A thorough review of the relevant literature was combined with a rigorous and systematic examination of the driving task to derive a set of visual functions important to the driving task. The functions included both static and dynamic measures, containing both sensory and perceptual aspects. A device was developed to test performance on these functions, including three measures related to night vision: static acuity under low levels of illumination, in the presence of veiling glare, and under spot glare. The battery of tests was administered to a total of 669 passenger car drivers and 235 truck and bus drivers. Three-year driving records were obtained for all subjects and were examined in relation to performance on the vision tests. Because no data on night accidents were available, an adequate evaluation of the night-vision-related tests was not possible; however, the results showed a high degree of variability in visual acuity performance obtained under conditions similar to those encountered in night driving and also showed that acuity measured under normal light conditions does not adequately predict acuity under typical night driving conditions.

# DRIVER SCREENING FOR NIGHT DRIVING

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The importance of vision to driving is well recognized. This recognition has been intuitive, for until recently there has been no evidence that poor vision is associated with increased accident likelihood. All states require driver license applicants to pass some test of visual performance, usually static acuity, at least for their first license. However, there is no standardization of tests, test procedures, minimum standards, or frequency of retesting among the states. In states without renewal examination, there is no assurance that even the minimal level of visual performance originally required is maintained by the driver over the years. When viewed in an international context, the problem is even more complex.

This paper describes a research program conducted to provide some of the information necessary before standards for driver vision screening can be established. The study had several specific objectives:

1. To determine analytically the basic visual requirements of driving by drawing on the existing literature relevant to the problem and by conducting a rigorous and systematic examination of the driving task;
2. To devise tests suitable for use in state driver licensing programs for visual performance parameters determined to be important to driving; and
3. To evaluate the accuracy of the empirical analysis and the adequacy of the devised tests by experimentally determining the relationship between visual capability as measured by tests and past accident involvement of those tested.

Only those tests that demonstrated a relationship between poor performance and high accident involvement would be appropriate for use in screening driver license appli-

*The research described in this paper was performed while Mr. Henderson was with the System Development Corporation.

cants. (The scope of the study subsequently was expanded to include visual and auditory requirements of driving passenger cars, trucks, buses, and motorcycles. This paper, however, discusses only visual requirements of passenger car and commercial driving, with particular emphasis on night driving.)

## GENERAL APPROACH

Identification of the visual requirements for each class of driving (automobile or truck and bus) was based on a three-step procedure:

1. Review of relevant literature;
2. Examination of the driving task, as defined in available task analysis documentation; and
3. Consolidation of the results of the first two activities, identification of common findings, and resolution of differences.

The final output was a list of visual requirements felt to be of sufficient importance to warrant consideration as candidates for inclusion in screening programs. Activities that led to this list of candidates are reported in detail elsewhere (10, 11).

Each requirement identified was then reviewed in terms of how an individual's basic capability to meet the requirement could be measured. Because commercial tests frequently did not exist for this purpose, new tests and test procedures had to be designed and constructed. Once this was accomplished, all tests were administered to a sample of drivers, and their performance on these tests was related to their past accident involvement. Tests found to be of value in predicting accident involvement, i.e., those on which poor performance was related to high accident involvement, were then considered suitable for screening driver license applicants.

## SPECIFIC APPROACH

Initially, a list of visual functions potentially important to driving was established. Development of the list relied heavily on the expertise of the project's optometric consultant. This list was not intended to be final and, as expected, was modified as a result of the literature survey and task analysis. The revised list contained 18 visual functions considered potential candidates for inclusion in the vision test device: accommodation amplitude, accommodation facility, adaptation, angular movement, color vision, dynamic visual acuity, field of fixation, fusion, glare sensitivity, movement in depth, phorias, pursuit fixation, saccadic fixation, static acuity, steady fixation, stereopsis, vergences, and visual field. Only two functions in the list appear to be directly related to night driving: adaptation and glare sensitivity. As the following brief review of the literature shows, this is a misleading assumption.

## REVIEW OF THE LITERATURE

### Adaptation

Adaptation is the change in sensitivity of the eye as a function of change in illumination. Sensitivity increases under reduced illumination (dark adaptation) and decreases under increased illumination (light adaptation).

Although the adaptation process can be an important factor in driving during daylight hours, for example, when a driver enters a long tunnel, the more common concern is with initial dark adaptation at dusk and with perturbations to the state of adaptation that occur during night driving as a result of roadway or roadside lighting and head lamps of other vehicles.

The progress of both light and dark adaptation in the normal eye is well-known and well documented in the physiological and psychological literature and will not be repeated here. Schmidt (19) presents an excellent summary of the pertinent facts and distinguishes among the three levels of adaptation corresponding to photopic (daytime), mesopic (twilight), and scotopic (night) vision. The mesopic range (15), in which the illumination level varies from 0.003 to 4.0 ft-L (1.0 to 13.7 cd/m$^2$), is of primary interest in night driving.

Schmidt (18), in reviewing the adaptation process, emphasized the magnitude of the individual differences in adaptation facility and pointed out that the greatest variability is found in the mesopic range. Schmidt also discussed the importance of the correlations between dark adaptation and other visual functions in the design of a night vision tester. On the basis of the generally low correlations found, she concluded that it is safer to test the specific function about which information is desired at the specific level of illumination of interest than to rely on correlations with other functions at other levels of illumination. In short, tests for the various visual functions important to driving must be conducted under conditions of illumination actually encountered in night driving if meaningful results are to be obtained.

Domey and McFarland (8) made a detailed study of the relationship between age and adaptation and found a regular decline in adaptation ability with increasing age. The authors showed that the progress of adaptation during the first 10 min allows accurate prediction of the final adaptation level and, although they referred to the 10-min test as a short clinical test of adaptation, it seems prohibitively long for use in a high-volume screening procedure such as driver licensing. Thus, testing for adaptation in screening drivers would appear to be ruled out. However, because the driving task rarely involves scotopic vision, the ultimate level of scotopic adaptation may not be relevant, and adaptation to mesopic levels is essentially complete in 5 min (19). Further, examination of dark adaptation curves indicates that roughly 90 percent of adaptation to mesopic levels occurs during the first 2 min. For screening purposes, therefore, 2 min may be sufficient for testing visual functions at the higher mesopic levels of illumination.

