Vision at Levels of Night Road Illumination

VI. Literature 1960[*]

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•MANY STUDIES of vision were produced in 1959. Some articles on night vision and others of interest to the committee are reviewed. As it is impossible to examine all of the literature, omission of any paper merely reflects the limitations of a single reviewer.

The translation (64) of Jayle's Night Vision (63) is welcome. The translators have condensed the original monograph, omitted most of its bibliography and added some recent material. References, other than general sources, are not cited for much of the added material and some of it needs revision. Lauer (74) has summarized the contributions from the many years of work of the Driving Laboratory at Iowa State College. The visual needs of driving form a chapter. May the second edition have another chapter on night driving vision!

An issue of the Journal of the American Optometric Association is devoted to the visual problems of automobile driving (1, 3, 33, 69, 104, 115, 127). A colloquium on driver licensing was held at the University of Michigan (2, 46, 11, 116). Barr and McEwen (15) provide a world list of periodicals concerned with vision. General bibliographic sources are available (11, 32a, 107), and Hopkins has reviewed literature on peripheral vision (59). Brindley (24) organizes much useful information on retinal physiology and discusses proper experimentation on seeing. Arden (12) reviews some spatial and temporal aspects of retinal organization and Lombard (78) reviews seeing at low luminances. Examination of 1,000 age 18-22 men in Great Britain reveals that 80 percent had normal vision without glasses, and the amounts and kinds of defects found are listed by Sorsby (9, 117).

Research needed on night driving vision is listed (1). Richards (104) discusses the basic problems of night driving which derive from insufficient light for adequate seeing, and some means for alleviating the difficulties. Driver performance and deficiencies are discussed by Forbes (45, 46) and by Darrell and Dunnette (36). Platt (98) proposes research based on his previous traffic analyses. This should be extended to include night driving.

Questions as to the usefulness of, and the optimum kind of visual training for auto drivers, increase in frequency (104, 116). As seeing is a learned function, what should the night driver look for? What does he need to see? How should he look (optimum scanning, rate time, pattern)? What distortions prevent or reduce seeing? Are general technics practical, or are the innate personal search patterns better than random patterns? The considerable information now available on visual search and detection opens another source of aid toward night driving seeing problems and points the way to further research (20, 27, 89).

Night searching should be done by moving the eyes in a circle with short jumps of 12 to 20 deg always focusing off center according to Tuxbury (124), and Dayle (35) found that few subjects used the superior step-wise approach in searching for faults.

Scleral reflections are used by Smith and Warter (114) to record and measure tracking movements of the eyes. Tracking errors increase with visual noise, which raises an interesting question of noise on dynamic seeing in night driving (62). Methods for recording the direction of seeing are described (65, 110, 142). Their use in analysis of the seeing task of automobile driving should be profitable research.

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Blackwell and Kristofferson (20) give a neural formulation of the effects of target size and shape on visual detection and V. Bekesy (16) proposes a neural unit concept consisting of an area of sensation surrounded by an area of inhibition for both skin and eye and relates the unit to the Mach bands. Stereoplotting has been done at luminances similar to night driving and improves with illumination (140).

Illumination and Glare

Measurements by Blackwell (21) indicate a need for some 1.9 (0.7 - 2.8) ft-c horizontal illumination to see a black dog, or a mannequin with 20 percent reflecting clothes, in the driving lane at 200 ft and 5.7 ft-c in the curb lane at 200 ft, based on his field factor for 99 percent seeing. Such lighting is rare and may not be practical for all roads. Nevertheless, the way is pointed toward improved analysis of the geometry of seeing and better lighting. Brightness scaling is practical (93, 119) and illuminating engineers should consider brightness as well as luminance in their professional work. The design and performance of battery-operated flashing warning lights are described (61).

Rex (100) summarizes advances in highway lighting and he and Franklin (101, 102) discuss discomfort from glare. Spencer and Peek (118) compare relative visibility with low and high mounted luminaires in clear and foggy weather. A preliminary report on glare from large sources promises useful information (60). Autocorrelation is another technic for night vision study used by Logan and Burger (77) by comparing the amount of information in pairs of pictures made with different lighting. The efficiency of seeing is not seriously reduced by changes in brightness ratios of one to three (Boynton, 6). Wolf (131) reports an increased sensitivity to glare about age 40 and that between ages 5 and 15 and 75 and 85 increases of fiftyfold to seventyfold in brightness are required to see against glare. Examination of aphakic and cataractous patients indicates that the vision is reduced from opacities of the ocular media and entoptic light scatter. Investigation of glare from white and yellow light gave inconclusive results, although the yellow was thought to spare the blue cones (41). The Holland Tunnel transitional lighting is described (49). Taragin and Rudy (123) discuss traffic operation as related to illumination and delineation and Fitzpatrick (44) the advantages of fluorescent, colored materials for coordinating signs and pavement treatments for motor traffic guidance.

