The Ability To See a Pedestrian at Night: Effects of Clothing, Reflectorization, and Driver Intoxication

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In the United States, pedestrian deaths account for nearly 20 percent of all traffic fatalities. During darkness the pedestrian's risk is increased, and is further increased if a pedestrian is wearing dark clothing or must travel on a roadway concurrently with a driver who has been drinking.

In the laboratory phase of this study it was found that at low levels of illumination an individual's sensitivity to contrast decreases as his blood alcohol level increases. In the road test phase, visibility distances were found to be unacceptably short for "dummy" pedestrians covered with black or grey fabric. Dummies covered with white fabric were safely visible for a driver traveling at speeds up to 50 mph; however, only reflectorized dummies were safely visible above that speed. As blood alcohol levels of the observers increased, the visibility distance decreased for each of the simulated pedestrian conditions.

•IN THE United States alone an estimated 149,000 pedestrians are either killed or injured as a result of motor-vehicle accidents in a single year. The approximately 9,000 pedestrian deaths in the United States each year account for nearly 20 percent of the total traffic fatalities (1). Even though 65 percent of the pedestrian deaths occur in urban areas, if the density of pedestrian and motor-vehicle traffic is considered, the risk to the rural pedestrian may be as great or greater than that of the urban pedestrian. It has been reported that in urban areas 4 percent of the pedestrian accidents and only 0.7 percent of the non-pedestrian accidents are fatal. For rural areas 25.3 percent of the pedestrian accidents are fatal while 4.2 percent of the non-pedestrian accidents are fatal (2).

Darkenss increases the pedestrian's jeopardy. Pedestrian accidents occur more frequently during twilight and darkness, in spite of reduced pedestrian and motor-vehicle traffic during these hours. While overall pedestrian deaths represent slightly less than 20 percent of all motor-vehicle fatalities, in a three-year study of twelve U.S. cities with populations greater than 500,000, pedestrian deaths were found to account for 50 percent of the total nighttime traffic fatalities (2). In rural areas pedestrian deaths at night account for 10 percent of the traffic fatalities, even though pedestrian traffic is distinctly limited during this period.

There are several other prominent trends in pedestrian accidents: specifically, three-fourths of the pedestrian-involved accidents occur when the pedestrian is crossing or entering the roadway; children under 15 and adults over 50 years of age are more frequently involved; males account for about 70 percent of the total pedestrian deaths;

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within urban areas pedestrian accidents are more likely to occur away from built-up shopping centers; a major portion of involved pedestrians are not licensed to drive; socioeconomic factors influence pedestrian accident involvement (3, 4); and "alcohol is a significant factor (in accidents) for pedestrians as well as for drivers" (5).

To determine how the driver fits into the pedestrian accident complex, accident reports for 1965 in Indiana involving pedestrian fatalities were reviewed. Statements made by the investigating officer and the driver revealed that 87 percent of the drivers who hit a pedestrian at night claimed difficulty in seeing the pedestrian, while only 11.8 percent made the same claim for accidents occurring during daylight. In fact, 23.4 percent of the nighttime drivers claimed that they did not see the pedestrian until after the impact! Further, 50 percent of the drivers who killed a pedestrian during the twilight hours felt that poor visibility of the pedestrian was the major contributory cause. The majority of the drivers involved in pedestrian fatalities were driving within the posted speed limit and were not cited for other motor-vehicle traffic violations.

The "Grand Rapids Study" (6) has provided data on the characteristics of accident-involved drivers compared with a control group of drivers similarly exposed but not involved in accidents. It was found that drivers between the ages 15 and 24 and over age 70 were over-represented in accidents. Furthermore, it was found that for drinking drivers, blood alcohol levels of 0.04 percent and greater were associated with an increased accident involvement. The probability of accident involvement increases rapidly at alcohol levels of over 0.08 percent and becomes extremely high at levels above 0.15 percent. Recent estimates indicate that drinking may be a factor in as many as 50 percent of the fatal motor-vehicle accidents (1).

PEDESTRIAN ACCIDENT CAUSE

"The concept of 'cause' has little operational significance in the study of accidents. Traffic accidents are more meaningfully viewed as failure of the system rather than as failures of any single component. To a larger extent than usually appreciated, several factors simultaneously contribute to most accidents; changes made in any of these could have prevented the accident or at least moderated it" (5).

