Some Factors Affecting Driver Efficiency At Night

T.W. FORBES, Assistant Director Highway Traffic Safety Center, Michigan State University, East Lansing

Combining the results of certain published researches yielding background information on human reactions brings out certain relationships of importance in traffic design, operation and safety. Some of these affect night driving efficiency. Increased task difficulty leads to longer perception-judgment-response times. At night, driver response time may be slowed an additional amount by reduced visibility.

Data on time for dilation and constriction of the pupil of the eye in adapting to light and to dark indicates that the "dark hole" effect in entering a tunnel can be eliminated by design taking account of the human reaction. It also explains accident experience reported in crossing certain highly illuminated thoroughfares and suggests remedial measures. Reduced sensitivity and a change of relative sensitivity to colors may lead to driver errors. These characteristics of the human eye should be given proper consideration in highway design and traffic engineering activities to improve operation and reduce hazards.

Fatigue results in reduced human efficiency and, for most drivers, probably will be greater at night. Studies in industry indicate that moving bright sources in the periphery of vision tend to induce fatigue. They may be also a factor in inducing sleep. An experimental study of drowsiness in driving showed an increasing frequency of eye closure leading up to actual drowsing behind the wheel. Turnpike and other studies of one car accidents seem to indicate a high proportion of sleep accidents between midnight and 6:00 a.m.

It is suggested that discomfort glare may be of great importance as a fatigue and drowsiness inducing factor and that the threshold for discomfort glare may be lower under sleep deprived and fatigued conditions of the driver.

Drivers must realize that critical phases of the driver's task often are even more critical under night driving conditions. Proper consideration of eye characteristics in design of lighting, signing and marking of highways can help to reduce hazards from the various factors discussed.

● CONSIDERABLE INFORMATION is available from research in the human factor sciences which can be put together to contribute to better understanding and solutions of various highway problems. An attempt to do this was made for certain areas of behavior some time ago (1). From this and other studies, this paper points out some factors affecting highway efficiency at night. Many factors affect driver efficiency in daylight as well as at night, but some of them are more likely to occur at night or may be of greater influence under night conditions.

PERCEPTION, JUDGMENT AND RESPONSE TIME IN REDUCED VISIBILITY

Combining the results of various studies of perception, judgment and response time measurement shows clearly that perception-judgment-and-response time increases with the complexity and difficulty of the task, that is, the number of component stimuli and responses. Times required for these human reactions in driving range from less than 0.5 sec to 3 or more sec depending on the complexity of judgment involved (1).

Superimposed on this response time increase as a result of task complexity is another increase due to task difficulty from lower illumination or other conditions leading to poorer visibility. Figures 1 and 2 show results of two different studies illustrating this increase of response time as task difficulty posed by poorer visibility conditions increased. In both cases, the whole curve showing the effect of complexity is

