor scores were in younger as well as older age groups.

Figure 9. Poorest score subjects common to NVPT and TSAT.

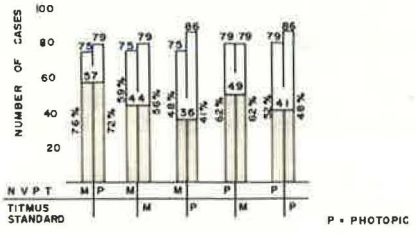


Figure 10. Poorest score subjects common to NVPT and TLCT.

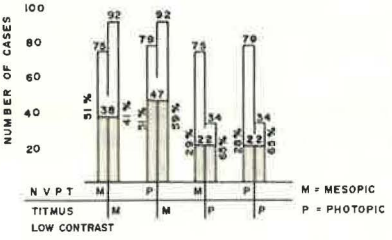


Figure 11. Poorest score subjects common to TLCT and TSAT.

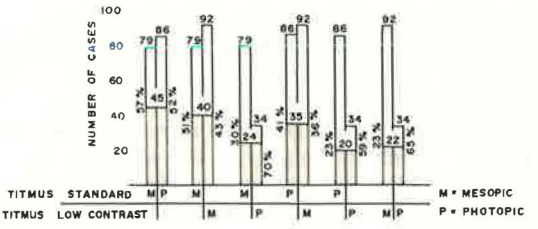


Table 2. Intercorrelation of test scores.

	Mesopic			Photopic		
Test	NVPT	TSAT	TLCT	NVPT	TSAT	TLCT
Mesopic						
NVPT						
TSAT	0.547					
TLCT	0.501	0.439				
Photopic						
NVPT	0.867	0.601	0.540			
TSAT	0.482	0.621	0.485	0.516		
TLCT	0.361	0.413	0.468	0.391	0.497	

Figure 12. Visual acuity of subjects.

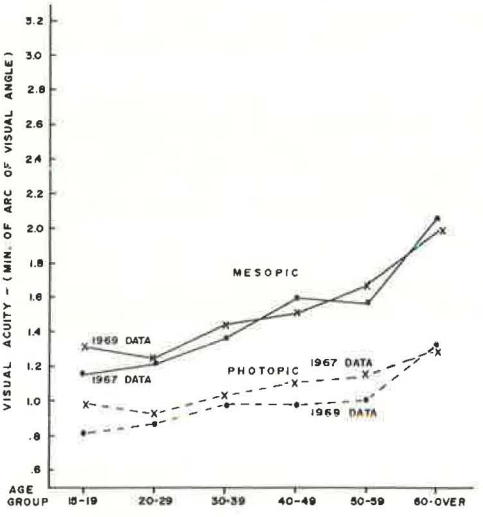


Figure 13. Effect of target contrast.

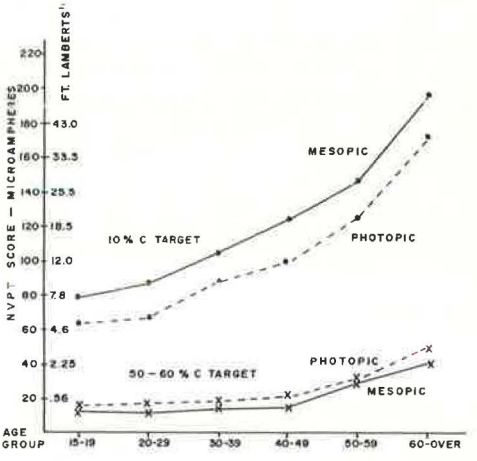


Table 3. Score averages and standard deviations by age groups.

	Mesopic						Photopic					
	Avg NVPT		TSAT		TLCT		Avg NVPT		TSAT		TLCT	
Age Group	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
15-19	78.93	37.28	1.16	0.32	0.05	0.04	63.68	31.84	0.81	0.16	0.02	0.02
20-29	87.13	53.05	1.21	0.51	0.06	0.06	67.65	42.82	0.87	0.26	0.02	0.02
30-39	104.63	59.36	1.36	0.70	0.08	0.08	87.27	54.53	0.98	0.57	0.03	0.02
40-49	123.67	58.12	1.60	1.05	0.11	0.10	98.63	49.70	0.98	0.27	0.03	0.02
50-59	146.29	68.08	0.57	0.73	0.09	0.06	124.53	60.71	1.01	0.45	0.02	0.02
60+	196.97	61.40	2.06	0.95	0.18	0.19	173.22	73.50	1.34	0.90	0.08	0.17
All	115.47	65.54	1.44	0.79	0.09	0.09	94.38	60.04	0.97	0.44	0.03	0.05

4. In the TLCT, however, many subjects discriminated targets at 12 percent contrast or lower, but some in each age group required 25 percent contrast or higher for discriminating the broken-circle test objects.

5. Correlations of the different test scores ranged from 0.36 to 0.55 for the tests involving low-contrast targets. Photopic and mesopic scores for each test showed higher correlations (0.55 to 0.87).

6. Each of the tests must be interpreted in terms of its own normative score distribution by age groups.

7. A difference has been demonstrated in the ability to discriminate low-contrast targets against a background of low-level luminance as compared to the ability to discriminate a very low-contrast target against a background of increasing luminance that may reach levels of glare. The NVPT appears to measure ability to see low-contrast targets against glare, whereas the TLCT apparently measured ability to discriminate low-contrast targets as such.

8. Although, as expected, subjects in the 50 to 60 age group showed poorer scores on the average, many did as well as most younger subjects. Some younger subjects had much poorer vision than their own age group and than most of the older subjects. Therefore, individuals should be made aware of such deficiencies regardless of age.

9. Use of the tests for selection or licensing is not recommended because no actual relation has been demonstrated to safe driving. However, use of such tests for informing drivers and alerting them to the existence of visual problems is probably desirable because of the possible relation to safe driving.

10. If the tests are used for informing and educating drivers and for research purposes, norms must be determined for the particular test and target contrast used as well as for the surrounding room illumination in the case of the NVPT with a very low-contrast target.

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