Dark Adaptation

Wulfeck (135) reports the contrast sensitivity threshold (DL) and the absolute threshold (RL) equally sensitive measures of the effects of different pre-exposures on dark adaptation and visual sensitivity. Similar measurements are needed on the peripheral retina at night driving luminances. Variations of 0.3 to 0.5 log unit threshold value are reported by Wolf (133). The effects of pre-exposure on dark adaptation are analyzed (53-55), and of clear and tinted windshields (86). The association between retinal sensitivity and glare is reported (95). Recovery time from looking directly into an arc va varies from 7 to 10 sec at a 100 ft-c/sec to 55-60 ft-c/sec exposure (87).

Mandelbaum and Nelson (83), using saturation matches, found rod sensation predominant at levels above cone threshold and equality between rod and cone sensation at a thousand times cone threshold. At one log unit above cone threshold (7.2 $\mu\mu$L) rods contributed 4 times as much brightness as cones for violet, 8 times for red, 16 times for green light. Wald (125) uses a two-filter method to determine the mixed role of rod and cone function in dark adaptation. Rod participation at photopic intensities may explain some of the problems of night driving seeing at low photopic and upper mesoptic levels.

The information capacity of the human eye at low luminances is examined by Benarie (17). Acuity of a dark-adapted eye was not less when the other eye was exposed to 100 ft-L, although at exposures shorter than 3 sec gave some interaction. Under the two conditions, the targets looked different suggesting that sensitivity may not be the same as acuity (81).

A night visibility meter with a standard light and attenuator was patented by Vos (136). A night vision sensitivity tester developed at New London is reported reliable and to reveal marked differences in visual sensitivity. The best man was six times better in terms of the visual angle seen 50 percent of the time, and could see at 10 miles with almost 1/7 of the light needed by the poorest man (71, 122). Scotopic sensitivity of people varies (Sweeney and Kenney, 121) with a seasonal exposure to radiation, being best in winter and early spring and poorest in summer.

Acuity and Contrast

Brierly (23) reviews some of the general information on acuity. Better vision at 15 deg from fixation was obtained with some blurring of the retinal image than with the sharpest image (66). Luckiesh-Moss visibility measurements and Blackwell's VTE measurements are convertible according to Eastman and Guth (40). The discussion indicated that Blackwell was not in agreement.

Sloan's test letters (112) have average legibility equal to corresponding Landolt rings, increase in size by a tenth log unit per line, are available from 20/200 to greater than 20/20. Spectral energy thresholds for acuity resolution are measured (27). Television characters of 10 min vertical visual angle on the screen have essentially maximum visibility (109). Black on white was more visible than white on black. Breneman (22) provides a graph of increased luminance required for 50 percent seeing on motion picture screens of varying brightness, and a test method for judging the quality of projected images (73). Some of the brightnesses fall within levels found in night driving. Prince's final report on letter legibility and subnormal vision is available (94).

Ronchi (108) reports that correcting chromatic aberration helps seeing at low retinal contrast, but not when resolution is complicated by border defects. Van den Brink and Bouman's (28) plot of spherical aberration of the unadapted eye shows variation from 0.9 to 1.8 diopters. Acuity varies with luminance and distance because of these inhomogeneities of the lens exposed by the pupil. Variations in the power of the lens and in acuity were measured by Arnulf et al. (13) in an investigation on tolerances for spectacle lenses; also the microfluctuations of accommodation (141).

Variations of visual acuity with pupil size measured by Campbell and Gregory (32) suggest that the natural pupil size for a given illumination adjusts the eye to optimum acuity. The average pupil area was found to vary with the interest value of the visual stimulus (57) which adds another complexity to the problem of the control of the pupil and another means for varying the illumination on the retina.