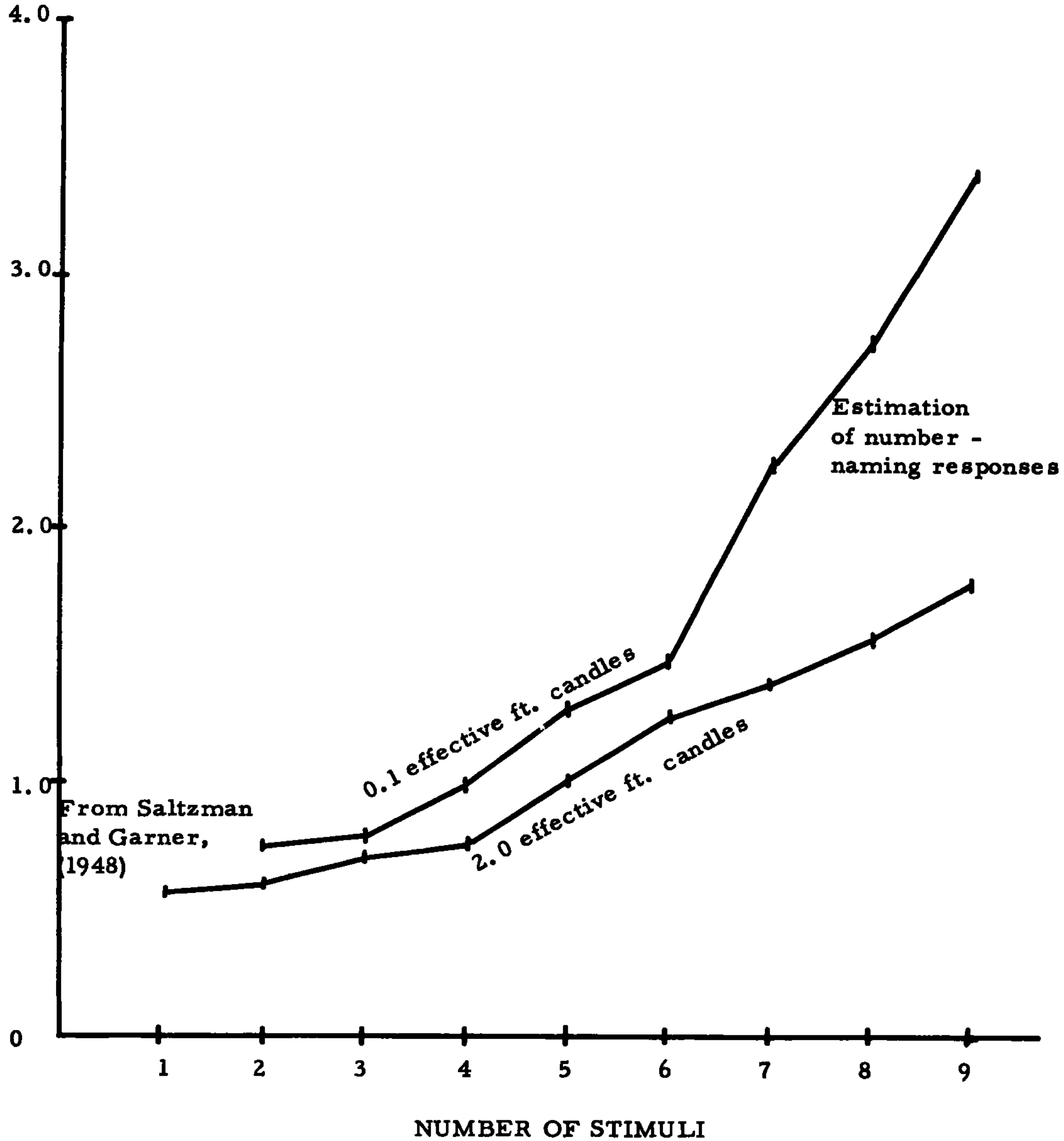

Figure 1. Increase of response time with increased difficulty of perceptual task; estimating number of circles and dots during short presentation (From (1), p. 15).

transposed upwards under lower illumination and visibility. Figure 1 resulted from a laboratory study whereas Figure 2 represents results from outdoor, full-scale experimental simulation of a judgment required in driving.

Thus it is seen that the decreased visibility (often characteristic of night driving)