Although no studies that related adaptation ability to driving record were found, it is obvious that the adaptation function is a part of the complex of visual functions required in night driving. Because adaptation ability is known to decline with advancing age, it should at least be considered for inclusion in retesting and screening programs for older drivers. Inasmuch as individual differences in ability tend to be greatest in the range of mesopic vision typically encountered in night driving, some gross test of adaptation might be warranted for all drivers. Further information is required on the magnitude of individual differences and the relationship between adaptation and other visual functions at mesopic levels of illumination before any firm decisions can be made.

## Glare Sensitivity

The second function on the list that relates to night driving is glare sensitivity. Relatively bright light that produces unpleasantness or discomfort or that interferes with optimum vision is termed glare. Glare sensitivity refers to the ability to resist (glare resistance) or recover from (glare recovery) the effects of glare.

Any degree of light falling on the retina that does not contribute to clear vision constitutes glare. Vehicle drivers may be subjected to glare during daylight hours either from direct impingement of the sun's rays on the eye or, more commonly, as a result of reflections from shiny surfaces. A dirty or pitted windshield can scatter sunlight so as to create a light veil that tends to obscure objects in the environment. Similarly, reflections of the interior of the vehicle on the inside surfaces of the windshield can also produce veiling glare. Although the importance of glare during daytime driving should not be minimized, the majority of research on glare has been directed toward night driving in which the primary glare sources are headlights of opposing vehicles and light from roadway luminaires, advertising signs, and the like.

The effects of glare in reducing seeing depend on the intensity and position of the

glare source relative to the line of sight (16). Glare along the line of sight reduces vision maximally, and the adverse effects fall off rapidly as the angle between the line of sight and the source increases. Connolly (7) states that, when the glare source is more than 10 deg from the line of sight, its effect on visual performance is relatively meaningless.

Burg (4) obtained glare recovery data from almost 18,000 subjects of all ages and reported a progressive deterioration in glare recovery ability with advancing age, but no differences between males and females. Burg's data, as well as those by Wolf (21), show that the rate of deterioration with advancing age is greatly accelerated after age 40. Reading (14) reported that recovery time from headlight glare increases significantly with age and that recovery time is shorter after exposure to white light than to yellow light, particularly in the older age group.

In general, recovery from the effects of glare depends on the retinal area involved, its previous adaptation level, intensity of the glare, exposure time, color of the glare source, accompanying changes in pupil size, and visual health of the individual (16).

The specific effects of glare on driving behavior have not yet been clearly defined; however, experimental data in general support the widely held opinion that in night driving glare degrades visual performance when a glare source, such as an opposing headlight, is encountered and immediately thereafter. Forbes (9) suggests that, in addition to its direct physical effects, discomfort glare encountered in night driving may be an important factor in inducing fatigue and drowsiness, even if the glare is not strong enough to directly reduce visual efficiency.

Burg (5, 6) found a slight but statistically significant relationship between glare recovery and driving record, but reported the relationship to be inconsistent. He points out that the inconsistent results might be attributed to the particular device used to measure glare effects. Allen (1) suggests that the low correlations found by Burg may be attributed to the fact that dirt and scratches on the windshield, plus hygroscopic deposits from tobacco and the like, may create so much glare that the contribution measured in the driver's eyes may not be reflected in accident statistics. In any event, it appears likely that glare sensitivity is an important visual function in driving and, in spite of the low correlation found with driving record, should be a part of any vision screening program for driver licensing including periodic retest in the over-40 age group. Again, however, it is important to test the effects of glare in situations pertinent to driving and on a number of visual functions, not just one, since the effects may be different for different functions. Particularly, the effects of glare on complex visual perceptions should be studied because they depend on a number of cues that may be degraded more seriously by glare than basic sensory responses such as acuity.

## Other Visual Functions

Adaptation and glare sensitivity are of direct concern in night driving primarily because of their influence on other visual functions necessary in night driving such as static visual acuity. Many factors influence acuity, but of particular relevance to night driving are luminance, state of adaptation, and contrast.

### Luminance

Target luminance is an important controlling factor in visual acuity. Acuity is poorest under low levels of illumination and gradually increases to a limiting value as illumination is increased. It is not generally recognized, however, that the correlation between acuity at high and that at low levels of illumination is rather low. This has significant implications for driver license tests since it points out the inadequacy of current practices in terms of screening out individuals whose visual acuity is unacceptably poor at levels of illumination encountered in night driving.

### State of Adaptation

The luminance stimulation in the immediate past has an important influence on acuity largely because of its effect on sensitivity of the eye. If the eye is subjected to a relatively bright stimulus and its sensitivity is then measured in terms of the time required to read a small acuity target at various luminance levels, the resultant data are very similar to the typical dark adaptation curves based on absolute threshold to light stimuli, including the rod-cone discontinuity (2, 3). At the other extreme, the dark-adapted eye exhibits an oscillation of sensitivity and in acuity when subjected to a bright adapting light.

### Contrast

The effect of target-background contrast on visual acuity is of primary interest in the context of night driving (17). Stevens and Foxell (20) and Pease and Allen (13) report that maximum visual acuity is achieved when the luminance of the surrounding field is equal to or slightly below that of the central field.

Based on review of the literature, it was concluded that glare sensitivity and overall visual performance under low levels of illumination were among those functions that definitely appeared to be important to driving, whereas the role of adaptation in driving had yet to be established.

## EXAMINATION OF DRIVING TASK ANALYSIS

None of the literature on vision and driving has attempted to identify the visual requirements of the driving task. Therefore, available driving task analysis information was examined in an attempt to draw inferences regarding visual requirements. The most comprehensive driving task analysis available was conducted for the U.S. Department of Transportation (12), and this document provided the basis for the systematic evaluation of the visual requirements of driving conducted as part of this study.

Briefly, the analysis identified some 1,500 driving "behaviors" required of the driver. Each of these behaviors was then evaluated in terms of its criticality to safe performance of the total driving task and assigned a criticality rating.

In the current project, each one of these behaviors was examined to determine which, if any, of the 18 visual functions listed were required in normal performance of the behavior. When a visual function was required by a specific driving behavior, the degree to which it was essential to that behavior was judged and a weighting factor assigned.

