Vision at Levels of Night Road Illumination
II. Literature 1952-1956

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● CIVILIAN night driving is done within a range of 4 to 0.003 ftL (foot-Lamberts). This range was derived from data available in 1952 (63) and has been accepted by others. Further information available in this field since the earlier report, however, is summarized herein. Another summary by Payrau (60) is of interest and the problems proposed by Bartley (8) as needing study include some pertinent to night driving.

Average road illumination and reflections indicate luminances of 0.018 to 0.35 ftL for asphalt and 0.08 to 3.03 ftL for concrete roads (81). The new Hudson Road illumination is reported within 2.30 and 0.41 ftC on the center line and 0.04 to 0.12 ftC at 100 ft from the luminaire (82). De Boer and Oostrijck (13) discuss a simple measurement for the reflective properties of wet and dry roads, although it is difficult to calculate from their data values appropriate in this country.

Drive-in motion picture screens may have an average luminance of 0.39 ftL (range 0.005 to 1.9 ftL) during projection, and of 0.003 ftL when the projector is not running. During projection the average stray light is about 0.17 ftL (22). The 0.003 ftL is another measure of night brightness without headlamps.

The limit of color vision occurs about 0.037 ftC, according to Middleton and Mayo (51), and 0.012 ftC is needed to distinguish between blue and orange. No evidence was found for the alleged blueness of twilight vision. Hunt (32) reports a gradual decrease in saturation of colors as the adapting light was lowered. At full levels the saturation increased with increasing test color intensity. Dim light to the dark-adapted eye appeared blue rather than colorless. Color seen by the dark-adapted eye is pale blue rather than colorless. Middleton's "Vision through the Atmosphere" (50) should be helpful in evaluating vision out-of-doors. Luminous efficiency varies with intensity for colors in the Purkinje range (61).

Morrison (55) and Holmes (5) object to too bright stop lights. A red light of 50 candles was recommended before the Bristol meeting of the British Association (5) as adequate for a seeing distance of 50 yards against oncoming glare. Stop lights of 100 candlepower give a dazzle out of proportion to the general level of lighting and are said to confuse the following driver rather than aiding him by increasing his confidence.

Motoring at night by civilians is done at photopic and upper mesoptic levels and further study at these levels should aid traffic problems more than at scotopic levels (79). Age lowers the ability to see at night (2).

DARK ADAPTATION

Recent work of Arden and Weale (6) suggests that after 8 to 20 minutes dark adaptation, the integrating power of the retina increases with time, as part of the adaptive process involves change in the size of the receptive field. While this occurred at lower levels than usually found in night driving, a possible nervous function in the retina should be considered.

Dark adaptation varies with individuals and more precise information may be expected from Mote and his assistants (56). Zeidner et al.(80) believe that five minutes is adequate time for dark adaptation to the mesoptic level, which suggests that only a few minutes are necessary to adapt to the higher level at which most driving is done. Dark adaptation varies in accordance with the previous state of adaptation of the eye. Wolf and Zeigler (78) have examined some of the conditions involved in transitions between the scotopic and photopic vision. Preexposure to ultraviolet radiation may raise the threshold of the dark-adapted eye. This increase is scarcely more than normal variation and seems to be a transitory effect but would probably have little effect on night driving.

Further work (5) extending the original investigations of Lythgoe adds information on the effect of surround. Surrounds of 38 degrees and 120 degrees did not have significantly greater effect than a 6 degree field. At all luminances of the central field exceeding 1 ftL, the presence of a luminous surround improved acuity, the optimal effect being observed when the central field and the surround were matched in luminance. Below this level, presumably, the surround should approach but not equal the luminance of the viewed subject. This indicates that only the illuminated road and nearby surround may affect the adaptation of the eye; also that silhouette seeing (pedestrian, etc., darker than the road) common to night driving will be less efficient than viewing an object that is a little brighter than its surround. With such poor visual conditions, brighter clothing, edge road lines, etc., should favor human survival.

Impaired vision has been reported by Landau and Bromberg (40a) in adiposogenital dystrophy, this suggests that the mechanism of scotopic vision may be related to the function of hypothalamus. Another paper (40) indicates further evidence of impairment of scotopic vision from diseases of endocrine origin. They also note variations in dark adaptation during pregnancy, manifested by impairment of scotopic vision from the fourth to seventh months, and showing striking improvement in the eighth and ninth months. Neurotic and psychotic individuals in the 20 to 30 age group had poorer dark adaptation than normal individuals (29). Slight improvement of night vision has been reported from the use of intermedine, a pituitary hormone (49, 60). Recommendations for the control of night driving may some day have to consider potential danger from illness, and such abnormal states may account for some accidents.