Pedestrian characteristics, environmental characteristics, and the characteristics of the driver and his vehicle compose the "system" of pedestrian motor-vehicle accidents. Within this framework one can imagine numerous unfavorable changes which could occur within each of the components of the "system." Any one change in and of itself could be sufficient to entail a pedestrian accident. Alternatively, individually innocuous system changes may in combination produce an accident.

The likelihood of an accident becomes greater as the number of pernicious changes increases. Thus, the action of a child running into the roadway in the presence of an oncoming automobile could lead to a pedestrian accident, particularly if there were concurrent detrimental changes in the characteristics of one or both of the remaining components of the system, such as environmental illumination or weather that was poor and a driver who had imbibed alcohol.

Three factors that appear to influence the likelihood of pedestrian accidents are nighttime, dark clothing, and an intoxicated driver. It is the purpose of this study to investigate these parameters of the pedestrian motor-vehicle accident system.

METHOD

The first phase was a laboratory investigation of the effects of ethyl alcohol on the brightness difference threshold of eight male graduate students, ages 22 to 39. The second phase was a series of road tests in which two of these graduate students and two additional graduate students served as observers (O's). These tests were designed to investigate the O's ability to detect simulated pedestrians (P's) with various clothing at night, and to study the effects of ethyl alcohol on this detection task. All O's selected for these investigations had normal binocular vision and corrected visual acuity of 20/20 or better.

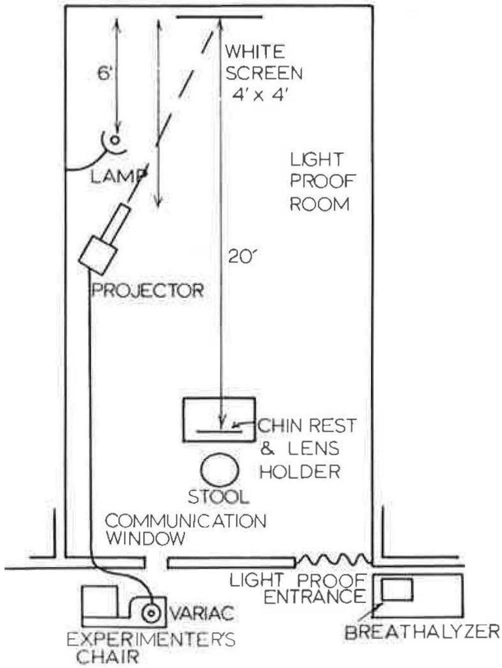

Figure 1. Light-proof testing room and apparatus.

Laboratory Experiment

Figure 1 is a diagram of the light-proof testing room. At one end a smooth-textured 4-ft square white screen was uniformly illuminated by a lamp 6 ft from the screen and powered by a constant voltage transformer. A projector superimposed a 17-mm spot of white light on the center of the screen. A Variac supplied by a constant voltage transformer was used to vary the intensity of the projected spot. The subject was located 20 ft from the screen in a head rest supporting auxiliary test lenses. A Breathalyzer[1] was used to measure the percent blood alcohol levels (BAL).

Two practice sessions were conducted on the days prior to data taking. Data were gathered on two evenings with four different O's being tested each evening. The day of the experiment the O's ate normal meals, but drank no alcoholic beverage. Each O performed 8 visual observation "blocks" consisting of 30 invisible to visible stimulus presentations. After each block O was given 66 cc of 100-proof vodka mixed with lime soda and ice. The O was allowed 5 minutes in which to drink the vodka, followed by 25 minutes free time. Each O was then given a Breathalyzer test and his percent BAL was recorded. After the Breathalyzer test the sequence was repeated. Prior to each block, O was allowed 2 minutes to seat himself and to adapt to the background luminance of the screen, which was 3.5 apparent ft-candles for the first four subjects and 0.15 apparent ft-candles for the second four. The task of the O was to say "now" when he first detected the superimposed spot of light. Ten trials were run for each of three different conditions in a single block. The O was rendered artificially emmetropic for the first condition. For the second condition O made the observations through additional -0.50 D lenses and for the third condition -1.00 D lenses were added. All observations were made binocularly and searching fixation was permitted. Each O was allowed to terminate his alcohol intake when he felt that he had reached his limit. However, each O was encouraged to complete 8 blocks of visual testing. The following day the O's returned to the laboratory for one additional block of visual observations without alcohol.