Once this analytical procedure was accomplished, each of the 18 functions was ranked on two dimensions—the average criticality of the driving behaviors it was involved in and the average degree of essentiality of the function to these behaviors. On the basis of these two rankings, a hierarchy of each function's importance to the driving task was established. However, glare sensitivity and adaptation were not included in this hierarchy because they are not specifically task-related visual functions but can be involved in all tasks under certain conditions. For example, glare sensitivity can conceivably be related to any and all driving behaviors involving visual performance when sufficient glare is present to impair that visual performance. Such glare may take the form of opposing headlights or extremely bright roadside lighting encountered during night driving, or it may occur during daylight hours from the sun shining directly or via reflections into the eyes of the driver. It may also result from the sun striking a pitted and dirty windshield at the right angle to practically obscure all vision. The point is that the presence of glare is determined by environmental conditions and is essentially independent of any specific driving behavior. Because significant individual differences in glare sensitivity are known to exist, it is obvious that glare sensitivity must be considered as a visual function important to driving. However, evaluation of the relative importance must be made on grounds other than analysis of driving behaviors.

Adaptation is another function very similar to glare sensitivity in terms of its rela-

tionship to specific driving behaviors. At any time environmental conditions create a situation in which relatively large changes in illumination level occur, then adaptation becomes a pertinent factor in any driving behavior requiring visual performance.

Two other functions, phoria and fixation field, though not necessarily dependent on environmental conditions in the same way as are glare sensitivity and adaptation, are also difficult to evaluate through analysis of driving behaviors. These functions represent difficulties with the muscular control of the eye, which cause the individual to lose fusion and to suffer diplopia under certain conditions, e.g., poor visibility as a result of visual fatigue. Their importance to driving must be ascertained on grounds other than analysis of individual driving behaviors.

## SUMMARY OF ANALYTICAL FINDINGS

As a result of both the literature survey and examination of the driving task, the following six functions were judged relatively high in importance to driving:

1. Static acuity,
2. Perception of angular movement,
3. Perception of movement in depth,
4. Dynamic visual acuity,
5. Visual field, and
6. Saccadic fixations.

In addition, the literature review suggests that the following functions also are highly important:

1. Glare sensitivity,
2. Pursuit fixations,
3. Steady fixations, and
4. Overall visual performance under low levels of illumination.

It is not to be inferred from these lists that other visual functions play no role whatsoever in driving. Some, such as color vision, are felt by some investigators to be very important; however, neither the literature nor the analyses of the driving task provide evidence in support of this view. As a consequence, development of the prototype test device concentrated on those functions itemized above, which were felt to have the greatest value in a screening application.

## DEVELOPMENT OF A PROTOTYPE TEST DEVICE

Most of the visual functions identified above are not measured by any commercially available test device; therefore, a device was developed specifically for use in the evaluation program. The device consists of three major components:

1. A plywood enclosure approximately 50 in. wide, 24 in. deep, and 24 in. high ($1.27 \times 0.6 \times 0.6$ m). Looking through a viewing aperture, the subject is presented stimuli over a field of view of approximately 180 deg laterally and 30 deg vertically. The enclosure houses all test stimuli and excludes ambient illumination.
2. An electronic control box connected to the enclosure by a 3-ft (0.9-m) cable. The control box contains all the electronic circuitry and manual controls required by the experimenter to select and sequence tests and control test parameters.
3. A specialized projector system that includes a standard audio cassette tape playback unit to present standardized verbal instructions to the subject and to control an 8-mm film cassette that presents the stimuli for certain tests.

A photograph of the prototype device is shown in Figure 1. Shown are a side view of

**Figure 1. Integrated driver vision testing device.**

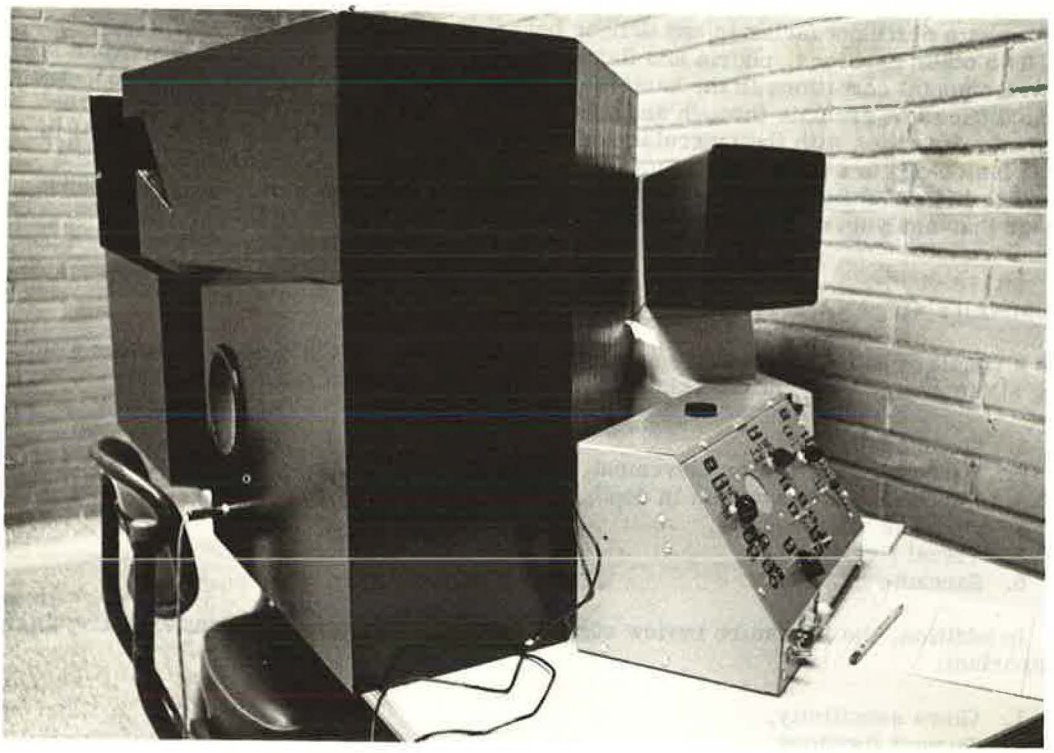
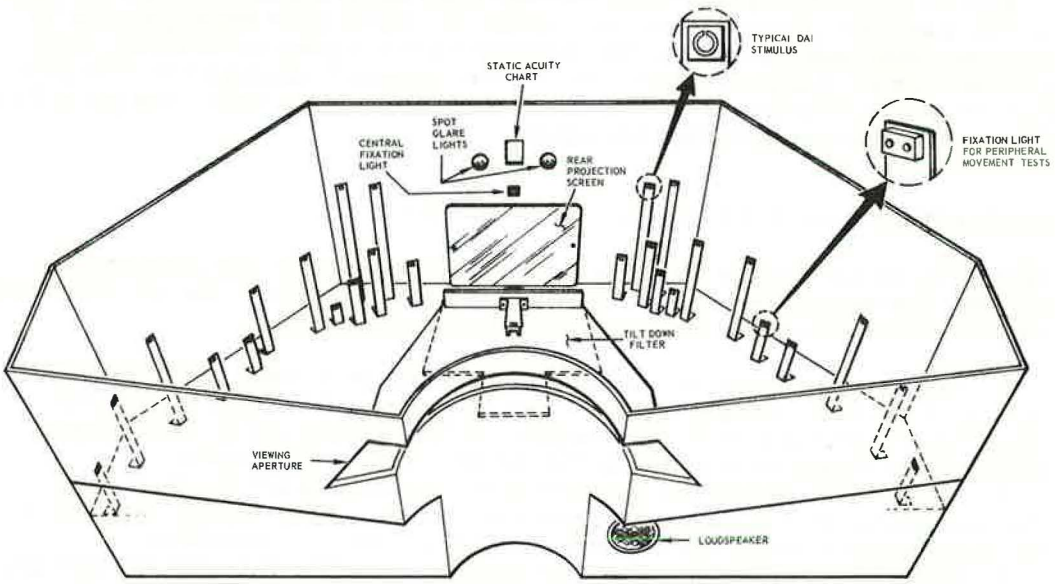