GLARE

The effect of glare, or dazzle, is important. With well-spaced traffic the exposure time may be about two seconds (63). Stiles (73) places the level for discomfort glare at 20,000 trolands, which for an average pupil of 2.3 millimeters diameter would be about 1,500 ftL. The effect of glare is that of a veiling luminance on the retina that degrades the contrast of the image and vision. An increase will cause the pupil to close, which reduces the light into the eye and, when not too great, improves the sharpness of vision by reduced aberrations. This reduced illumination of the retina is unfortunate, as it impairs seeing at the edge of the road and other critical low-luminance regions. The expansion of the pupil follows and depends on the amount and time of the glare exposure. Most of the investigation of glare has not directly concerned night driving, but the information should soon be adequate for application to driving (24, 25, 26, 30). Glare measuring equipment has been devised by Fry and Alpern (26) and Jehu (35).

COLORED LIGHT

The use of colored light, or colored glasses, usually decreases vision by about the same amount as the decreased visual transmission of the colored glass. An exception to this statement is Berte's (10) report, showing a small consistent gain in vision, using a Sulzer chart illuminated with yellow light from filters like those used on French automobile lamps. His results are apparently a copy of a table from Monnier and Mouton (54). Since it has not been possible to obtain information on this chart, comment on the results is limited. However, an acuity of 1.00 only occurred at the highest level (about 9 ftC) and it is amazing that with such small differences, the acuities are always just a few units greater in the second decimal place with yellow, than with white illumination.

Miles (52) reported that when clear visibility was 20/32, with yellow it became 20/34, with pink 20/40, and with green 20/46. Combining the pink glasses and a green windshield further reduced vision to 20/60. Amber and green filters decrease visual acuity (9) and while some variation is found when small differences are tested, colored glasses did not improve vision (74). Blackwell (12a) investigated two yellow-tinted night driving glasses and found that these glasses can reduce simulated detection distance by as much as 33 percent as compared with no glasses. Ross (65) reports that using any colored goggle reduces firing accuracy; Malone et al. (46) found yellow less conspicuous than orange for air-sea rescue work. Haber (31) found loss in visibility distance when tinted glasses are worn and that the loss increased with decreasing distance.

A neutral-colored object could be seen at about the same distance with white or yellow light, but Jehu (36) reports that the drivers in the test preferred that their own beams be white. Willis (76), summarizing a British meeting, stated that Grime gave results with white and yellow headlamps, having the same distribution of light, showing that the distance at which an object could be distinguished with yellow was 5 percent greater than with white light. The 20 observers significantly preferred white light without glare. Yellow light was thought to be less glaring at close approach, although a small majority favored white light. (It should be, since the yellow decreases the luminance.) The consensus was that changing to yellow light would not solve the headlight problem. The major fallacies of yellow light have been resummarized by Luckeish (45). Richards (64) tested the effect of yellowness separately from the loss in vision from less light and found yellow poorer at night driving levels of illumination. Miles and Richards work has received favorable editorial consideration (3). Loss of light is more serious at night driving levels, when there is scarcely enough for seeing. When braking distance and visibility distance are the same, a slight decrease in seeing may result in a rear-end collision. While only slight losses in vision have been reported in tests of colored windshields (66, 83), it does amount to driving day and night with colored glasses, and many vision specialists consider any loss dangerous at night.

NIGHT MYOPIA

General agreement has been reached that about 0.50D increased nearsightedness of the eye occurs as the luminance decreases and that this is due to the combination of the Purkinje shift and chromatic aberration. Greater night myopia occurs, but there is no generally accepted explanation for it. Tousey, Koomen, and Seolnik (75) believe that the night myopia can be accounted for by the abberations in the eye. O'Brien (57) accounts for the extra myopia as a result of the zonal aberrations of the eye and the change in the best focus moving towards the lens, together with the structure of the retina. Biessels (11) explains night myopia in that the image curves at the retina for sagital and tangential directions are different. With a large pupil and the greater sensitivity moving from the macula to the periphery, these curves come nearer to the more sensitive region of the retina. He further suggests that it should be called marginal or peripheral myopia rather than night myopia. Knoll (38) has published a review of the literature.

