ATTENTIONAL DEMAND AS A MEASURE OF THE INFLUENCE OF VISIBILITY CONDITIONS ON DRIVING TASK DIFFICULTY

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Six drivers were required to negotiate a slalom course at an automatically controlled speed (30 or 45 mph) while wearing goggles fitted with various neutral-density filters and a motorcycle helmet with a gas piston-operated translucent face shield. The face shield could be moved from its normally occluding position for a ½-sec "look" by means of a foot switch accessible to the driver. Attentional demand as measured by frequency of looks increased significantly with increasing goggle density at both 30 and 45 mph. The effect of the goggles on attentional demand was stronger at 45 than at 30 mph and for frequently looking than for infrequently looking subjects. Within subjects (error) variability was very low. Other measures of performance were not influenced by the goggles. It was concluded that attentional demand provides a measure of control task difficulty or operator skill to which conventional measurements may be insensitive.

•THE PURPOSE of this experiment was to evaluate the vision interruption apparatus (VIA), developed by Senders (2), as a method of measuring the sensitivity of drivers to degraded visibility conditions in steering and control tasks. The VIA consists of a helmet with a movable translucent face plate that can be controlled to periodically interrupt the driver's vision. A recent review of the literature (1) has revealed no data demonstrating a relation between night visibility conditions and driver steering-tracking performance measures. This is not surprising for it is frequently difficult in tracking tasks to demonstrate an objective decrement in performance in response to degraded operating conditions. This is especially true where the basic control task is undemanding. In such cases, it is presumed that the operator compensates for degraded conditions or increased task difficulty by attending more intently to the control task, with the result that his output remains constant under a wide range of conditions. Under more difficult conditions, however, a driver is closer to the limits of performance and is presumably less able to respond to sudden increases in task load.

Attempts have been made to measure "spare capacity" or its complement, "attentional demand," by means of subsidiary tasks. However, this approach has not been generally successful in driving research. A direct measure of attentional demand is provided by the VIA. In experiments with the VIA the driver, under instructions to look as infrequently as possible, determines his own visual sampling rate by controlling the movement of the face shield with a foot switch. In earlier research, Senders (2, 3) demonstrated that attentional demand, defined in terms of looks per unit time, depended on the apparent difficulty or complexity of the driving task.

In the present study, the VIA was used to obtain a measure of the attentional demand associated with degraded visibility conditions roughly approximating poor nighttime highway lighting conditions. The study was performed during the day, and the degraded visibility conditions were produced by goggles with neutral-density filters. The light-

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reducing goggles do not produce for the viewer a scene that is phenomenologically equivalent to the normal nighttime scene; they do, however, produce a qualitatively similar degradation of visibility.

METHOD

Test Vehicle

The test vehicle was a 1970 Plymouth Fury 440 equipped with power steering, power disk brakes, automatic transmission, 380-hp engine with 440-in.^{3} displacement, and a speed-control device. The speed-control device when activated at a given speed will maintain that speed to within 2 mph. The car was instrumented to record time, speed, distance, lateral acceleration, and VIA face-shield activations, i.e., "looks."

Visual Interruption Apparatus

The VIA consists of a motorcycle helmet whose face shield can be moved up or down by means of a gas-operated piston mounted on the helmet. The piston is activated by a solenoid valve whose switch is accessible to the driver's left foot. The shield was spray-painted to render it translucent. During testing the normal position of the shield was down (the occluding position). Depressing the solenoid switch drives the helmet to the up (seeing) position for ½ sec during which time the switch is inactive. To obtain repeated looks, the driver must wait for the helmet to return to the down position before depressing the switch again. As a safety measure, an up switch was incorporated into the horn ring. Depressing the horn ring drives the shield to the up position and locks it there. The experimenter's control unit also incorporated a safety switch to lock the shield in the up position.

Goggles

The illumination reaching the driver's eye was varied through the use of neutral-density filters (Eastman Kodak 96, 3-in. gelatin) cut to fit the 50-mm lens hole of Bausch and Lomb S-84P goggles. These goggles have opaque side panels and can be adjusted for a snug fit with no light leaks. The 3 densities of the filters were 0.0 (100 percent transmittance), 2.6 (0.25 percent transmittance), and 3.6 (0.025 percent transmittance). The actual transmittance values were probably about 10 percent less than the nominal values, but the difference was not felt to be important.