**Figure 2. Interior of integrated driver vision testing device.**



the enclosure, the electronic control unit, and the rear of the projector unit in the upper right corner of the figure. An artist's drawing of the interior of the enclosure shown in Figure 2 illustrates the basic simplicity of internal design.

The device was designed to provide the following performance measures:

1. Static visual acuity under normal illumination (SA-NORM),
2. Static visual acuity under a low level of illumination (SA-LL),
3. Static visual acuity in the presence of veiling glare (SA-VEIL),
4. Static visual acuity in the presence of spot glare (SA-SPOT),
5. Dynamic visual acuity,
6. Ability to perceive movement in depth (both centrally and peripherally),
7. Ability to perceive angular movement (both centrally and peripherally),
8. Lateral visual field, and
9. Ability to detect, acquire (fixate on), and interpret stimuli presented at random locations in the visual field for brief periods of time.

Except for the tests of movement threshold, the stimuli for all other tests consist of Landolt rings—circles with a break in them.

To keep the overall size of the device within practical limits, we presented all test targets at a nominal 20 in. (0.51 m) from the observer's eyes. To prevent penalizing older drivers who may not be able to focus (accommodate) on an object at that distance and to simulate distances important to the driving task, supplemental lenses are used to make stimuli at 20 in. appear to be at optical infinity [assumed by convention to be 20 ft (approximately 6 m) or more]. This is common practice in all compact vision test devices and is usually accomplished with fixed optics. However, because freedom of head movement is required by some of the tests in this device, these supplemental lenses are provided in conventional eyeglass frames for those who do not normally wear eyeglasses and in clip-on frames for those who do.

The device is flexible enough to permit measurement of performance on any of the tests under varying illumination or glare conditions or both. However, performance measurement on all tests under low levels of illumination and glare obviously was impossible because it would have made testing time prohibitively long. Therefore, the effects of low illumination and glare were measured solely on static acuity, a visual function that is simple to measure and about which much is known. Of the tests listed above, then, only those dealing with static acuity are discussed. The interested reader is referred to Henderson and Burg (11) for a discussion of the other vision tests involved in the research program.

## Static Acuity, Normal Illumination (SA-NORM)

The ability of the eye to resolve detail in a stationary object is measured by presenting to the subject a series of Landolt rings, calibrated in size to correspond, in terms of the angular subtense of the break in the circle, to the Snellen system of notation, e.g., 20/20, 20/40, etc. A series of rings of graduated size is presented to the observer who is instructed to call out the location of the break in each circle beginning with the largest (20/175 equivalent) and going toward the smallest (20/20 equivalent). The Snellen equivalent of the smallest circle in which the gap position is correctly identified at least four out of six times is the subject's static acuity score. The test targets used have a brightness of 2.3 ft-L (7.9 cd/m$^2$) and a background brightness of 0.019 ft-L (0.65 cd/m$^2$), yielding a contrast of 0.99.

## Static Acuity, Low Level Illumination (SA-LL)

A measure of the individual's visual acuity under levels of illumination typically encountered in night driving is obtained by administering the static acuity test again. This time a neutral-density filter is interposed between the subject and the target (and back-

ground), which keeps the contrast the same but reduces the Landolt ring target brightness from 2.3 to 0.02 ft-L (7.9 to 0.7 cd/m$^2$). Although this level of brightness is not in the deep mesopic range and does not represent the worst case in night driving, it was representative of night driving yet not so dim as to require long-term dark adaptation. (Long-term adaptation is not practical for a screening test situation.) In practice, most subjects spend approximately 10 to 15 min in the dark test room viewing test targets no brighter than 2.3 ft-L (7.8 cd/m$^2$) and, during the 5 to 10 min immediately preceding this test, view moving targets of comparable brightness to those used in this test. The same procedures and scoring criteria are used for this test as for the SA-NORM.

### Static Acuity, Veiling Glare (SA-VEIL)

To obtain one measure of an individual's sensitivity to glare, the static acuity test is administered again. In the veiling glare test, the subject is required to view the test targets through a uniform field of reflected white light of 40.25 ft-L (137.9 cd/m$^2$) brightness. The brightness of the test stimuli is 42.5 ft-L (145.6 cd/m$^2$), giving a contrast of 0.05.

