Vision at Levels of Night Road Illumination

VII. Literature 1961

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•SOME CONTRIBUTIONS from the current literature on vision have been selected for their interest to the HRB Night Visibility Committee (86). No person can find or read all the literature, and omissions reflect the limitations of a single reviewer. Snydacker (97) reviews some 377 papers on vision, and the reports of the Armed Forces Vision Research Committee are summarized for 1957-60 (56). Danielson (31) discusses the visual aptitudes of motorists, the Fourth American Optometric Association Motorist's Vision meeting is reported briefly (8), and Schmidt (89) presents a detailed analysis of seeing at night driving luminances, methods for testing dark adaptation, and the desiderata for a suitable test. The problems of aging are brought together by Marsh (69). LeGrand (65) has a small volume on seeing for those reading French. Ogle (77) provides the optics needed for eye care, and Weale (109) presents recent knowledge about vision from a modern viewpoint.

The limits of vision seem determined by the minimum number of light quanta that can stimulate the retina and by the upper safety limit of the tissues (83, 110). Screening testing of motorists visual abilities is now underway in England (6) and Davey (34) describes the League of Safe Drivers which requires annual retests of driving abilities. Driving simulators are discussed by Fox (46, 47) and Hulburt and Wojcik (59).

ILLUMINATION, GLARE AND DARK ADAPTATION

DeBoer (17) calls attention to the advantages of sodium lamps (100 l/W) for lighting highways where color is unimportant. Sodium lighting gives better distance visibility than mercury or incandescent lamps. Mercury lighting of 4/3 that of sodium appeared equally bright, and for equal visibility mercury should have 154 percent of the sodium lighting. DeBoer (18), from measurements indoors and outdoors, concludes that road surfaces should be at least 0.6 ft-L for safety and comfort in dense traffic.

An elementary symposium of illumination is reported (42). Cleveland and Keese (25) summarize their experience with intersection lighting in Texas, and Huber (58) reports on reflectorized color coding of a Minnesota interchange. The advantages of surface-mounted and low side lights during fogs are described by Finch (45) and Spencer (98). Luminance measurements of roads are discussed by DeBoer (18) and Rex (85). Nagel and Troccoli (75) describe a light meter for reflex reflective materials. Dawson and DuPre (36) describe vision and techniques of measurement at low luminance levels, and the standardization of measuring methods for scotopic and mesoptic seeing.

Rex (85) reviews means for rating glare and comfort factors. Wolf (117) reports an increase in sensitivity to glare with increasing age, especially after age 40. Some of the effects of speed, road elevation, and curvature on glare have been measured by Fries and Ross (48) for use in the design of glare protection by a median divider between lanes.

The glare problem and dark adaptation while driving in street traffic is discussed from an ophthalmologist's viewpoint by Gramberg-Danielsen (51 through 54). He points out that although the external luminances at the site of an accident can be measured, the state of dark adaptation of the driver is not obtainable. Glare recovery, according to Salvi and Venturi (88), is more rapid in individuals with dark-colored irides, although after yellow light, recovery is better for individuals with blue irides. Recovery after red glare was not related to the color of the iris.

Reducing the pupil area with pilocarpine lessens illumination on the retina, raises the luminance threshold at mesoptic levels by some 20 percent, and reduces the peripheral fields by 6.5°. Thus Jayle et al.(60) reemphasize the importance of knowing the the actual amount of light on the retina. Older people have smaller pupils and some drugs in common usage alter pupil size (93, 96). Lowenstein and Loewenfeld (67) find that dim light from smaller pupils alters the functional condition of the Westphal-Edinger nucleus within the brain and consider adaptation involving the central nervous system.

Recent work questions the duplicity theory of dark adaptation, and Weale (111) shows that there is little threshold difference between rods and cones (see also 86).