Zoli (137) has compiled a bibliography on night myopia. Perception in empty space myopia is described by ten Doesschate (38). This myopia is different from night myopia and an empty field rarely occurs in nonblackout night driving. Pitts (79) measurements of the transmission of the bovine eye show a slow decrease in transmission from about 600 mμ to 450 mμ and an increasing reduction for shorter wavelength radiation.

Contrast effects are important in night vision and an integration of night vision needs involves contrast adaptivity and inhibition (4), border gradients (128), blurring of moving edges (19), Mach bands (16, 151), etc. (70, 134). Contrast thresholds were measured by Ogle (92) in the fovea for increasing amounts of blurred image. An image in white light out of focus by one diopter increased the threshold about ten times. The threshold increases as the second power of the out-of-focus imagery. This work supports and explains the reviewer's experience that correction of night myopia reduces the person's sensitivity to glare and the improved night vision reported from even small changes in spectacle power.

Interest in the visibility of fine lines continues. Nachmias (91) found no evidence to link the nonuniformity of directional eye movement during fixation with the variation of the visibility of differently oriented fine lines. Fender and Mayne (43) used fine wires as a visibility test with fluctuating lights and conclude: "Thus if the illumination is to be flickered to facilitate the performance of a visual task, the frequency of intermittence must be 'tuned' to the subject with some care."

Another report on dynamic visual acuity from the University of California finds little correlation between it and static visual acuity or critical flicker fusion (30). The least detectable difference in speed measured in terms of visual angle degrees per second at the eye is a linear function of speed from 0.1 to 20 deg visual angle per second; therefore, drivers react to relative velocity rather than to relative speed (25, 26, 29).

Bhatia (18) expresses the maximum angular velocity of eye movements as a function of perceived size and distance to the target, emphasizing the importance of distance. McColgin (84) finds the absolute threshold for perception of rotary motion increases with distance from the fovea and the resulting isograms plot as ellipses. Vertical motion is perceived better than horizontal motion, and velocity is more important than area in influencing the threshold. His results were confirmed when the head is rotated 90 deg. Keesey (68) found from the study of involuntary eye movements that acuity increased with exposure from 0.02 to 0.2 sec and concluded "...that acuity is mainly based on the discrimination of the spatial pattern of retinal illumination, regardless of any temporal changes of intensity pattern on the receptor cells."

Changes in speed to and from 60 mph in a fluid drive transmission automobile gave the impression of change in distance, size, or both to subjects looking at a fixed target in the car. The target seems to approach on acceleration and recede on deceleration (49).

The impression of movement obtained from momentary stimulation of the peripheral retina by a stationary light is explained by White (130) as due to the two retinal images which are separated with slightly different subjective onset times. The retinal images are from the stimulus and the catoptric image of the second order which is focused at the retina of an emmetropic eye.

Binocular Vision

The similarities of fluctuation of the accommodation of the two eyes of the subject indicate central nervous origin according to Campbell (31). The fluctuations are appreciably smaller with a fixed convergence angle. Convergence control of the eyes is maintained by the vergence components of the drifts and saccades (42). Krauskopf and associates (72) found that the monocular response functions determine the occurrence, magnitude and direction of the saccades for each eye during binocular fixation as well as monocular fixations and correct for the slow drifts. The eye most off target triggered the saccades of both eyes and the vergence is corrected by a smaller saccade of the other eye. There are more saccades in binocular than monocular fixations and this is expected because the drift in each eye is independent. Eye movements and nervous control of the accommodation convergence relation are discussed by Morris (90). Fused images are brought to corresponding retinal areas within 2 min of arc (139).

Using two special ophthalmoscopes to see and regulate the disparity of the retinal images, Pickwell (97) found retinal image slip from a lag, in the change of vergence in the eyes, behind the rotation of the target and the retinal images. These observations suggest another kind of incoordination that could play a role in triggering an accident in poor light.

Mandelbaum (82) reports that a screen at 14 to 25 in. from the eye prevented seeing letters at 85 yd by preempting accommodation and suggests that "possibly the appearance of imperfection, dirtiness, and other blemishes on the windshield of the cars and airplanes interfere more with the perception of distant objects, under certain conditions, than by their mere interposition."