### Static Acuity, Spot Glare (SA-SPOT)

A second measure of glare sensitivity was obtained by presenting the static acuity stimuli to the subject in the presence of two spot glare sources, one on each side of the test targets. Brightness of each bulb, measured directly at the light, is 40,000 ft-L (137 kcd/m$^2$). Separation between the two lights is approximately 5 in. (127 mm) and, as with the test stimuli, they are approximately 20 in (0.5 m) from the subject's eyes.

The score on each acuity test is the smallest row of acuity targets in which the individual can reliably identify the location of the gap in four out of six targets.

The four tests described above were not administered in the order shown but were worked into a carefully planned sequence that included all the tests listed earlier. All testing was conducted in a dark room.

## EVALUATION OF THE PROTOTYPE TEST DEVICE

A full description of the methodology used in collecting vision test data on the prototype device can be found elsewhere (11). Briefly stated, the tests were administered to both passenger car drivers and truck and bus drivers. A total of 669 passenger car drivers were tested, the majority at California Department of Motor Vehicles' field offices. The subjects ranged in age from 16 to 86 and were of both sexes (37 percent female). In addition, a total of 235 male truck and bus drivers were tested at their places of employment. They ranged in age from 25 to 64, with a mean age of 41 years. All subjects were volunteers. Subsequent to testing, 3-year driving record information on each subject was obtained (from DMV files for passenger car drivers and from company records for the truck and bus drivers).

The data collected from both groups of subjects were subjected to three types of analyses: correlational, multiple regression, and graphical. The results of these analyses are summarized below.

## RESULTS OF EVALUATION STUDY

The data collected during the evaluation program were analyzed in a number of ways. Because of the known relationship between age and general visual capability and between age and accident involvement, the total passenger car sample was divided into three age groups for most analyses. These age groups were 16 to 24, 25 to 49, and

50 and above. Tables 1 and 2 give selected personal and vision test data for all subject groups.

Correlational and multiple regression analyses were carried out. They revealed that, of the four tests being discussed, only SA-NORM was a significant predictor of accident record and then only for 25 to 49-year-old passenger car drivers.

A graphical analysis was also carried out to evaluate the hypothesis that individuals with poor performance on a given test have a mean accident rate significantly greater than drivers with better visual performance. Used in this fashion, graphical analysis is a more appropriate statistical technique than either correlational or multiple regression analysis for establishing the feasibility of using a particular test in a screening program, for the impact of using various cutoff scores for each test can be assessed.

The results of the graphical analysis show that for the passenger car drivers, even when day and night accidents are grouped together, poor performers on all four static acuity measures have higher accident rates than do good performers. (A similar analysis was not conducted for truck and bus drivers.)

Review of the findings of all the analyses shows that SA-LL, SA-VEIL, and SA-SPOT, which deal with aspects of vision involved in night driving, were not adequately evaluated in this study in that no information was available concerning night accidents to provide an appropriate criterion variable.

What the data do provide is an indication of the degree of variability in visual acuity performance obtained under conditions similar to those encountered in night driving. The data also show that acuity measured under normal light conditions does not adequately predict acuity under conditions typical of night driving. Figures 3 through 7 show cumulative frequency distributions for the various acuity tests and subject groups, and Tables 3 and 4 give intercorrelations among the vision tests and age. Figure 8 shows a comparison of mean performance scores on the tests for the various subject groups.

It is clear from the figures that

1. The effect of age on acuity, regardless of how it is measured, was dramatic;
2. Performance on the spot and veiling glare tests was very much alike within each age group;
3. The range of acuity performance within each age group increased dramatically under low illumination and in the presence of glare (as shown by the relatively low intercorrelations, some individuals are affected much more than others by these adverse viewing conditions); and
4. Truck and bus drivers reacted to the adverse effects of low illumination and glare as did passenger car drivers, in spite of the fact that the acuity test procedure was significantly modified for administration to truck and bus drivers (this modification had the effect of making the test easier at the poor performance end of the scale and at the same time more reliable).

The data given in Table 3 and shown in Figures 3 through 8 are consistent with the literature and clearly suggest that tests of daytime vision do not suffice for the prediction of vision-related nighttime accidents. There is, then, an urgent need for a controlled study of the relationship between night vision performance and night accidents.

## PLANS FOR THE FUTURE

The National Highway Traffic Safety Administration is currently sponsoring a program to design and construct an improved vision testing device that incorporates those tests found most promising in this study. Specifically, this program has the objective of constructing a feasibility prototype of a Mark II device that will automatically administer and score tests that measure

1. Static acuity,
2. Static acuity under a low level of illumination,

**Table 1. Summary of personal data on drivers tested.**

| Drivers Tested | Sample Size | | Average Age | Estimated Average Annual Mileage (thousands) | Number of Accidents in Past 36 Months | Accidents per 100,000 Miles |
|---|---|---|---|---|---|---|
| | Number | Percent | | | | |
| Passenger car | | | | | | |
| 16 to 24 | 155 | 23.2 | 20.8 | 16.1 | 0.50 | 2.03 |
| 25 to 49 | 310 | 46.4 | 35.9 | 17.6 | 0.32 | 0.69 |
| 50 and over | 203 | 30.4 | 60.0 | 13.4 | 0.15 | 0.80 |
| All ages | 668 | 100 | 39.7 | 15.9 | 0.31 | 1.03 |
| Truck and bus | 235 | | 40.9 | 69.2 | 0.64 | 0.79 |

**Table 2. Summary of vision test data.**

| Drivers Tested | Normal | | Low Level | | Veiling Glare | | Spot Glare | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Passenger car | | | | | | | | |
| 16 to 24 | 23.4 | 7.2 | 129.5 | 39.7 | 64.0 | 32.7 | 54.3 | 28.8 |
| 25 to 49 | 23.1 | 6.0 | 128.2 | 41.0 | 66.7 | 35.3 | 60.0 | 32.4 |
| 50 and over | 31.6 | 15.2 | 149.2 | 42.4 | 95.9 | 50.9 | 96.1 | 53.1 |
| All ages | 25.8 | 10.7 | 134.9 | 42.1 | 74.9 | 42.4 | 69.5 | 42.8 |
| Truck and bus | 21.5 | 5.9 | 73.8 | 26.0 | 45.8 | 21.9 | 40.2 | 20.8 |