Dynamic Road Test

The apparatus for the dynamic road test consisted of two simulated pedestrians (P), a 1964 Mercury station wagon, four stopwatches, a Breathalyzer, and a straight 1400-ft test road. The P's were boxes 12 by 12 by 48 in. covered with fabric. One side was white fabric of 75 percent reflectance, a second was black fabric of 9 percent reflectance, and a third was grey fabric of 16.0 percent reflectance. The fourth side was covered with the same grey fabric and, in addition, had a strip of solver reflectorized tape (1 by 11 in.) placed horizontally 15 in. from the ground. The reflective strip had a candlepower reading of 50 candles/ft^2/ft-candle.

[1]The Breathalyzer (designed by Robert F. Borkenstein, Department of Police Administration, Indiana University) instrument analyzes alveolar breath for alcohol content and yields an equivalent percent BAL reading. It is presently used by the Indiana State Police and other law-enforcement agencies.

Dynamic testing was conducted on two dark nights, and two O's were tested each night. The two P's were placed in alternating randomly preselected positions on or near the roadway for each test run. Each block consisted of 22 test runs, 18 of which contained 2 P presentations, 2 contained only 1 and there were 2 empty runs. Within a single block of trials the grey, white, and reflectorized sides of the P were presented 9 times each. The black side was presented 11 times. The headlight aim of the test vehicle was adjusted to the manufacturer's specifications. There was no opposing glare in any of the tests. Each test run was begun with the headlamps on low beam, approximately 1000 ft from the location of the P's. The two O's were in the front seat of the vehicle next to the driver. Each O held two stopwatches and was to start the watch held in his right hand when he saw the first P, and to start the watch held in his left hand upon seeing the second P. Both watches were stopped when the P's were reached. The vehicle approached the P's at a constant speed of 35 mph, and thus the elapsed time could be translated into distance. After the first block of trials the O's were given 66 cc of 100-proof vodka. Thirty minutes after finishing the first drink each O was given a Breathalyzer test and his blood alcohol level was recorded. Thereafter a Breathalyzer analysis was made midway through each block of trials and immediately following each block. An additional 66 cc of vodka was given at the midpoint of each subsequent block of trials. Each O completed four entire blocks. Only one declined to finish the entire allotment of vodka.

RESULTS AND COMMENT

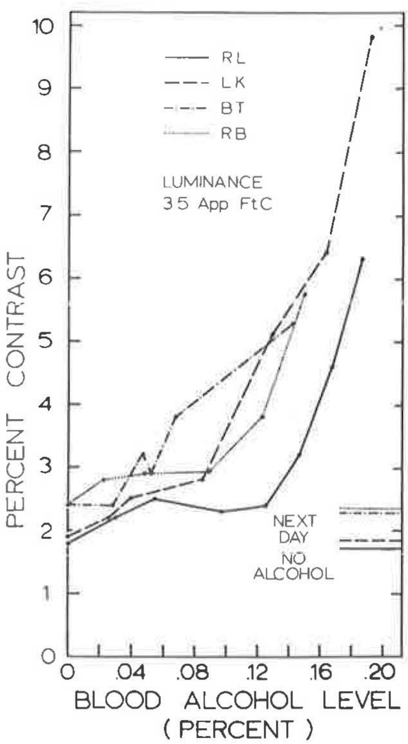

Figure 2. Percent contrast needed by four observers with increasing levels of blood alcohol to "just notice" a 17-mm spot of white light superimposed on a uniform white background of 3.5 apparent ft-candles luminance. Observers were allowed searching fixation.

Laboratory Tests

The formula for a brightness difference threshold is Contrast = $\Delta L/L$, where ΔL is the increment of luminance added to an area on a uniform background which is enough to make it just noticeably brighter than the remainder of the background L, O being adapted to L.

Results of the laboratory tests are represented graphically in Figures 2 and 3. In Figure 2 the ordinate is the percent contrast ($\Delta L/L \times 100$) needed to just notice the superimposed spot of light against the uniform white screen of luminance 3.5 apparent ft-candles. The abscissa is the percent BAL. Each of four O's is indicated by a separate curve representing mean values for emmetropia. The -0.50 D and -1.00 D conditions followed the same trend.