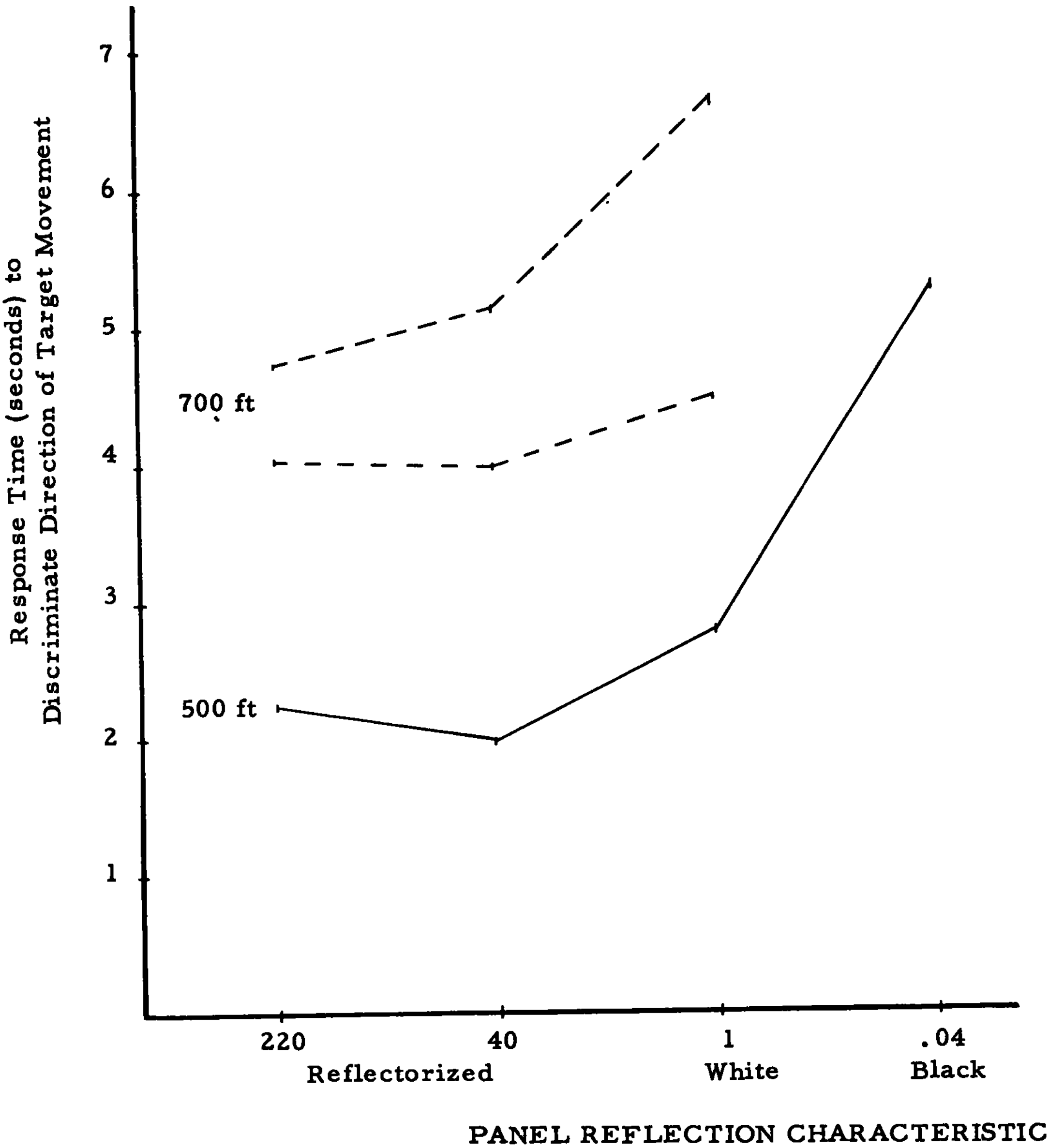

Figure 2. Increase of perception-response time when target distance is greater and illumination lower; judging direction of relative motion of panel on rear of truck, relative target speed ± 5 mph (From (10)).