**Figure 3. Cumulative distribution of static acuity scores for passenger car drivers, both sexes, all ages.**

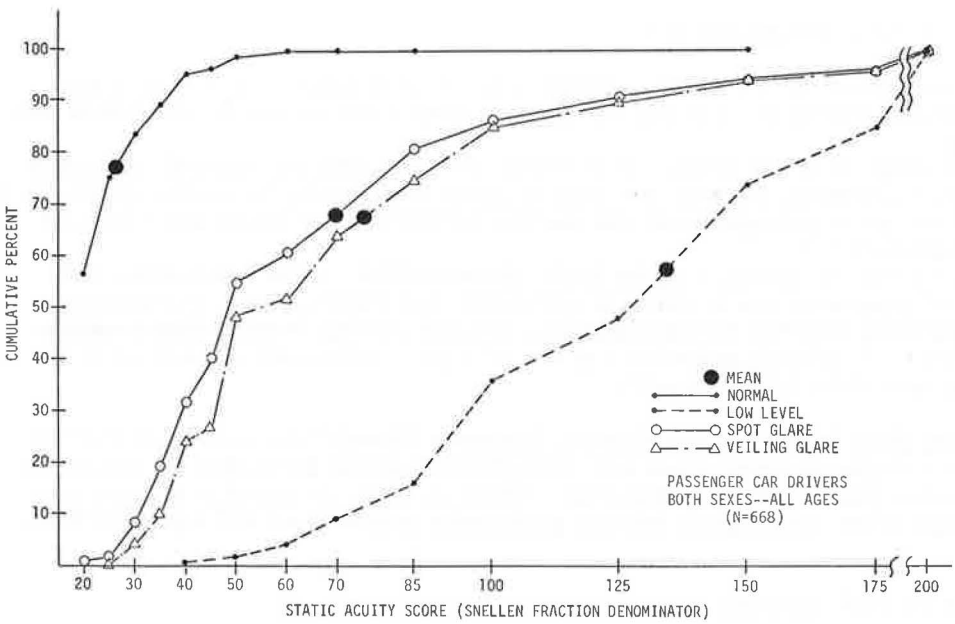


Figure 4. Cumulative distribution of static acuity scores for passenger car drivers, both sexes, ages 16 to 24.

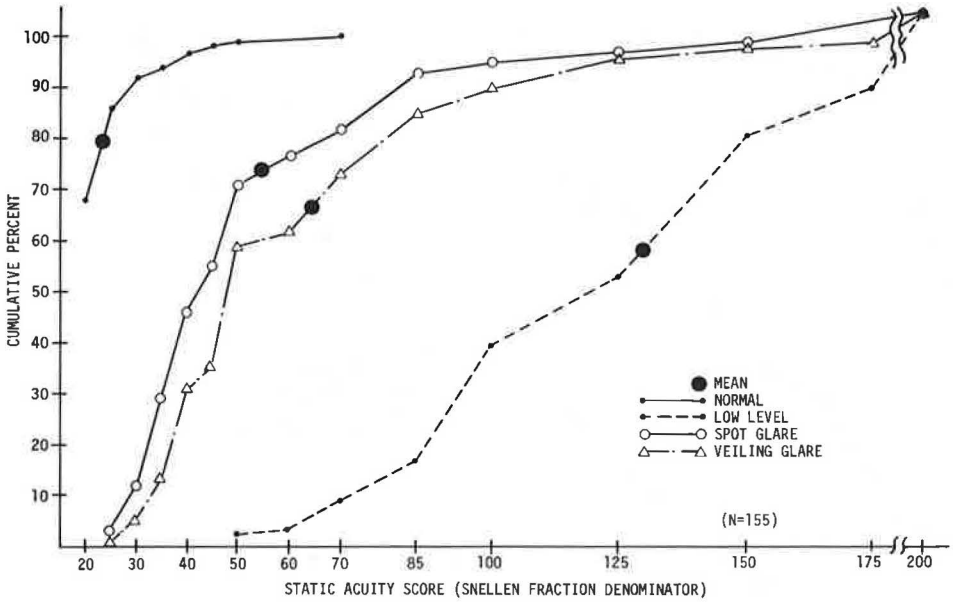



Figure 5. Cumulative distribution of static acuity scores for passenger car drivers, both sexes, ages 25 to 49.

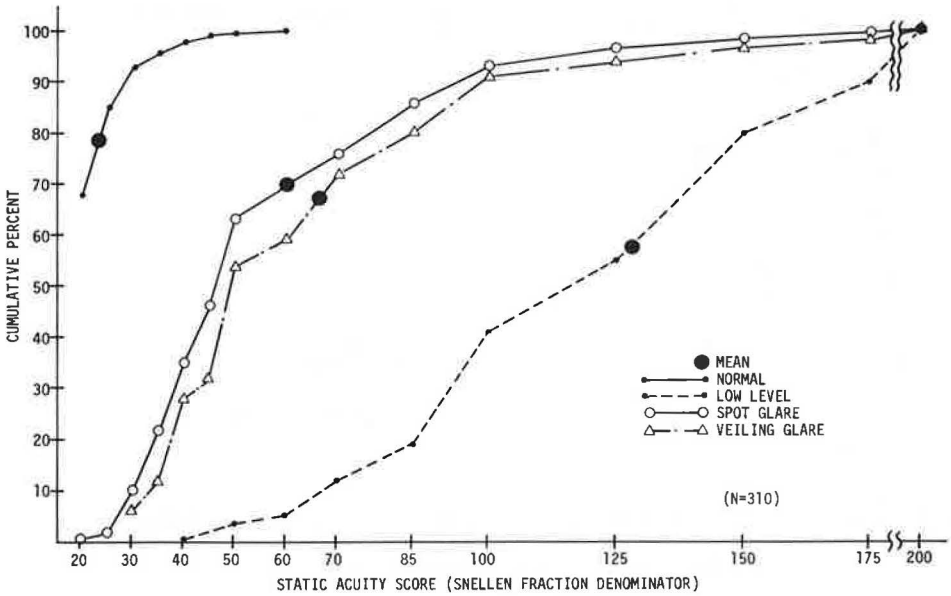


Figure 6. Cumulative distribution of static acuity scores of passenger car drivers, both sexes, ages 50 and over.