Subject B. T., who showed the most erratic decrease in contrast sensitivity, also showed the greatest subjective reaction to alcohol and became sick just prior to the 0.05 percent level. L. K. exhibited the least subjective effect from the alcohol and at the 0.18 percent level had good control of his faculties. Yet his overall decrement of contrast sensitivity, above the 0.09 percent level, was greater than any of the other four O's. B. T. and R. B. terminated their drinking just prior to reaching the 0.15 percent level of blood alcohol. (The legal limit accepted as "prima facie" evidence for being under the "influence" in most states is 0.15 percent.) L. K. and R. L. expressed dissatisfaction when the experimenters terminated their drinking at a considerably higher BAL.

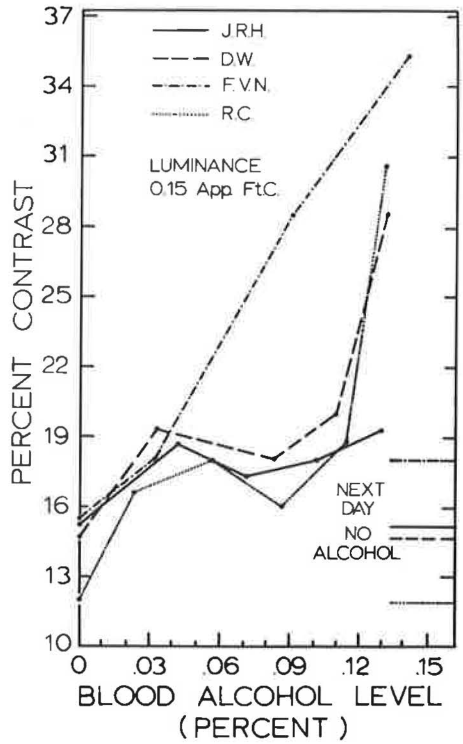

Figure 3. Percent contrast needed by four observers with increasing percentage levels of blood alcohol to "just notice" a 17-mm spot of white light superimposed on a uniform white screen of 0.15 apparent ft-candles. Observers were allowed searching fixation.

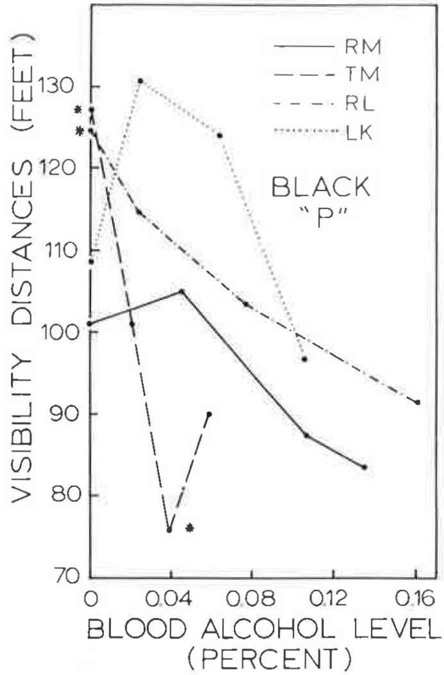

Figure 4. Mean visibility distances of black simulated pedestrian obtained by four observers at increasing percentage levels of blood alcohol. Asterisks represent visibility distance of zero for one observation (i.e., simulated pedestrian was not seen at all).

The following day the performance of every O returned to essentially the same level as that prior to the intake of alcohol.

Figure 3 is plotted in the same manner as Figure 2, but represents the responses of four new O's to the task with a background of 0.15 apparent ft-candles luminance. Individual differences were more noticeable in this set of observations with subject F.V.N. showing a steady decrease in sensitivity over the entire range of BAL from 0.00 percent to 0.14 percent. (He also appeared to be more intoxicated than the other four O's.) R. C. and D. W. did not exhibit a rapid decrement in performance until above the 0.08 percent level. J. R. H., who appeared to be the most sober of the four O's, did not show a major decrement in performance. All O's terminated their intake of alcohol before reaching 0.15 percent BAL. On the following day the performance for each O had essentially returned to its original level.

All O's except one, B. T., felt that their visual performance had not noticeably declined throughout the experiments.

Road Tests

An ample visibility distance must be greater than the combined reaction distance and braking distance. The "critical visibility distance" is just equal to reaction distance plus braking distance.