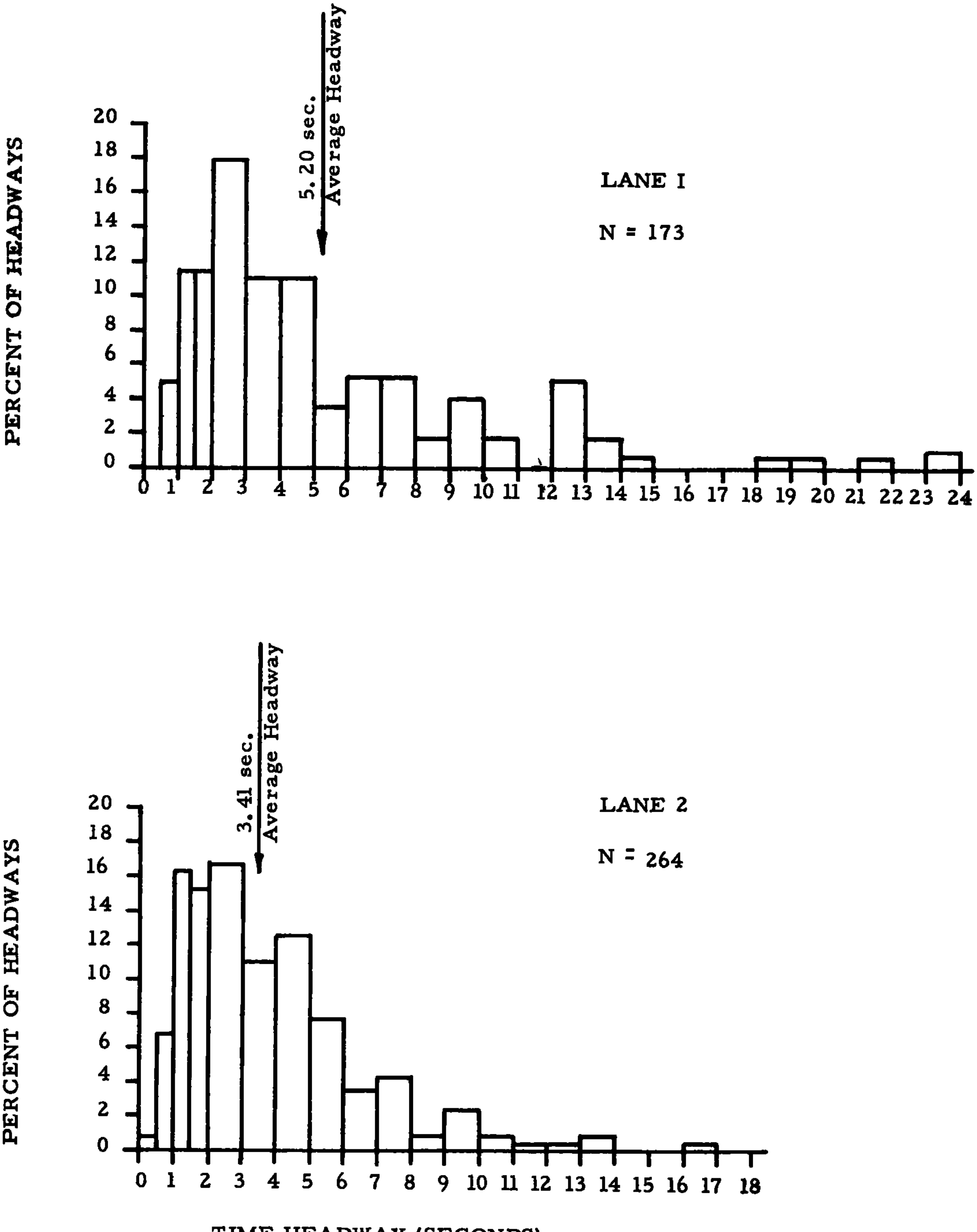

Figure 3. Distribution of individual time headways at night, Ford Expressway, Detroit; 7:15 to 7:30 p.m., Feb. 14, 1958, lighted.

will tend to decrease efficiency in this process of perception-judgment-and-response in terms of response time. Errors also may be expected to increase.

IS THIS AMOUNT OF SLOWING CRITICAL?

Increases of response times to the above extent may be very critical. In a recent paper (2) it was pointed out that in modern traffic on high-speed highways in daylight many drivers are led to operate at time spacing between vehicles as low as 0.25 sec quite commonly. A similar situation was found in records of night driving made in Detroit (3). Figure 3 shows an example of such headways measured after dark on a lighted urban expressway. Time headways under 1.5 sec were less frequent than in daylight but still constituted from 16 to 23 percent of the cases.

As many as 23 percent of time spacings were under 1.2 sec in lane 2 and about 7 percent were under 0.7 sec. Center to center spacings of 0.5 to 1.0 sec occurred in some 5 to 7 percent of the cases and almost one percent were under 0.5 sec. To determine time between vehicles, the length of the vehicle must be subtracted. This represents from ¼ to ⅓ sec at 50 and 40 mph. Thus these time spacings in nighttime traffic were from 0.25 to 0.70 sec; that is, at or below minimum perception-response time values. Time headways below 1.5 sec represented spacings below 1.2 sec approximately.

Therefore, increasing the time for perception-judgment-and-response to 1, 2 or 3 sec is of great importance both for safe operation and for effective highway capacity as well.

On rural highways, if several cars are traveling together in platoons, time headways may be of similar magnitude. If traffic is lighter on open high-speed highways, time headways may be longer and driver response somewhat less critical. However,

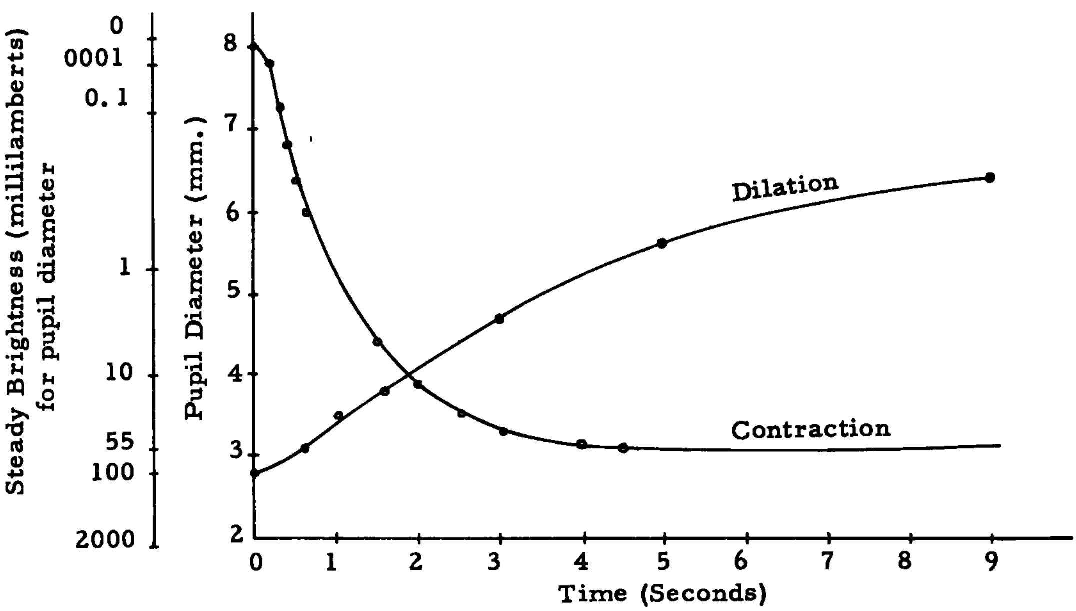

Figure 4. Pupillary contraction and dilation (From (1), Fig. 11).

at intersections or interchanges, or whenever there is passing or bunching of vehicles, response times still will be critical.

