The Effect of Glare in Simulated Night Driving

RUDOLF G. MORTIMER*, Purdue University

Two experiments were carried out in the laboratory in which illumination and glare conditions in night driving were simulated. Steering accuracy was measured as the dependent variable. The interactions between roadway illumination, glare illumination, glare duration and glare frequency were investigated.

It was found that there were no differences in performance between the glare illumination levels used in these studies, and that the duration and frequency variables (which reflect traffic speed and density) required further clarification. Road illumination was clearly important as well as the overall effect of glare in tracking performance. The presence of high order interaction effects showed that the investigation of the glare phenomenon was complex.

It was suggested that the glare hazard and the problems of night visibility could be alleviated by increased reflectance of road surfaces and objects in the road. With respect to the glare source it was felt that the power of current headlamp units should not be decreased since this would lead to undesirable loss in road illumination. Headlamp units would require further redesign to reduce glare.

•A NUMBER of approaches are used in the study of highway accidents, none of which is entirely satisfactory. Laboratory investigations are frequently too specific in nature and lack the power of generalization, because accidents are caused by multiple factors. Thus, although vision is unquestionably important to vehicle operation few useful correlations have been obtained between vision and accidents. The survey approach, while yielding data of considerable interest pertaining to the cause of accidents, lacks the convenience and precision of controlled research and since it must obtain data after the accident has occurred, it must deal with inferences which would be difficult to validate.

Simulation mediates between the strictly laboratory study and the survey approach and has some of the advantages of both methods. Compared to laboratory studies of very specific aspects of behavior, simulation can measure relatively more complex responses as found in the actual driving task, thereby insuring more valid transfer of results. Its advantage over the survey method is that it allows accurate measurements to be taken of various facets of behavior with control over environmental and other factors for systematic investigations.

The extent to which a simulated task and environment should approach the real situation can only be decided when the scope of the behavior to be studied is known, but it is the basic psychological variables that have to be carefully considered in the design of all simulators for effective use. High physical fidelity of simulation may add little to the value of the device (4). Inasmuch as the major problem in the design of a general purpose driving simulator lies in the construction of the visual display, it should be apparent that a night driving simulator could be a relatively simple device. This is

*Now at Research Laboratories, General Motors Corporation, Warren, Michigan.
Paper sponsored by Special Committee on Night Visibility and presented at the 43rd Annual Meeting.

because the visual display in night highway driving is relatively bare, and at mesopic luminance levels resolution is comparatively poor. The wealth of detail present in daytime driving is not visible at night and the task becomes, basically, one of tracking the road and maintaining vigilance for obstacles upon it, including the maneuvers of other traffic. The principal limitations to night driving visibility would appear to be the luminance of the road and objects in the road and the effects of glare from the headlamps of approaching vehicles.

The studies reported seek to investigate the interaction of the latter variables using a simple simulation device.

METHOD

Two experiments were carried out in a sequential order and they are described in detail by Mortimer (3). However, since the major findings of these studies were essentially similar, the present paper will report the details of only one of them.

Apparatus

The apparatus consisted of a tracking device in which a simulated gray roadway (reflecting 27%), 3 in. wide, was attached to a continuous, black, neoprene conveyor belt (reflectance 9%), 42 in. wide and 46 ft long, mounted on a series of rollers driven by an electric motor (Fig. 1). The roadway described a complex sine wave course. By means of a steering wheel which acted as a velocity control the student subjects