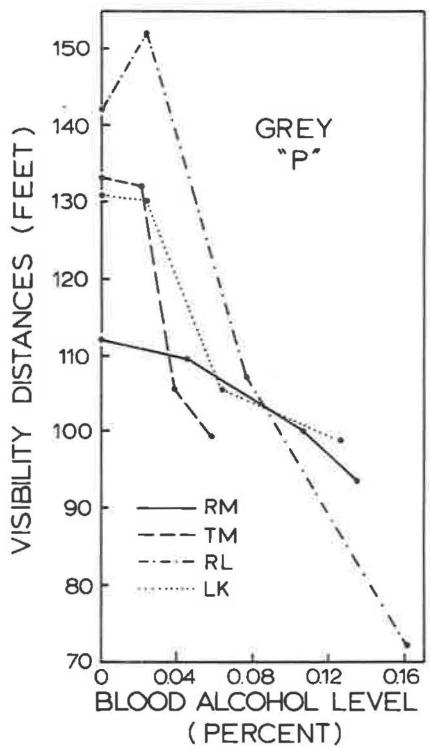

Figure 5. Mean visibility distances of grey simulated pedestrian obtained by four observers at increasing percentage levels of blood alcohol.

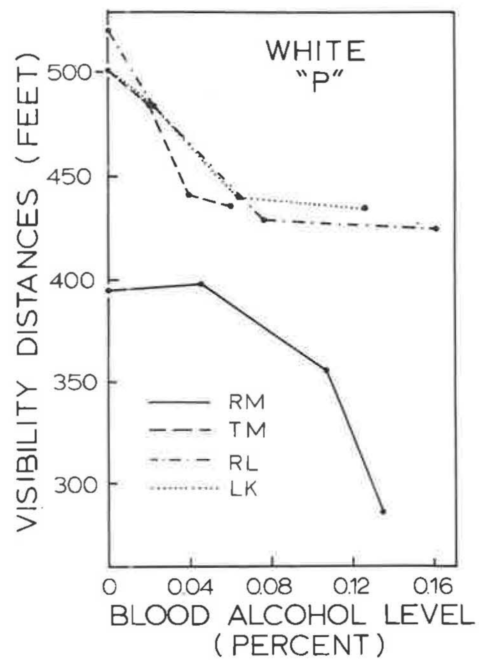

Figure 6. Mean visibility distances of white simulated pedestrian obtained by four observers at increasing percentage levels of blood alcohol.

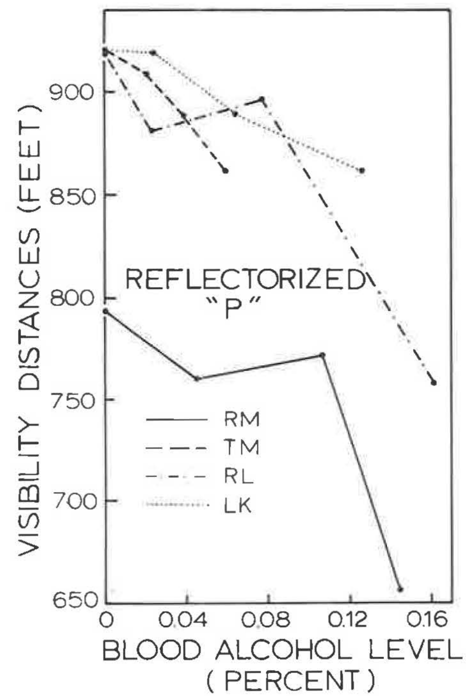

Figure 7. Mean visibility distances of reflectorized simulated pedestrian obtained by four observers at increasing percentage levels of blood alcohol.

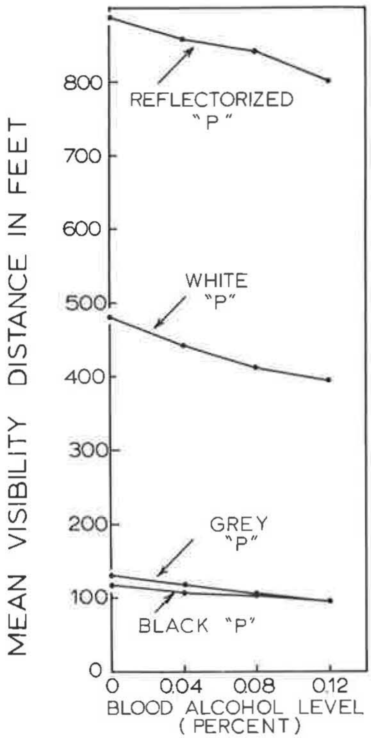

Figure 8. Mean visibility distances for black, grey, white, and reflectorized simulated pedestrian for all observers at increasing percentage levels of blood alcohol.