Or, if the drivers assume a greater time spacing because of poorer visibility, there may be a backing up effect at that particular point which will affect the interchange capacity. Even then, slower perception-judgment-and-response time may result in greater hazards as vehicles enter from side roads or ramps.

PUPILLARY RESPONSE TIMES AND VISIBILITY

Effects of time required for pupillary dilation when entering the dark and pupillary contraction when emerging into higher illumination are now compared. Data from several well-known studies of pupil diameter changes (Fig. 4) show that the dilation response is considerably slower than the contraction to light (1).

The slower rate of dilation may lead to an almost continuous lowered visibility for dark objects in passing a succession of headlights or street lights. The eye will be going through a series of fluctuations in pupil size almost continuously under such circumstances.

For seeing in moderately low brightness, the retina adapts relatively rapidly as

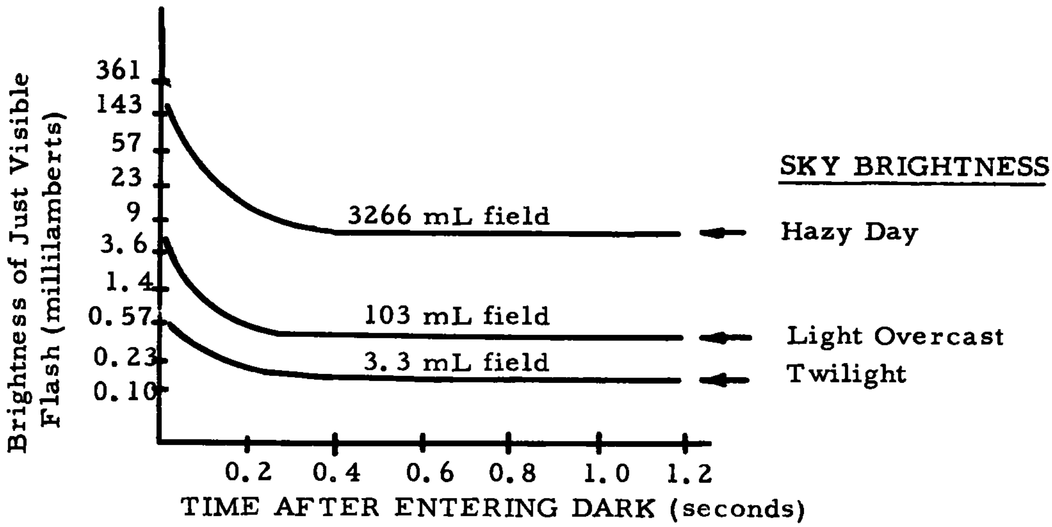

Figure 5. Visual sensitivity to brief flashes of light very shortly after entering the dark from various field brightnesses with constant small pupil opening (See (1), Fig. 12).

compared to the pupil. Figure 5 shows that when the pupil size is artificially held constant the eye reaches its new threshold of sensitivity in a little over 0.2 sec when entering the dark from various field brightnesses. Other studies, of course, show that the length of exposure to a brighter field and the degree to which dark adaptation must be carried, affect such measurements greatly. However, where lower illumination levels are moderate and where intensities vary rapidly, as in streets and highways, Figures 4 and 5 together show that the response of the pupil will control visibility because the retina cannot adapt until the pupil allows more or less light to enter the eye.

ACCIDENT FACTOR AT BRIGHTLY LIGHTED INTERSECTION

Referring again to Figure 4, note that contraction in going from a field brightness of one millilambert to one of 50 millilamberts takes place in about 1.5 sec. In contrast, dilation to adapt to the reverse change (from 50 ml to 1 ml) requires some 3.5 sec.

Therefore, as a driver approaches an intensely lighted intersection his pupils will contract by the time he has reached it because he is seeing the brightly lighted area as he approaches. Thus his visual efficiency will be maintained. However, if there is a relatively sharp cut-off of the light, he will go suddenly into the dark again. The pupils will not have dilated to the 1 millilambert condition for another 3 or 4 sec and his visual efficiency will be much reduced.

The brightness for each pupil diameter is shown beside the pupil diameter scale in Figure 4. Because the light transmitted is proportional to area of the pupil, in the preceding example, there will be roughly a 3:1 reduction in the effective brightness of objects and dark objects may drop below the visual threshold. This is undoubtedly a factor in accidents when crossing brightly lighted streets and highways where a driver hits a pedestrian or other dark object beyond the lighted area. A gradual reduction of illumination should be provided on side streets to avoid reduced visual sensitivity before the eye has dilated again.