Domey (38) and Domey and McFarland (39) indicate that after 3 min preadaptation to 1,600 mL, 10 min of measurement at intervals of 1 min permits accurate prediction of the ultimate level of dark adaptation, which could be useful as a screening test. Boardman (16) reports that 300 ft-c of red light have about the same effect as 3 to 10 ft-c of tungsten light on preadaptation changes. Alpern and David (3, 7) show that lessened illuminance on a test chart is associated with an approach of the far point (night myopia), recession of the nearpoint (night presbyopia) and the reduced effectiveness of a given stimulus to evoke an accomodative response.

SEEING WHILE IN MOTION

Dynamic visual acuity is being investigated actively. Feldhaus (44) summarizes some of the earlier literature in an attempt to explain motion seeing problems.

Berg and Hulbert (22) find dynamic visual acuity unpredictable from measurements of static visual acuity and not related to flicker fusion or lateral phoria. Females gave better performance than males. Brown (19) compares thresholds from several studies expressing speed in terms of the visual angle (ω) subtended at the eye by a moving stimulus. The threshold increases in direct proportion for nonsuperimposed stimuli from 0.1° to 20° per sec ($\Delta\omega = k\omega$). Difference of $\Delta\omega$ for adjacent and for separate stimuli are used by Brown (20) to interpret tracking behavior.

An enclosed area pattern on the back of the preceeding car reveals motion of that car better than the same area painted with stripes. Motion towards is seen easier than motion away from an observer, probably due to the increasing brightness. These suggestions of Potter (84) may be helpful toward lessening rear-end collisions.

A series of papers by Crawford (29) is of interest. A decrement in visual performance begins when the motion is about 75° per sec, although much individual variation was found. Crawford confirmed the third power relation of the velocity previously reported by Ludwig and Miller. The seeing pursuit of a fast-moving object usually occurred in two stages or saccades. Latent periods averaged 200 msec. Over one-half the observers showed a second saccade eye movement when the velocity was over 50° per sec. The typical response to a moving target involved a latent period and intersaccadic interval followed by a steady state. The timing of the various phases depended on the rates of movement of the target. Subjects with high capacity for seeing detail in moving targets have greater extrafoveal acuity then those with less ability. Fixation errors of 1° to 2° of arc in position and 1.5° to 6.5° of arc per sec do not interfere with perceptual ability when the detail of the object to be perceived is of the order 1 to 3 min of arc. Simultaneous errors of position and velocity severely reduce visual acuity. Corrective eye movements that take time are necessary with greater errors. Because the equipment was not adapted to present vertical target movements, measurements were made with the subject turned horizontally (30). The results show changes in apparent movement and location of the horizontal when the visual and perceptual are disparate. A fixed head position could not be used in the study of eye movement because the head not only rotates about the horizontal axis in large pursuit movements but inclines in the vertical plane. Eye and head movements, when both are used, are analysed. With rapid movement the eyes look beyond the position of the head. These brief references indicate something of the scope of Crawford's useful investigations.

Miller and Ludwig (73) found that the apparent speed of an object in an empty field is dependent on the square of the real velocity, its duration, and size, from measurements of when a moving object was seen to have stopped moving. The time delay in the perception is more than the latent period of the response.

SEEING TIME LIMITATIONS

In actual life, much seeing must be done within a limited time. Sperling (99) reports that more information seems to be taken into the system during brief visual exposures than is reportable, and Averbach and Coriell (11) find visual read-in to be rapid, read-out slower, and erasure local. The information in storage was estimated to vary from 37 to 54 bits. Storage times varied from 250 to 300 msec and maximum performance from detecting and reporting was 250 msec. Information is becoming available toward knowing how much information can be utilized by motorists confronted by a choice of routes and how much time must be provided to insure orderly traffic movement.

Visual detection or discrimination is being investigated by Ments (70) through signal-noise considerations. Siegel and Crain (94) report stimulus effectiveness from color, size, shape, and distribution. Blackwell and Bixel (15) describe preliminary work on instrumentation for varying contrast and lighting on target and background for the analysis of the role of contrast rendition in seeing. How the detectable target size and shape may be limited by the organization of the nervous system is also being analyzed (63).