Color

Decreasing the illumination by a sixth gives normal subjects some idea of the reduced clarity of color as would be seen by those with a mild deficiency (126). To keep discrimination errors below 1 percent, Gustafson (52) shows that the contrast must be at least 75 percent. Changes in the photochromatic interval with dark adaptation are reported by Lie (76) and Luria and Schwartz (80) are measuring preadaptation effects from colored light. Baglien (14) mentions among other factors of vision that yellow is first identified and seen most clearly. On the contrary with poor light, yellow turns gray and is less visible than other colors (105). Another paper states: (10) "...yellow tinted lenses are a particular handicap to colour-deficient drivers." A more thorough test of tinted windshields by Wolf et al. (132) confirms the fact that seeing is reduced proportionately to the loss of light from absorption by tinted windshields and McFarland et al. (86) show that this loss is of greater consequence for the older driver. Brightness can be scaled with both white and colored stimuli (Olney, 93).

Color vision is reviewed by Hurvich and Jameson (62a). Schroeder (111a) explains color vision based on three different sensitive regions on one cone receptor in the retina. Boynton's (21a) theory involves three types of photopigments among five kinds of cones, opponent color processes to the lateral geniculate body, and coding in terms of the four psychologically unique colors from there to the cerebral cortex, to quantify color vision and explain color vision deficiencies. Vos (138) explains why some people see blue in front of red, and others red in front of blue.

Age

Hirsch and Wick (58) bring together much of the information on the adverse changes in seeing with advancing age. Walton and Kaplan (127) discuss the driving-seeing problems of senior citizens. Domey et al. (39) have analyzed their information on the age changes of dark adaptation and offer a mathematical equation for senescence in terms of dark adaptation. Tinted windshields are no help to the aged driver (86) and Wolf (131) shows that a marked increase in illumination is required to see against glare after about 40 years of age.

Driving and License Problems

Most methods of communication between drivers are visual according to Davey (37). Peletier (96) discusses the importance of vision in driving, the responsibility of the ophthalmologist, and what should be tested and evaluated in eye examination of motorists. A similar article is directed to optometrists (5).

The proper testing of drivers and the inadequacy of the British acuity test of ability to read a motor license at 25 yd is discussed (37). The comprehensive studies on the design and visibility of American license plates should be helpful (56, 67). Wilkie (129) reports that of more than 1,000 people with driving licenses from a 4,400 British practice, 45.5 percent could read a license plate at 25 yd without glasses, 47.1 percent with glasses, and 7.5 percent did not have glasses and could not read the plate. Deficiencies by age groups are given. Properly lighted targets are recommended. Sorsby (117) gives vision statistics for young men.

Another British contribution (47) discusses the importance of small uncorrected visual errors, fatigue, and their role in causing driving accidents. Riley (106) mentioned that "thousands of people needlessly wear sunglasses for driving because they mask symptoms of certain eye disorders which would require treatment," which is wrong because it lets the disorder go unchecked.

Motor licensing practices are discussed (7, 69, 111) and Crinigen (33, 34) reports on the requirements of the various states.

Accident prone drivers are more distractable and have poor eye-hand coordination according to Smeed (113). Allgaier (2) recommends giving night driving tests to night accident repeaters. Faults of driver behavior are listed by Sheehe (111) who also states that 80 percent of the human failure is due to driver error and that more than 75 percent of accidents occur in familiar country within 50 mi of the driver's home.

Alpern (3) states the advantages and disadvantages of contact lenses. Wearers of these should carry a card stating they use the lenses so that the lenses will not be left on the cornea for several days in case of an accident. Danger can arise from displacement of the lenses on the eye from wind in open-top cars, from turning the head too far in backing, from increased tears, and from a foreign body getting behind the contact lens (requires removal of the lens). Occasionally a contact lens will slide off the cornea for no apparent reason. Sensitivity to light is increased with contact lenses. Discomfort from allergies and colds can be a problem for contact lens wearers. When contact lenses are needed, the driving license should be marked with the restriction, as with spectacles. A check by removing the lenses need not be required as with proper lighting the contact lens can be seen on the eye.

King (70) discusses how to measure seeing from within an automobile, its importance, when it can be responsible for accidents, and some desirable limits for the restrictions of driver's vision by the shape of the vehicle. Stonex (120) reviews vehicle dimensions, McFarland and Domey (85) human factors and evaluate 1957 models, and Lee (75) discusses driver eye height and design features of automobiles. The technics available to discover and record where a person looks (65, 110, 142) should be used to obtain information on actual seeing from the driver's seat so that the car design will least restrict seeing at night.

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