Although this effect is well-known to most of those in technical fields dealing with visibility, it is not always known to those in traffic engineering and highway design. Questions raised as to the cause of accidents in going from brightly lighted to dark areas suggest that this result of characteristics of the eye may be of practical interest to traffic engineers.

TIME VALUES IMPORTANT FOR TUNNEL APPLICATIONS

This same principle relates to the entrance to tunnels. The effect is well-known and illumination intensity is usually increased at the mouth of the tunnel for daylight conditions. In such applications pupillary response times are fundamental and should not be overlooked.

From the curves it can be seen that by gradual reduction of daylight before reaching the entrance of the tunnel at a rate to allow for pupil dilation time it would be possible to reduce or eliminate the effect of plunging into the dark. Such a plunge is still found in some tunnels in spite of increased artificial illumination in the entrance. At night, the problem is met at the exit of the tunnel in going from a lighted tunnel into darkness. Here, approach illumination usually is provided by luminaires outside the tunnel. How-

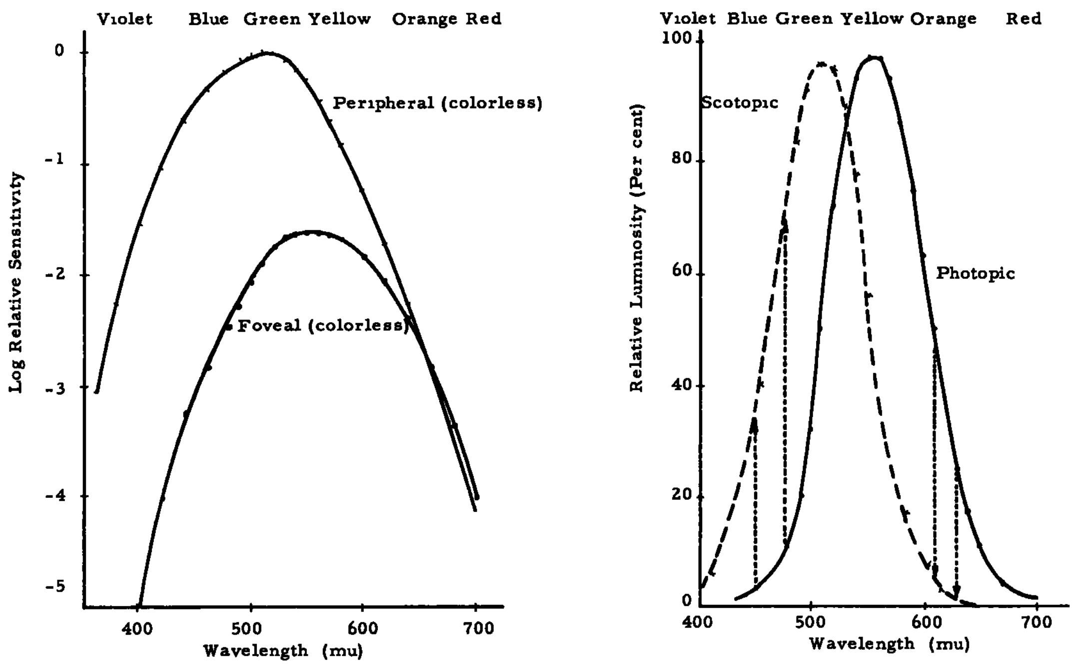

Figure 6. (Left) Reciprocals of least relative energy to produce a sensation of light (See (1), Fig. 11a). (Right) Relative luminosity of colored stimuli under daylight (photopic) and night (scotopic) illumination levels (See (1), Fig. 11b).

ever, unless carefully designed, gradual reduction of intensity is provided at the end of the lighted section, a period of several seconds of reduced visual sensitivity may yet occur in leaving the lighted approach section. Hence, an unlighted vehicle parked at such a location may be visible to a person standing near it but not to an emerging driver.

REDUCTION AND CHANGE OF COLOR SENSITIVITY

Change from photopic vision in high illumination to mesopic and scotopic or vision under lower illumination conditions at night involves complex mechanisms on which much research has investigated the many and complicated interrelationships. For practical purposes of the traffic engineer, however, it may be said that in general there is a marked loss of sensitivity to most color stimuli and a change in relative sensitivity to the different colors.

Figure 6 (left) shows the relative sensitivity for both foveal and peripheral vision. It is well-known that under high illumination and brightness conditions foveal vision is most acute and is most used in seeing. Under low illumination peripheral vision is more sensitive.

In Figure 6 (right) relative luminosity shows the relative effectiveness of light of different wave lengths as stimuli under the two extreme conditions of seeing. It shows that the greatest sensitivity moves from the light yellow region over toward the greenish. Furthermore, dark red is very much reduced in stimulus effectiveness under low illumination conditions and blue wave lengths have gained effectiveness relatively.