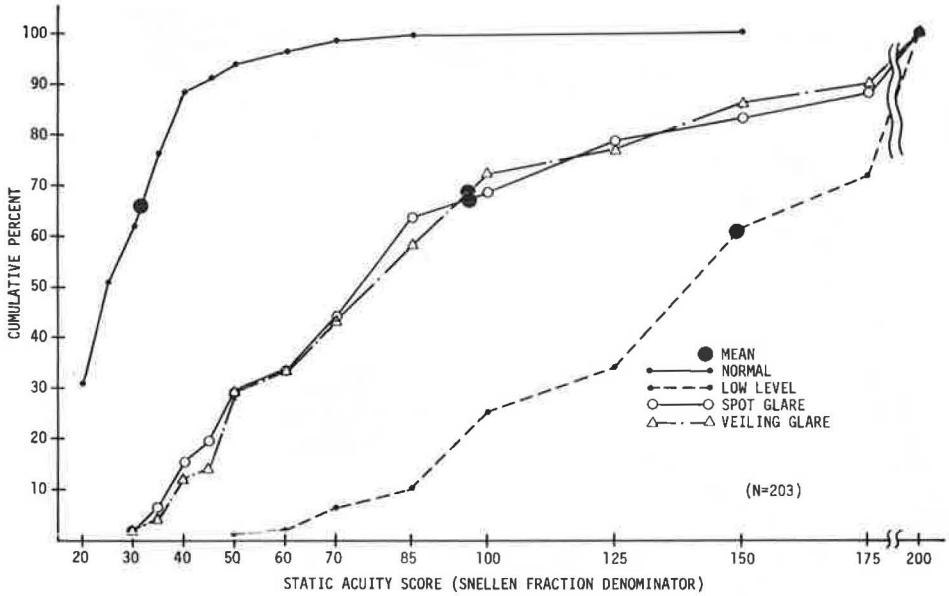



Figure 7. Cumulative distribution of static acuity scores for truck and bus drivers.

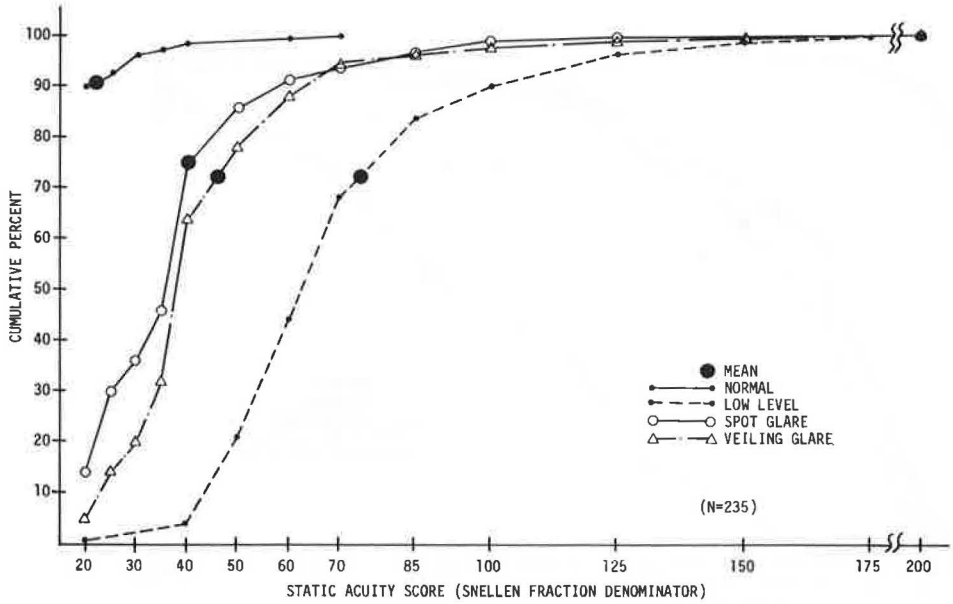


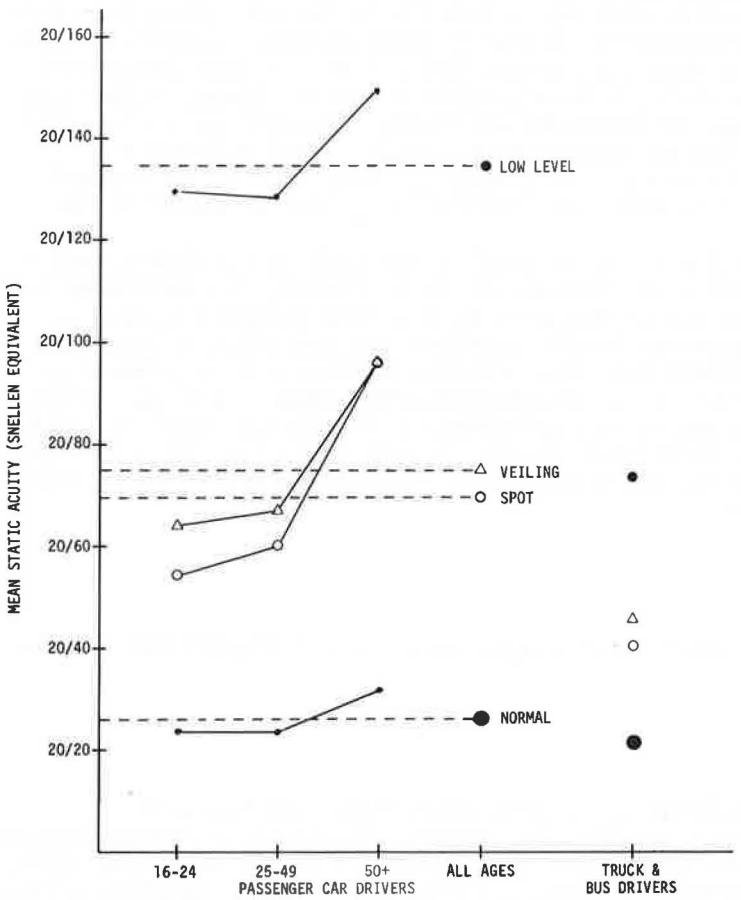
**Table 3. Product-moment correlations for automobile drivers significant at P ⩾ 0.90.**