Ivanoff (34) believes that the mechanism of night myopia is largely that of binocular night convergence, which would increase the curvature of the front surface of the lens. Changes in the focus of the lens have been measured by Campbell (17), Campbell and Primrose (18), and Chin and Horn (20) using infrared observation of the Purkinje-Sampson images. Campbell and Primrose conclude that both accommodation and aberrations play about equal part in producing the night myopia. When the eye does not see detail there seems to be a tendency for the lens to focus closer to the eye than infinity. This may be related to the empty field myopia, found at higher illuminations. Chin and Horn do not find that the eye tends to a fixed focus and that the refractive state of the eye can increase, decrease, or remain about the same, as the luminance decreases. The authors object to spectacles with such correction for the Armed Services, because of the difficulty of getting the proper prescription, the fact that they would add to the burden of equipment and bring up the ever present problems of fogging, etc.

Scober (67) recommends increasing the spectacle prescription by -1.00D, or more, for driving after dark and for viewing the motion picture screen. With presbyoptic individuals, he recommends bifocals correcting the distant segment but leaving the lower segment so that they can see the instrument panel. He notes that individuals who are hyperopic (+2.00D) see better at night without glasses. With bluish or white fluorescence the myopia is more at low luminances than with other forms of lighting (68). Rasmussen (62) recommends reducing the hyperopic correction by 0.50D and increasing the myopic correction by -1.25D for night driving and for motion picture viewing. He advises consideration of the activity of the pupil of the eye in connection with the prescription. Wiseman (77) reviews the question of prescribing and concludes "there certainly would appear to be scope for additional research on the subject."

A field test was made by McGuire, Kathan, and Leopold (48). Young soldiers wore negative lenses of varying strengths from -0.5 to -2D and the distance at which they could discover a target was measured. A lens of -1D was superior to plain glass in many cases, but it was impractical to use any general prescription (as -1D) because one-third of the men actually saw less well with, than without it.

There is also a problem involving the changes of the eye in old age and whether or not there is more night myopia than would be expected from the aberrations from increased pupil size and from the Purkinje shift. Until more information is available as to the distribution of night myopia in civilian populations, only a competent eye specialist should prescribe for or experiment with it.

VISUAL ACUITY

Miles (53) and Sloan (71) have reviewed the literature. Gilbert (28) has discussed the definition of visual acuity and Linksz (44) has discussed the standard visual acuity chart. The fine movements and involuntary motions of the eye need to be considered in discussing resolution (21, 62a). Thresholds for acuities are given by Brown et al. (16) and Leibowitz's (43) data on pupil size should be considered. The visibility of road signs has been reported on by Allen and Straub (1) and Case et al. (19). Much work has been done, yet little of it can be applied directly to the problems of night vision.

The importance of contrast and acuity is stressed in Fortuijn's (23) analysis and units for measurement of visual efficiency. Decreasing contrast reduces readability when a flickering light source is used (27).

NIGHT DRIVING VISION

From basic data Jehu (37) has published formulas and tables for calculating seeing distance from the light distribution on the road. Simmons and Finch (70) describe an optical instrument for the measurement of night driving visibility which views an object on the highway and adds enough veiling brightness to determine the threshold. They believe that the most satisfactory way of defining night driving visibility is to relate it to the threshold at which it is just perceivable. Other factors concerned with night driving visibility are discussed, and it is stated that "the roadway situation is one in which relatively large objects (6 min of arc or larger) have to be recognized with certainty in a short period of time (0.2 to 0.02 sec) at relatively low adaptation levels (1 to 0.005 ftL)." Ohara (58) has provided data on the distance at which objects are visible from moving vehicles. His results suggest that acceleration causes reduced visibility at higher speeds. Vibration is a serious factor in limiting vision. The visual loss is greater when the individual is standing on the moving vehicle because of the increase effect of vibration on the eyes. One report (84) indicates more rapid driving at night.

Black (12) discusses problems and methods used in England. Keen vision is required for fast driving, as acuity decreases with speed. He believes the myope is safer, because he is more apt to wear glasses, though truck drivers were found to be exceptions. Keen vision is also required to see the driver who puts out one finger to signal, to be able to see a small hole at a distance, or to perceive a slight change of speed of a car ahead. Illumination on the highway should not change too frequently. At night a myope of 6/18 (20/60) may become 6/36 (20/120) or less. Black is particularly concerned with the dangers of restricted visual fields (tunnel vision).