Luminance around a test area influences the seeing in the test area by the amount and distribution of the surrounding light. Inducers evenly spaced around the test site make it harder to see than when they are grouped along one side of the test area. Surrounding sources are more effective in raising the threshold for peripheral than for foveal vision (Kaplan and Ripps, 62).

Involuntary eye movements were examined by Shortess and Krauskopf (92) at short exposures (0. 02 to 1 sec) by means of stereoscopic acuity thresholds for normal and image-stabilized eyes. Their results are reported as being consistent with static but not with dynamic theories of acuity.

Roger (87) reports the design of an eye movement camera, and Sunkes and Pazera (101) state that measurements of the eye movements of helicopter pilots were used in designing the windshield. A similar study with automobiles would be desirable.

The oscillations, flicks, and saccades of eye movements have been described many times. Howarth and Gibbins (57) emphasized these by the statement that one sees by means of the sequence of short exposures lasting from $^1/_{10}$ to $^1/_2$ sec; during these, the image drifts up to 60 min arc across the retina with a high frequency tremor of 20 sec visual angle. Clowes (26) believes that these movements, together with the known physiology of vision, account for contrast discrimination. Bryngdahl (21) applying linear filter theory analysis to vision finds a relationship between theory and the actual eye movements, which suggests that the eye movements give vision greater ability than predicted from the form and function of the eye. Thomas (102) describes how to observe the saccadic movements of one's own eyes with the aid of a cathode ray tube.

ACUITY, CONTRAST, ACCOMMODATION AND FIELDS

Visual acuity measurements using the optokinetic nystagmus correlates 0. 92 with subjective tests on a Snellen chart according to Voipio (105), and Schumann (90) discusses this as an objective method for testing acuity. Walton (108) has published refractive errors found in 1, 000 patients. With decreased illumination and small viewing angles, shape fluctuates more rapidly, according to Contincelli (27). Conscious effort can reduce the fluctuating shape. Peters (82) shows the relations between visual acuity and refractive errors for several age groups by ingenious graphs. British practice for improved legibility of scales is summarized by Maddock (71).

Uhlaner (104) describes a night vision test combining visual accuity detail in brightness contrast sensitivity for use at moonlight levels. A useful relationship is reported between vision measured at moonlight and at starlight levels of luminance. Morris (74) has devised a size-contrast test having two panels with circular targets decreasing in both area and contrast by factors of two. The test is also useful for testing vision through instruments and testing television fidelity. It also supplies a vision efficiency index.

On visual contrast, Dreyer (41) has decided from further experiments that contrast thresholds for brighter than background are independent of the area of the background; likewise, for negative contrast stimuli. The similarity of the two kinds of stimuli suggest that the simultaneous contrast phenomena may be considered to be a result of an indirect adaptation process. Another paper (40) shows that a dark frame around the test area aids seeing fine detail darker than the background, but not fine detail brighter than the background. Simon (95) discusses the problems of determining contrast visually and within instruments.

Ogle (78, 79, 80) gives a formula relating contrast thresholds for small bright disc targets seen against a white background, pupil size, and the blurredness from out-of-focus imagery. Measurements were obtained for both fovea and periphery of the retina. Thresholds increase with out-of-focus blurring of the retinal image, more so for small (0. 6-min) than for larger (20-min) targets. For discs smaller than 3 to 4 min the effective image size approaches a minimal limit of about 6 min of arc. His results "imply that the size of minimal effective retinal image is determined more by dioptric factors than by quasi-independent retinal areas within which summation of luminous energy is supposed to occur" (78). Fry (49) warns against spurious resolution from out-of-focus images.

Logan and Berger (66) use autocorrelation methods to study degraded contrast and loss of information. The discussion of the paper revealed skepticism, difficulties, and the possibility of another method for the analysis of vision. Stevens (100) proposes repealing Fechner's Law and discusses the contrast seen with gray on a white surround.