Thus in terms of driver efficiency, it may be said that at nighttime under low illumination, sensitivity to the red end of the spectrum becomes much less efficient and sensitivity to the blue end trends to become more efficient relatively. At intermediate levels of illumination, both mechanisms of the eye may combine to give intermediate visual sensitivities.

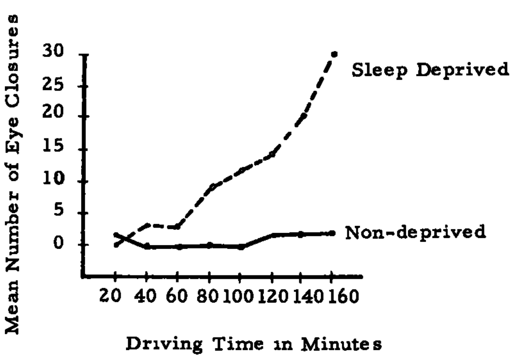

Figure 7. Comparison of deprived and non-deprived groups on eye closure (From (7), Fig. 4).

COLOR CONSTANCY AND DRIVER ERRORS

Under low luminance conditions where colors in the red end and blue end of the spectrum have almost passed below threshold of a driver's sensitivity, a well-known psychological effect called color constancy may cause errors in driver judgment. Under these conditions, a driver may detect a visual stimulus but not the color characteristic. He then unconsciously reads into it a color he associates with an object or which he anticipates, and this may prove to be an erroneous one. This effect can be demonstrated experimentally in the psychological laboratory with ease.

Because of this reduced efficiency in detecting color stimuli, especially of the extreme red and violet ends of the spectrum, problems are introduced when these colors are used for low luminance traffic indications. An unreflectorized sign background or highway marking of a dark red or dark blue color, therefore, may be interpreted as another color which the driver erroneously expects. Also, this means that the traffic engineer who is familiar with the color of the sign or the marking cannot judge validly its effect on a motorist who is not acquainted with this particular marking. Tests of such signs with appropriate control of conditions must be made using subjects unfamiliar with the signs being tested to obtain representative results.

VISUAL FACTORS AND PHYSICAL FATIGUE AT NIGHT

The effects which are generally known as fatigue are generally familiar. Again, without going into the details of a complex field, it is noted that certain effects are quickly reversible and therefore are usually classified as subjective or "psychological" fatigue. Other effects are more long-continued and are of a more physiological nature. Reduction of efficiency of human reactions has been one index for measuring fatigue and studying its causes. A very extensive study of fatigue from driving was carried on by the U.S. Public Health Service several years ago (4). More recently, fatigue has been shown to affect pilot responses not in keenness of visual discrimination ability but in alertness and speed of corrective action (for example, see studies by Bartlett and by Macworth discussed by Chapanis, Garner and Morgan (5)).

There is greater likelihood of decreased driver efficiency from fatigue at night. A driver who arranges his schedule to work at night does not necessarily start out with any reduced efficiency from fatigue, but the majority of drivers have carried activities during the day and, therefore, the probability of fatigue effects at night will be higher. Furthermore, visual factors have been shown to be of importance in inducing fatigue. Reduced efficiency and accuracy of responses and reduced alertness as reflected in judgments and responses to stimulus situations are characteristic of fatigue effects.

GLARE, FATIGUE AND SLEEP

Studies of industrial work conditions have brought out the importance of brightness contrasts and of bright sources of light in the periphery of vision as fatigue inducing factors (6). They are especially fatiguing if continually changing or moving (relative to the eye). Light from overhead luminaires or from passing headlights would, therefore, be expected to be fatigue and sleep inducing influences on the highway in addition to its direct effects in reducing visibility. The tendency of the eye to turn reflexly toward the bright source is probably part of the mechanism leading to physiological fatigue, and the blinking and eye closure may be regarded as protective reactions.

An experimental study produced drowsiness behind the wheel (7) in less than 3 hr of driving even during daylight conditions. Among the reactions observed and recorded, drifting, speed changes, eye blinks and eye closures showed similar increasing trends during the trip. Sleep deprived subjects showed more eye blinks during the driving period than the same subjects under normal schedules. It was significant that for both groups blinks increased during the time of the drive. For the sleep deprived, actual eye closures began to appear and became uncontrollable, resulting in drowsing in nine out of ten cases in less than 3 hr of driving. Obviously, there was 100 percent loss of efficiency at those times (Figs. 7 and 8).