Some British accident statistics are analyzed by Smeed (72). No correlation was found between accidents and binocular perception and the rate of dark adaptation, but he did find a correlation of more accidents with better roads and vice versa. McGuire (47) reports that the non-accident driver is more mature, more conservative, more intellectual in his interest and tastes, has a higher aspiration level, and is usually a product of a happier family background than the accident-incurring driver.

Lavergne (42) has reviewed various tests used for automobile drivers in Belgium with respect to night vision. Measurement of dark adaptation would be important in critical cases. Ordinarily, only the first ten minutes of dark adaptation would need to be measured. Acuity and peripheral vision also are important for night driving, although no tests are described for them. Fatigue and the possible advantages of using simple threshold tests are discussed by Ibbs (33).

An interesting experiment is reported by Brier (14) who made himself deficient in vision from 6/5 to 3/60 (20/15 to 20/400) by wearing +6.00 spheres. A number of trips were made and he found that after five minutes he had no great difficulty, even when driving at fairly high speed. His general impression was like that of driving through a light fog and no further precautions were required than would be necessary for such conditions. At night he had to lower his speed to about 25 mph. Headlights were reported less troublesome, but it was difficult to see pedestrians, bicyclists, and road obstructions. It is Brier's opinion that a visual acuity of 3/60 (20/400) is adequate for day, and at reduced speed for night. The loss of one eye is of little importance in driving and he reports that several of his patients with acuities of 3/60 drive, although one preferred his glasses when driving at night. Road signs should be made larger and easier to read for those with poor acuity. Brier's views are summarized by stating that "in short we should aim at minimum restrictions and a better appreciation of accident psychology in common sense approach to this question."

A few years ago there were a number of letters to the editor in the British Medical Journal discussing what visual acuity is important for driving and the fact that many drivers (especially truck drivers) will not wear glasses, yet have no accidents although some drive with poor vision.

A change of prescription may lead to difficulty in driving. Such a case is reported by Morrison (55): "The patient stated that the glasses were quite comfortable but when driving he experienced difficulty in keeping his vehicle in the correct part of the road, a symptom typical of aniseikonia." The patient had reported because he had had a minor collision.

Corrected myopes, according to Ames (55), tend to locate objects more distantly than corrected hyperopes. Newly corrected nearsighted people may brake too quickly and farsighted people may brake too slowly, both when first corrected, or while getting used to a change in spectacles. Space perception abnormalities or distortions tend to increase with motion. Although it appears possible to adapt to changes in aneisikonia, compensation may not occur. Morrison (55) considers that night driving is more dependent on stereopsis because there are fewer visual clues. Impaired space perception, such as aniseikonia, could then control the motorist's actions, much as the normal person does not respond to an added size correction lens in familiar space, but loses orientation without familiar clues (as a "leaf room") and sees a markedly distorted world. This change and possible disorientation of space at night could contribute to accidents and Morrison urges that motorists be screened for aniseikonia. He also recommends that motorists do not drive until ten days after they receive their first spectacles.

Only those with corrected aniseikonia will appreciate the comments in the preceding paragraph. Some have experienced the improvement of driving from better seeing. There is little point to expecting space perception problems to clarify all driving accidents. Nevertheless, vision specialists should consider whether glasses or a change in prescription will disturb the user's space orientation sufficiently to endanger himself or others, should he drive with them before becoming used to them, and be responsible for advising their patient on proper use when necessary.

Drug effects can be of importance in driving. No success with drugs for general aid in dark adaptation has been reported. Atropin causes objects to recede. Alcohol is reported to increase esophoria or decrease exophoria, producing a tendency to drive in the center of the road (55).

There has been much discussion of the requirements and tests for driver's licenses (4, 59). Lauer (41) condemns many of the present practices and warns optometrists that if there is not some improvement, the visual examining program may fail. Sherman (69) advises eye specialists that there is a rich field in training people on how to see. The general problems of the role of vision in motor vehicle operations have been discussed by Brody (15). A modified program in use in Kentucky is described by Oldam et al. (59) and Bannon has described the studies carried out in North Carolina (7).

There seems to be no question but that poor vision does contribute to accidents during night driving, although exactly what deficiencies contribute most, or how, remains to be determined.

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