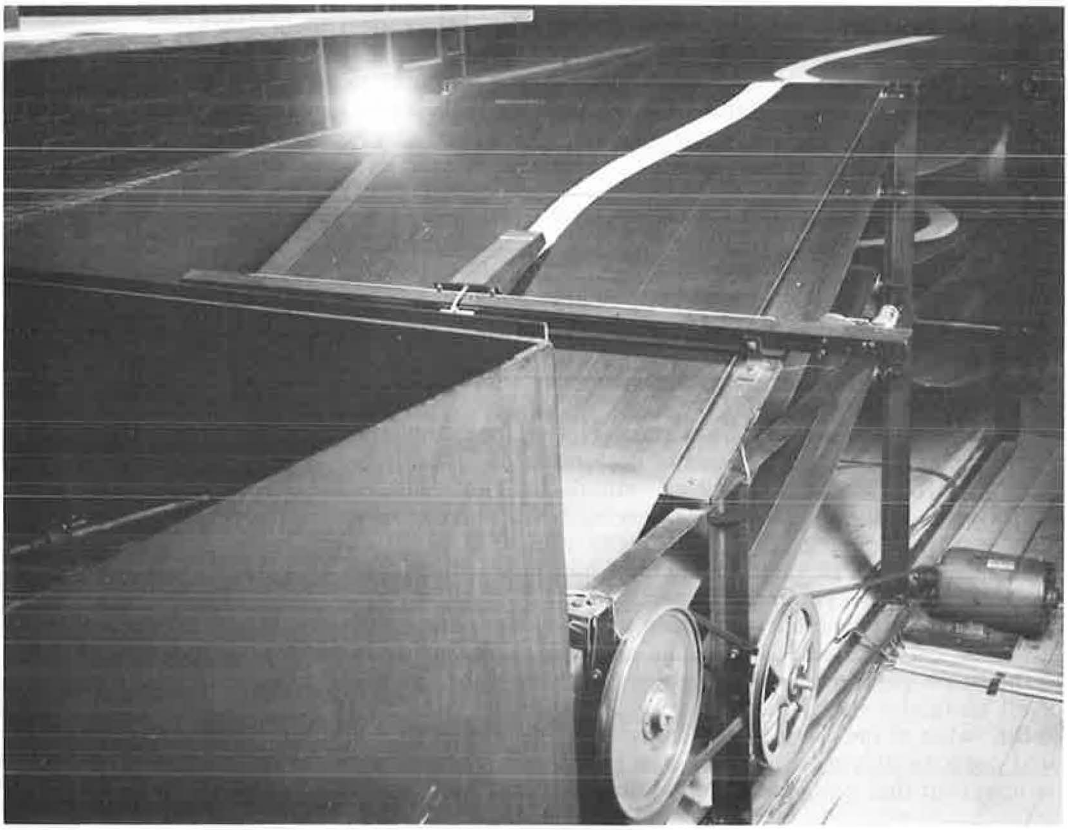

Figure 1. The roadway conveyor with the cursor above the simulated road; driver's cab is partly visible on the left, a glare light is on the glare conveyor.

controlled a 3-in. wide cursor which was free to move laterally across the conveyor in response to the steering input. The subject's task was to maintain the cursor above the moving gray roadway, tracking errors being electronically scored in terms of the time and distance that this alignment was not kept within some tolerance limit.

On the subject's left was another conveyor system which carried four lights that moved toward and past the subject, and simulated the headlamps of oncoming vehicles. Shadowless roadway illumination was provided by a source mounted on the roof of the driver's cab. The apparatus and the room in which it was housed was painted a flat black to minimize reflected light. The experimenter's booth was in the same room but partitioned off from the other apparatus. All experimental events during a trial were automatically programmed.

Independent Variables

The values of roadway illumination and glare illumination to be used in the experiments were obtained by taking readings at night using an actual vehicle and observing the road illumination at various distances from it produced by the headlamps, and by observing the glare illumination at the eye position from oncoming vehicles. All readings were made using a Weston light meter. The measures that were obtained corroborated those reported in the literature (1, 7). The variables of interest and the value of the levels of each were as follows:

1.	Roadway illumination (I)	I_1 = 0.10 ft-c
		I_2 = 0.60 ft-c
2.	Glare illumination (G)	G_1 = 0.30 ft-c (mean)
		G_2 = 0.90 ft-c (mean)
3.	Glare duration (D)	D_1 = 7.3 sec
		D_2 = 14.6 sec
4.	Glare frequency (F)	F_1 = 1/min
		F_2 = 2/min
		F_3 = 4/min

Subjects

Fourteen male college students were paid for serving as subjects. None wore corrective lenses and all had better than 20/20 vision.

Experimental Design

A complete factorial design was used. A subject received all combinations of the levels of the four factors ($2 \times 2 \times 2 \times 3 = 24$) and two additional treatments, in which glare was not present, for a total 26 treatments. Each treatment was received once and the order of presentation was randomly determined. There were two replications (R) of the experiment with 7 subjects in each replication. In the second replication speed was 11 percent greater than in the first.

Procedure

Each subject served for 7 consecutive days for one hour each day. The subject was seated in the driver's chair and its height adjusted until a specified area of the cursor and display were visible—the same for all subjects. Subjects were read the instructions. The room lights were turned off and the conveyor systems set in motion. A driving condition was then presented, as required by the experimental plan. When the roadway was illuminated, it was the subject's signal that the trial had begun and he would commence tracking by maintaining the cursor over the roadway with appropriate movement of the steering wheel.