Allen (2) describes an improved infrared optometer and reports a maximum accommodative change of about 5. 8D per sec. Reading from his graphs accommodation starts after a latent period of about ½ sec and lasts about 0. 3 sec; relaxation was slightly longer. Accommodation was steadier at distance. Fluctuations of about 3 cycles per sec were seen in the records for accommodation at near. Luria's (68) work on accommodation is interesting although at lower luminances than those of civilian night driving.

Empty field myopia, Doesschoate (39) points out, is different from night myopia and is not likely to appear when driving at night. Gramberg-Danielson (53) recommends wearing a correction for night myopia when helpful during night driving.

Visual fields and their relation to motor vehicle driving are surveyed by Kite and King (64). The first part describes the problem and gives some data; the second part should be useful when it becomes available. Davey (32), and Godfrey and Dickins (55) discuss the motorcyclist's limited fields of view from different kinds of goggles. A recent report shows that the 1960 American cars offer 310° of fair vision at the driver's eye level, which is an increase of 15 percent in the decade (10). The change in the fields of view with pupil constriction mentioned earlier may also play a role in night driving (60).

COLOR VISION

Judd (61) proposes a five-attribute system for describing visual appearance. Wilmer (115) discusses the unique problems of seeing blue, and Birch and Wright (13) discuss normal and deficient color vision.

Birmingham, England (9) is reported to be experimenting with colored roads, using green, red and white mixes. They also propose to make the beltways brown in color. It will be interesting to see whether the color-deficient persons can tell the difference between the red, green, and brown after the roads become dirty. From a study of driver responses to amber traffic signals, Olson and Rothery (81) recommend a constant amber phase of about 5. 5 sec as practical for a wide range of speed zones, with variation when needed to allow for extra wide cross-streets. Color discriminations for yellow and red were reported to be reduced considerably in workers on diesel engine trains after 12 hr of work (103). An examination of color-deficient individuals in Germany showed that there was little evidence that the present traffic lights were hazardous. The main difficulty is the shortening of the red end of the spectrum for protans. It is suggested that the only satisfactory solution of the problem would be to use an equal area shape rather than a color for the signal (52).

Thresholds were measured in the periphery of the retina for 2.6 min arc-subtence red, green, and white signals. The thresholds for red were above those for white and the thresholds for white were slightly greater than for green (72) Bishop and Crook (14) report that for targets of greater luminance than the backgrounds about 9 hues, 3 luminance levels, and 2 purity levels are useful for operational coding, providing no more than 30 of the possible combinations are included in the set. Under optimal conditions the maximum size of an identifiable set is 60 when trained observers are used.

Crain and Siegel (28) using 0.32° targets of red, yellow, orange, and blue fluorescent colors and matching nonfluorescent paints found that the ordinary paints were seen at lower thresholds than the fluorescents, but that the color thresholds were lower for the fluorescent colors. Tachistoscopic thresholds were determined for shape, color, perimeter, area, and organization of pattern for ordinary and fluorescent paints. Dichromatic stimuli were more effective than a single color, squarish were more effective than rectangular stimuli, and increasing the area of the stimulus increased effectiveness only until an optimal size was reached.

Refractive errors, Wienke (114) discovered, are related to the red/green ratio which matches yellow (Raleigh equation), and myopes use more green and hyperopes more red to match yellow than do emetropes. This was not due to the size differences in the images (113).

REGULATION AND BEHAVIOR

A detailed discussion of licensing problems by Algea (1) shows a need for basic information on the integration of the driver, vehicle, and highway. Davey (33) summarizes the visual tasks of road users. The lessened fatigue and easier seeing with proper spectacles, when such are needed, are emphasized (4, 5, 33).

Speed limits are effective only if they do not frustrate the driver, because a frustrated driver is believed to cruise at the maximum speed allowable and needs frequent control by looking at the speedometer which takes his view away from the road for periods as long as 3 sec, according to calculations of Gramberg-Danielsen (51). Feinberg (43) reports on measurements made of 115 transport drivers in the 1940's. Fewer nearsighted drivers appear to enter this occupation. Of 24 subjects tested before and after a day's driving, no differences were found by the use of several tests.