TABLE 1

CALCULATED CRITICAL VISIBILITY DISTANCES

Speed (mph)	Critical Visibility Distance (ft)
20	45
30	72
40	123
50	185
60	261
70	349
80	450

The results of the dynamic road test are shown in Figures 4, 5, 6, 7, and 8. In each graph the visibility distances are plotted against percent blood alcohol. Visibility distances found for both the black and the grey P's are shockingly short! Each data point represents the mean visibility distance for a given block of trials at the stated percent BAL. Although these graphs give an idea of the trends involved, there is doubt as to the appropriateness of using the mean when dealing with the topic of pedestrian safety. Although the mean visibility distance of the black P for all O's ranged from 115.2 ft with no alcohol to 90.4 ft at the high levels of blood alcohol, there were three of the black P's (out of the 176 presented to the four O's) that were not seen at all. Two were missed by one observer, and two of the three misses occurred before taking any alcohol. The visibility distance, for each test condition and for every O, generally decreased as the blood alcohol level increased. Learning no doubt took place as the tests progressed and the O's were in a high state of readiness for each trial due to group motivation; hence the measured visibility distances are probably greater than would be observed in the normal driving situation.

Table 1 gives the calculated critical visibility distances associated with 10-mph intervals of speed from 20 to 80 mph. Calculations were made for an automobile with safe tires and brakes traveling on dry pavement and driven by an individual with a reaction time of 0.75 sec.

TABLE 2

PERCENTAGE SAFELY VISIBLE BEFORE DRINKING

Type of P	Percent Visible at Given Speed (mph)						
	20	30	40	50	60	70	80
Black	86.4	68.2	45.4	15.9	0	0	0
Grey	100	100	47.2	13.9	5.5	5.5	0
White	100	100	100	100	97.2	91.7	52.7
Reflectorized	100	100	100	100	100	100	100

TABLE 3
PERCENTAGE SAFELY VISIBLE AFTER DRINKING

Type of P	Percent Visible at Given Speed (mph)						
	20	30	40	50	60	70	80
Black	90.8	63.6	15.2	0	0	0	0
Grey	97.2	73.2	14.2	2.7	0	0	0
White	100	100	94.4	88.9	80.5	61.1	25
Reflectorized	100	100	100	100	100	100	94.5

Table 2 gives the percentage of P's that were safely visible at distances greater than the critical visibility distance associated with the given speeds. The data are from four O's prior to the consumption of alcohol (BAL 0.00).

Table 3 gives the percentage of P's that were safely visible at distances greater than the critical visibility distance associated with the given speeds. The data are from four O's after the consumption of alcohol (BAL from 0.06 percent to 0.10 percent).

DISCUSSION

Visual Function During the Night Driving Task

The human eye is sensitive to a range of luminances of more than 10 billion to 1 (7). The adaptation level during night driving is within the mesopic or lower photopic range where contrast sensitivity is relatively poor (8). Glare, dark clothing, and the brief time available to see a pedestrian compound the problem. These visual disadvantages become more significant with age, lack of attention, the consumption of alcohol, etc.

Influence of Alcohol on Vision

Goldberg (9) reported that reduced fusion frequency begins at blood alcohol levels of 0.01 to 0.02 percent for abstainers, 0.02 to 0.03 percent for moderate drinkers, and 0.04 to 0.07 percent for heavy drinkers. Goldberg stated: "Alcohol has the same effect on vision as the setting of a grey glass in front of the eyes, or driving with sunglasses in twilight or darkness; a stronger illumination is needed for distinguishing objects and dimly lit objects will not be distinguished at all; when a person is dazzled by a sharp light it takes a longer time before he can see clearly again." This statement is supported by our findings.