| | 16 to 24 | | | | 25 to 45 | | | | 50 and Over | | | | All | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test | SA-NORM | SA-LL | SA-VEIL | SA-SPOT | SA-NORM | SA-LL | SA-VEIL | SA-SPOT | SA-NORM | SA-LL | SA-VEIL | SA-SPOT | SA-NORM | SA-LL | SA-VEIL | SA-SPOT |
| SA-LL | 0.36 | – | | | 0.38 | – | | | 0.38 | – | | | 0.39 | – | | |
| SA-VEIL | 0.41 | 0.32 | – | | 0.37 | 0.39 | – | | 0.52 | 0.55 | – | | 0.52 | 0.47 | – | |
| SA-SPOT | 0.54 | 0.40 | 0.75 | – | 0.41 | 0.42 | 0.75 | – | 0.43 | 0.51 | 0.79 | – | 0.51 | 0.49 | 0.80 | – |
| AGE | NS | NS | NS | 0.17 | 0.11 | NS | NS | NS | 0.27 | 0.27 | 0.42 | 0.57 | 0.37 | 0.23 | 0.37 | 0.48 |

**Table 4. Product-moment correlations for truck drivers significant at P ⩾ 0.90.**

| | Truck and Bus Drivers | | | |
|---|---|---|---|---|
| Test | SA-NORM | SA-LL | SA-VEIL | SA-SPOT |
| SA-LL | 0.21 | – | | |
| SA-VEIL | 0.36 | 0.56 | – | |
| SA-SPOT | 0.46 | 0.57 | 0.86 | – |
| AGE | 0.18 | NS | NS | 0.11 |

**Figure 8. Mean static acuity scores by subject group.**



3. Static acuity in the presence of spot glare,
4. Ability to detect, acquire, and interpret acuity targets randomly presented over a field measuring 30 deg laterally by 20 deg vertically,
5. Ability to detect angular movement in the central field,
6. Ability to detect movement in depth in the central field,
7. Ability to detect angular movement in the peripheral field, and
8. Field of vision.

Once this prototype device is built, a series of engineering tests and reliability studies will be conducted. If the results of these tests are satisfactory to NHTSA, a number of these Mark II devices will be constructed for use by various states (and foreign countries) in conducting a large-scale validation study involving 20,000 to 30,000 drivers. Driving record information including data on time of accidents will be used, so that the two measures of night vision can adequately be evaluated and validated.

## SUMMARY

In summary, a great deal more research is required before we can adequately answer the question of the importance of night vision screening of driver license applicants. At this point we know that visual performance is seriously degraded under conditions typically encountered in night driving, i.e., low levels of illumination, glare, and low-contrast targets. It may well be that target contrast is the key parameter, since both low levels of illumination and glare tend to reduce target contrast. Further, we know that some individuals are much more severely affected by these factors than others, and as a result the total variability in visual performance of the driving population increases significantly as level of illumination decreases, glare increases, or contrast decreases. We also know that accidents increase at night. What is lacking is clear evidence of a relationship between poor night vision performance and high accident probability. It is hoped that the research under way will provide an answer to this question.

A major problem, not unique to this research, is the quality of accident statistics that may be available for use as the criterion measure. Clearly, the relationship between night vision capability and accident probability must be evaluated relative to nighttime accidents, and more specifically, nighttime accidents where at least some minimal information is available concerning visibility conditions, e.g., presence or absence of fixed lighting, presence or absence of headlight glare, and so on. Obtaining information of this type may be the most difficult part of the total problem, and it is important that both state and federal agencies intensify their efforts toward developing accident data banks that are in a form, both qualitatively and quantitatively, that is most usable for researchers.

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At the Transport and Road Research Laboratory, lighting research is concerned with both vehicle and roadway lighting. Work is under way to establish the relationship between road light levels and accidents. The research involves extensive measurements of light levels and detailed recording of accident data. These will be supplemented by the findings of studies of near accidents (conflicts) recorded at specific sites, which should indicate the effectiveness of both conventional and experimental lighting schemes. Nighttime driving is particularly difficult on wet roads, and therefore a photometric evaluation of all types of surfaces both wet and dry is being undertaken to provide physical measurements relating to the problem. Vehicle lighting research is mainly concerned with the investigation of headlight glare-reducing techniques. These include the possible use of dimmed headlight beams as presence indicators in lighted areas, median glare screens, and special low-glare head lamps. A study of the merits of the low-beam head lamp patterns developed in Europe and in the United Kingdom and the United States revealed little overall advantage for either, but showed that there was a considerable problem resulting from head lamp misaim due to vehicle loading. This problem is being tackled by the development of head lamp self-leveling systems.

# LIGHTING RESEARCH AT THE U.K. TRANSPORT AND ROAD RESEARCH LABORATORY

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In the United Kingdom, vehicle and roadway lighting is regarded primarily as a safety problem rather than as an aspect of traffic engineering. Thus the priorities in both research and application are dictated by the accident situation.

Some 30 percent of all personal injury accidents take place at night (87,644 out of a total of 264,453 in 1972). Since nighttime traffic is about a quarter of the total, this means an overall night accident rate about 1.3 times that of the day rate. Three-quarters of all night accidents occur on lighted roads, and about three-quarters of these are on roads lighted to the highest standard. An analysis of weather conditions has shown that the combination of wet roads and darkness gives the worst accident figures. Against this background the lighting research at the Transport and Road Research Laboratory (TRRL) falls into the categories discussed below.

## EFFECT OF LIGHTING

Overall, studies have shown that installing roadway lighting effects a 30 percent reduction in the number of night accidents and a parallel reduction in accident severity. Some studies have discriminated between road types; for example, a recent British study showed a 50 percent accident reduction on 115-km/h trunk roads, and the current program to light motorways should achieve a comparable reduction. The motorway blanket speed limit is 115 km/h. Studies such as those of Turner (1) and Box (2) have attempted to relate accident rates to lighting levels, an area of vital importance for future lighting policy.

In March 1974 TRRL placed a $442,000 contract with a large commercial lighting firm to collect photometric data from actual roadway installations; those data will then be related to accidents at those locations. The opening phases of the work will use