An evaluation of the records of amateur sports car drivers in Great Britain failed to disclose any relation between ocular status, driving performance, and accident rate (12).

Chalfant's (23) summary of part of the California survey shows that professional drivers, chauffeurs and traveling salesmen, and labor or semiskilled workers comprise a greater proportion of the problem drivers than other occupational classes. Negligent drivers, as a group, averaged or exceeded the mileage of the ordinary driver. Sherman (91) also discusses the problem of accident-prone drivers and points out that they are, in general, ordinary normal individuals but ones that do not have good seeing habits. He believes that a proper training in the use of the eyes during driving (such as the Smith system) would improve driving, greatly reduce the accident record, and then make possible separating the real accident-prone from the negligent.

Nathan (76) briefly reviews some aspects of visual fatigue. No reliable criteria were found, although he does give suggestions for further experimentation. Chastain (24) reports from a practical test on 6 subjects that 0.10 percent blood alcohol definitely decreases driving ability. Westheimer and Rashbass (112) found that barbiturates interfere with the vergence and tracking movements of the eyes and Wilson (116) reports that prolonged chloroquine treatment caused irreversible damage to the retina. Both Shulman (93) and Sloan (96) summarize some of the effects of drugs on vision Some tranquilizers tend to blur vision. Other drugs affect pupil size and those that constrict the pupil could reduce night seeing. Adaptation and central nervous system correlation can be distributed by various drugs. The ophthalmologists should determine to what extent the usual dosages of commonly used drugs impair night driving ability of motorists.

Complex noise above 90 db did not cause any loss of visual acuity, fields, or the physical component of the stereoscopic sense, but did disturb perception and the nocturnal morphoscopic sensibility. The color vision disturbances were toward protanomaly (50).

DRIVING TASK ANALYSIS

In England an effort is under-way to find out what the seeing tasks of driving involve (Davey, 35; Waldram, 106, 107). In the earlier studies a voice recorder was installed within the automobile and the running comment of the driver was recorded; shortly thereafter, motion pictures also were made. Motion pictures were also projected before a subject with a television system showing where the subject looked at the picture.

The eye sees with quick fixations of ¼ to ½ sec. Hard to identify subjects are watched longer and some situations (such as a bicycle) take undue time with many fixations. Peripheral vision is used when the car being passed was not looked at. Blurred vision on the near side appeared to be sufficient, but offside the unexpected attracted the viewer's attention. At corners the eye tended to look ahead of the picture, in much the same way as was reported by Crawford for dynamic viewing.

Without traffic the eyes fixated a little opposite and a few hundred feet ahead. Steering was mainly by the centerline and the curbs were seen casually.

With medium traffic there was much use of peripheral vision, motion changes were noted, familiar patterns were reacted to, and fixation occurred when in doubt or when the unusual pattern appeared. Therefore, low illumination makes undue demands for fixation. When following, the eyes tended to concentrate on the car ahead.

In dense traffic the British experimenters show the problems of trying to respond to several orders of elements rather than one at a time.

Night driving illumination is less; the bright sky and color clues are gone. Color is stated not seen at night even when the lighting is adequate. Driving with dense goggles reducing the seeing in overcast daylight to night levels was less good than ordinary driving at night with the car lights. The lighting from the auto was adequate under good weather conditions, but Waldram shows a need for additional fixed lighting for adverse conditions.

Much information, as noted in this and previous reviews, is becoming available. The experienced driver is reported to pay attention to a closing situation. Waldram and Davey's analysis shows many similarities to the Smith-Sherman driving rules and supports Sherman's (91) often-repeated comment that improper use of the eyes results in automobile accidents. Applying modern means of showing where the observer looks (86, 87, 101) and analysis like Davey and Waldram are doing should form a basis both for better driver training and for removing the accident repeater from the highways.

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