A trial lasted 12¼ min with the last 12 min only being scored. There was an intertrial interval of 2 minutes. The first two trials were used to allow the subject to become familiar with the apparatus and procedure.

RESULTS

The data were analyzed by obtaining mean tracking error scores for the first and last six minutes of scored steering performance in each trial. Figures 2, 3, 4 and 5 show the interaction of driving time with the other variables. Low road illumination, long glare duration and high glare frequency led to performance decrements. Differences between glare intensity levels were slight. Figure 2 also shows that large improvements in tracking were found in the no-glare treatment (I_1 no-glare) and when illumination was raised (I_5 no-glare) to 12.5 ft-c to simulate a low daytime level.

The analysis of variance of these data is shown in (Table 1) in abbreviated form by presenting only the significant effects and their error terms. The main effects for

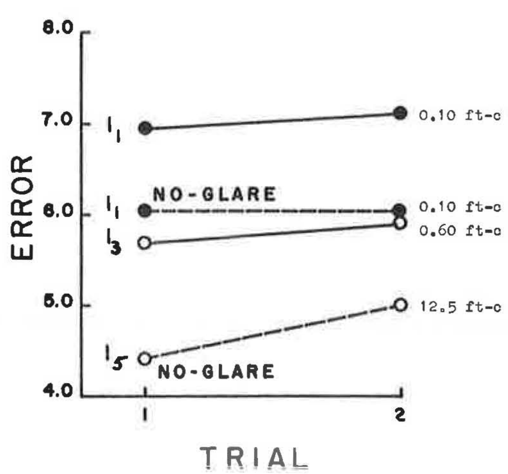

Figure 2. Mean tracking error as a function of roadway illumination and trial periods.

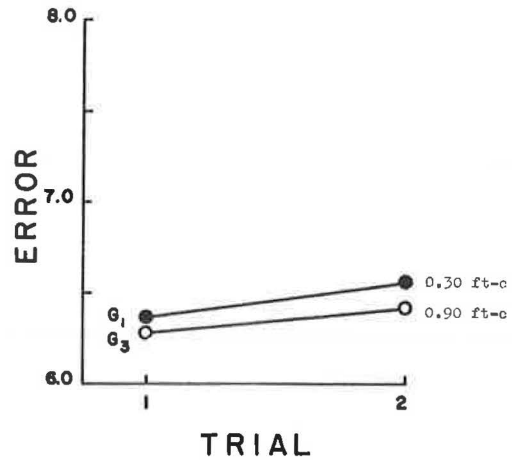

Figure 3. Mean tracking error as a function of glare illumination and trial periods.

Figure 4. Mean tracking error as a function of glare duration and trial periods.

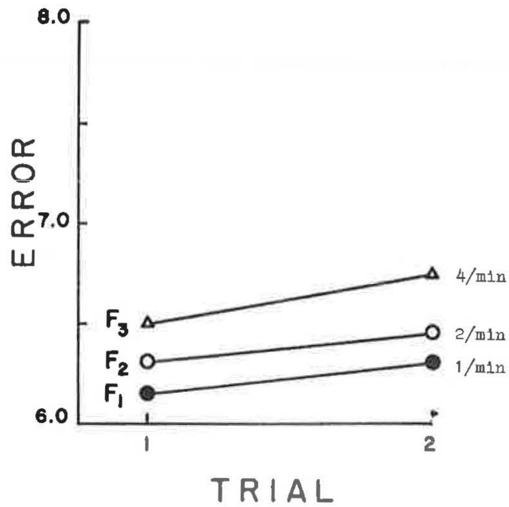

Figure 5. Mean tracking error as a function of glare frequency and trial periods.

TABLE 1

ABBREVIATED SUMMARY OF THE ANALYSIS OF VARIANCE

Source	df	MS	F
Road illumination (I)	1	257.102	90.656[a]
Glare duration (D)	1	13.070	4.830[b]
I × R	1	22.947	8.091[a]
I × D × R	1	27.905	9.839[a]
Error	372	2.836	-
D × G × F × R	2	26.774	6.336[a]
D × G × F × Ss in Reps	24	4.225	-
I × G × F × R	2	29.845	5.275[b]
I × G × F × Ss in Reps	24	5.657	-

[a]Denotes significant at less than 0.01 level.

[b]Denotes significant at less than 0.05 level.

road illumination and glare duration were significant. The I × R (road speed) and D × G two factor interactions, I × D × R three factor interaction, and the I × G × F × R and D × G × F × R four factor interactions were significant.