Goldberg (10), Wayne (11), and Seedorff (12) report that moderate amounts of alcohol will induce nystagmus. Wayne (11) and Stewart (13) report a reduction in the visual field, while Colson (14) found no change in visual acuity or the peripheral visual field. A U.S. Air Force publication (15) states: "Alcohol in the system produces symptoms like those of hypoxia. The effect of alcohol in the blood is to make body tissues less receptive to the oxygen in the blood. Therefore, the oxygen that is present cannot do its work as effectively. Drinking reduces depth perception and ability to distinguish between different brightnesses, and it shrinks the visual field to some extent." Goodwin and his associates (16) have found that alcohol decreases visual acuity, increases esophoria for distance, decreases the amplitude of convergence and accommodation, and increases the increment threshold. They conclude: "The increases in the increment threshold which generally explain the decreases in visual acuity might have serious detrimental effects upon the detection of low contrast targets such as objects along the roadside at night." Our findings support this conclusion.

Pedestrian Visibility

"The word 'visibility' in common usage expresses the clearness with which objects stand out from their surroundings" (8). A pedestrian becomes visible either as a silhouette (negative contrast) or as an illuminated object against a dark background

(positive contrast). Automobile headlamps create mainly positive contrast while most street lighting creates a negative contrast.

Rumar (17) of Sweden, in commenting on the visibility of pedestrians, states: "A frequent argument in discussions about night driving is that the silhouette-effects offer very long visible distances. Careful experiments have shown that, normally, these effects are of no help within 1 m from the near edge of the road. Certain conditions such as snowy or otherwise very bright roads, inside bends, light fog, etc., favor the effect. Drivers can never be sure, however, that the road is free because no silhouette effects have appeared." Pedestrians walking in well-lit areas are generally more visible, but well-lit areas combined with automobile headlights will produce both positive and negative contrasts and may obliterate a pedestrian!

Another factor influencing the safety of pedestrians is that they frequently overestimate their own visibility. Because they have adapted to a low level of ambient illumination and thus perceive an oncoming vehicle quite easily, they may fail to appreciate the difficulty of the driver's detection task.

Considering the low visibility distances found for the black and the grey P and the effects of alcohol on vision, it is fair to agree with Rumar (18) that the majority of nighttime pedestrian fatalities do not belong strictly in the category of "accidents." When a pedestrian is first seen at less than the critical visibility distance, a detrimental change has occurred in the "system" for which there can be little compensation. A disastrous result can only deceptively be termed an "accident!"

SUMMARY

1. Laboratory tests show a decreasing contrast sensitivity with an increase in percent blood alcohol level.
2. Roadway tests show a decreasing ability to detect pedestrian-sized objects with increasing percent of alcohol in the blood.
3. Roadway tests without alcohol show that with low-beam headlights in an automobile traveling at 40 mph an alert healthy driver looking for a pedestrian-sized object will not see it soon enough more than 50 percent of the time if the object is covered with black or grey fabric. Pedestrian-sized objects covered with white fabric or grey fabric and a 1 by 11-in. reflective material will be seen soon enough, but as alcohol is introduced only the reflectorized object remains safely visible for a 40-mph speed.
4. Three of the black simulated pedestrians (out of the 176 presented to the four observers) were not seen at all.
5. A review of the 1965 pedestrian accident records for Indiana showed that 87 percent of the drivers at night said they didn't see the pedestrian in time. Only 11.8 percent of the daytime drivers made the same claim. At twilight 50 percent of the drivers claimed poor visibility of the pedestrian. Further, 23 percent of the nighttime drivers did not see the pedestrian until impact, if then.

CONCLUSIONS

1. The literature and the results of this pilot study indicate that pedestrians are very difficult to see at night even under the best of viewing conditions.
2. Alcohol is indicated in the literature and in these results as causing an interference in the visual mechanism further compounding the visual task of night driving. The modern borderline highway lighting becomes significantly more inadequate to the driver who has consumed alcohol.
3. Pedestrian visibility distances could be increased and some of the losses of perception due to alcohol could be counterbalanced by either raising all roadway illumination or by increasing the positive contrast of the pedestrian himself. It was noted in these experiments that a small amount of reflectorization was detected in time even by the significantly intoxicated person. (No opposing headlight glare was present in these studies.)
4. Further study of the pedestrian visibility problem in the presence of headlight glare and alcohol is needed. The literature indicates that there is an increased hazard if opposing headlights are in the driver's field of view.

5. Further study is needed to evaluate the effectiveness of specific devices and environmental control techniques designed for the promotion of pedestrian safety.

6. The public should be further educated as to the importance of visibility in accident causation, and the hazards of alcohol need further emphasis.

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