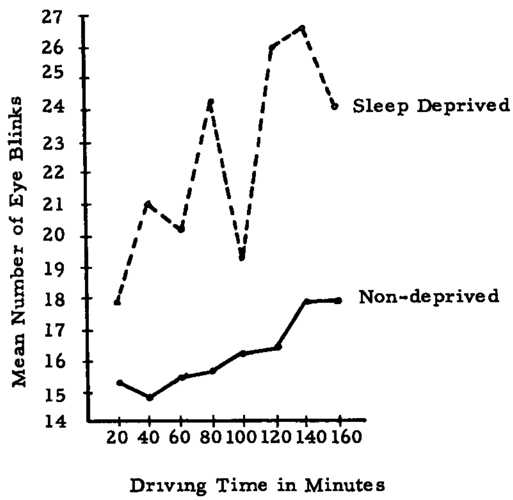

Figure 8. Comparison of sleep deprived and non-deprived groups on eye blinks; average values for five subjects, two 2-min samples each 20-min period, (From (7) Fig. 5).

DROWSINESS AND ACCIDENTS

A number of accident studies on turnpikes and state highways have indicated a higher proportion of one-car accidents (and possible sleep accidents) between midnight and the early morning hours (8). The effects of sleep deprivation shown during daylight driving in the drowsiness study would be even more likely to occur during night driving because of sleep habits of the vast majority of people.

Furthermore, the probability that people going on vacations may work late on preceding days in order to start after work would lead to a higher probability of sleep deprived drivers during night driving.

IMPORTANCE OF DISCOMFORT GLARE REDUCTION

Under sleep deprived and/or fatigued conditions, it is suggested that discomfort glare may be of even greater importance than under other conditions. Recent studies have made important contributions toward the measurement and study of discomfort glare (9) leading toward its reduction through design and other approaches. It is suggested that under the sleep deprived and/or fatigue conditions, the discomfort threshold may be lower and the effect on the driver even more important than when he is in a more normal or average state.

Under such sleep deprived conditions, observations and personal experience show that oncoming headlights and glaring overhead illumination may tend to increase the drowsiness effects experienced by the driver.

Under such circumstances of borderline drowsiness, the driver may be expected to be definitely slowed and less accurate in his judgments and responses even beyond the range discussed previously. The hazard presented by such driving is obvious.

CONCLUSIONS

It has been shown that increasing the complexity and difficulty of the driver's task can increase the time required for perception-judgment-and-response by a factor of two, three or more. Thus, under daylight conditions a complex and more difficult response may require 3 or more sec as contrasted with 0.2 to 0.75 sec for the simpler responses. In night driving, reduced visibility can be expected to increase this slowing of perception-judgment-and-response. Such increases may be critical in relation to time headways in night traffic on high-volume highways and under certain conditions in low volumes.

Pupillary response time may be a factor in some accidents. Changes in color sensitivity due to low illumination may cause driver errors. Proper consideration of these characteristics of the eye in highway design, lighting and traffic engineering can reduce critical situations which may present hazards.

Drivers must be informed and must come to realize that night driving is a somewhat more difficult task, that sleep deprivation makes this worse and that they must, therefore, avoid driving under sleep deprived conditions.

Finally, it is of vital importance that all lighting, signing and marking be designed with the characteristics of the eye taken into consideration and with a view to reducing fatigue and drowsiness inducing effects as much as possible. Discomfort glare may be of great importance here.

In these ways, driving efficiency impairment at night may be at least to some degree reduced.

REFERENCES

1. Forbes, T.W., and Katz, M.S., "Summary of Human Engineering Research Data and Principles Related to Highway Design and Traffic Engineering Problems." Amer. Inst. for Research, Pittsburgh, Pa. (Apr. 1957).
2. Forbes, T.W., " Human Factors in Highway Design, Operation and Safety Problems." Presented at Annual Meeting of Human Factors Society, Los Angeles (September 1959).
3. Data, specially analyzed for this paper, collected for a study of traffic flow at the Highway Traffic Safety Center, Michigan State University.
4. Jones, B.B., et al., "Fatigue and Hours of Service of Interstate Truck Drivers." Pub. Health Bul. No. 265, U.S. Govt. Print. Office, Wash., D.C. (1941).
5. Chapanis, Garner, and Morgan, "Human Factors in Engineering Design." Pp. 377-8, John Wiley (1949).

6. Fryer, D.H., and Henry, E.R., (Editors), "Handbook of Appled Psychology." Vol. 1, pp. 63 and 64, Rinehart (1950).
7. Forbes, T.W., Katz, M.S., Cullen, J.W., and Deterline, W.A., "Sleep Deprivation Effects on Components of Driving Behavior." Highway Research Abstr., 28:1, 21-26 (Jan. 1958).
8. Forbes, T.W., "Accident Analysis on High Speed Expressways." Pp. 24-30, Proc. 24th Ann. Mtg. Am. Bridge, Tunnel and Turnpike Assn., White Plains, N.Y. (Oct. 1956).
9. Rex, Charles H., "Ratings for Visual Benefits of Roadway Lighting." HRB Bul. 226, 27-55 (1959).