CONCLUSIONS

On the basis of this experiment it is noted that the effects of glare are complex as shown by the presence of high order interactions. This makes it difficult to provide clear-cut interpretations of results. However, it was seen that a large decrement in tracking accuracy occurred due to the overall effects of glare from the lights of simulated approaching vehicles. Glare can then be considered to be a potential hazard in the night driving situation. When glare was not present in the simulated night driving task, the reduced illumination available from vehicle headlights, as compared to low daylight levels, caused a marked decrease in tracking accuracy. The effect of roadway illumination in the presence of glare was also seen to be quite large. When illumination was reduced to 0.10 ft-c the decrement in performance was highly significant compared to the 0.60 ft-c level. Thus, roadway illumination between levels of 0.10, 0.60, and 12.5 ft-c as used in this study had a decided effect on tracking efficiency under both glare and no-glare conditions. As illumination was raised, performance improved.

The main effect of glare duration was significant with 14.6 sec of glare causing greater decrement in performance than 7.3 sec. But, the signficant high order interactions in both studies showed that the difference was specific to relatively few treatments so that there was no practical effect of glare duration for the levels used.

The glare frequency of 4 per minute resulted in poorest performance compared to lower frequencies. However, few significant differences were found in the analysis of simple effects of the complex interactions so that the effect of the frequency variable was probably not marked.

Both the glare duration and frequency variable would require further systematic investigation.

There was practically no differential effect attributable to the levels of glare illumination employed. This finding suggested that increasing levels of glare intensity have little effect beyond some minimal level and up to some maximum that was not attained in this study. In the field studies (5), it was found that the glare from the first few hundred candlepower of approaching headlights reduced visibility distance sharply, with a relatively decreased effect as beam candlepower was increased. These two sets of data pose an immediate problem in the alleviation of the glare phenomenon in night driving. It would appear that glare levels will have to be drastically reduced below some minimal intensity in order to be effective. Since it would be undesirable to reduce headlamp intensity due to the concomitant loss in road illumination, it would be necessary either to increase road illumination by some means without increasing glare, or to reduce glare without reducing road illumination. This has, of course, been the aim of headlamp lighting engineers who have attempted to reach a compromise between glare and road illumination by the design of optimal beam patterns. Our results have shown that reduction in headlamp intensity should be avoided since the road illumination variable was at least as potent as the glare factor and is operative under conditions of glare and when no glare is present.

One relatively simple means by which visibility of the roadway can be increased is to increase the reflectance of the surface. Concrete roads range from 25 to 50 percent in reflectance whereas black top has a reflectance of about 10 percent (2). Roper (6) has shown that an increase in reflectance of 3 to 14 percent of a dummy placed at the side of the road, for a driver not expecting the obstacle and at a car speed of 50 mph, doubled the distance at which it became visible. The recommendation from such data and from this study is to increase the reflectance of vehicles, pedestrian clothing and the roadway itself.

Finally, it may be suggested that since some correspondence between the results of this simulation approach and those from studies using actual vehicles has been found the simulation method may be useful in further studies to evaluate engineering, environmental and driver variables in night driving. This is not to say that proper validation of simulation methods is not important. On the contrary, it is a prime requirement to determine the transfer characteristics of laboratory driving simulators. With proper design, reasonable transfer should be attainable and establish the simulator as a valid and useful research tool.

ACKNOWLEDGMENT

This research was supported by the U. S. Public Health Service, Grant AC-87, from the Division of Accident Prevention.

REFERENCES

1. Finch, D. M., "Lighting Design for Night Driving." Illum. Eng., 45:371-386 (1950).
2. Miles, P. W., "Visual Effects of Pink Glasses, Green Windshields, and Glare Under Night Driving Conditions." A.M.A. Arch. Ophthal., 51:15-23 (1954).
3. Mortimer, R. G., "The Effects of Glare in Simulated Night Driving." Unpublished doctoral dissertation, Purdue Univ. (1963).
4. Newton, J. M., "Training Effectiveness as a Function of Simulator Complexity." NAVTRADEVCEN Tech. Rept. 458-1 (1959).
5. Roper, V. J., and Meese, G. E., "Seeing Against Headlamp Glare." Illum. Eng., 47:129-134 (1952).
6. Roper, V. J., "Aiming for Better Headlighting." HRB Bull. 191, pp. 49-52 (1958).
7. Schmidt, I., "Are Meaningful Night Vision Tests for Drivers Feasible?" Amer. J. Optom., 38:295-348 (1961).
8. Winer, B. J., "Statistical Principles in Experimental Design." McGraw-Hill, New York (1962).