Test Site

The tests were conducted in the northbound direction of a 1.4-mile unopened length of I-95 in Philadelphia. The roadway (3 lanes and shoulders) is 48 ft wide. Ambient illumination in the direction in which the trials were run was consistently around 1,000 ft-C. A course consisting of four 0.10-mile long traffic-cone slaloms was set up with 0.10-mile separations between slaloms. Each slalom consisted of five 2-cone gates.

Subjects

Six test subjects were used. All were men under 30 years of age. Three were college students, and 3 were technicians employed at the Franklin Institute. All claimed to have 20/20 vision, but this was not verified.

Procedures

The subject's task was to drive the slalom course at an automatically controlled speed without hitting any of the traffic cones. Subjects were told that they would receive bonus pay for good scores and that a good score depended on both minimizing looking time and not hitting any traffic cones. Prior to the start of formal testing, each subject had 5 practice trials without the goggles to familiarize himself with the course, the car, and the operation of the VIA. During formal trials, subjects wore the goggles fitted with neutral-density filters and the VIA helmet. Subjects were permitted to adapt to the higher density goggle conditions for 30 min before the start of trials with those goggles. At the start of a trial the subject accelerated to the assigned speed for that trial and then activated the speed-control device. He then negotiated the slalom course by using the foot switch to obtain ½-sec looks as required.

Experimental Design

Each subject had 4 replications of each of 6 speed-goggle combinations for a total of 24 trials. There were 2 speeds (30 and 45 mph) and 3 goggle conditions as described above. For each driver, speeds were alternated from trial to trial in the order of 30-45, 45-30, and 30-45. Order of presentation of goggle density was partially counterbalanced. Three of the 6 subjects had condition 3 first, one had condition 1 first, one had condition 2 first, and one had only conditions 2 and 3 in that order.

RESULTS AND DISCUSSION

Figure 1 shows the mean percentage of looking time (attentional demand) for each subject at 30 and 45 mph as a function of goggle density. Percentage of looking time is given by

$$P = (N/2T) \times 100$$

where N is the number of ½-sec looks and T is the total time of the trial. Table 1 gives the results of an analysis of the variance of these data. All of the main effects and all of the 2-way interactions were significant. Attentional demand increases with increasing goggle density and is greater at 45 than at 30 mph. Also there were large and consistent differences between subjects. The effect of the goggles was clearly more pronounced at 45 than at 30 mph and for frequently looking than for infrequently looking subjects. Further, the more frequently looking drivers were more affected by speed. Although there was increase in the percentage of looking time from 30 to 45 mph, the increase was less than would have been obtained had looks per unit distance been the same at the 2 speeds.

A striking feature of the results was the extremely low error variability; although there were large and reliable differences among subjects, the performance of individual subjects was highly consistent under a given set of conditions. Further, the ordering of the subjects changes little across the speed and goggle conditions as reflected in the low 3-way interaction term.

The goggle conditions had no effect on 2 other performance measures: "smoothness," as measured by peak lateral acceleration values, and frequency of traffic-cone knockdowns. In fact, only 1 traffic cone was struck during the entire course of the experiment. Figure 2 shows mean peak lateral acceleration as a function of goggle density for the 4 subjects on whom lateral acceleration data were obtained. The mean peak acceleration value was obtained for a given subject and set of conditions by averaging across replications the peak lateral acceleration values associated with the same slalom gate. Because the speed was automatically held constant during a trial, the peak lateral acceleration value is almost solely a function of path and is taken as a measure of smoothness. Neither at 30 nor at 45 mph was there any systematic relation between lateral acceleration and goggle density. However, the 2 subjects who had the highest lateral acceleration scores (RD and WS) also had the highest attentional demand scores.

These findings suggest that, for a given driver, attentional demand is a reliable indicator of task difficulty as mediated by visual conditions and that, on a given task, attentional demand scores reflect driver skill. In these terms the results can be summarized by saying that visual degradation increased the difficulty of the vehicular control task but that the more skilled drivers were less affected.

CONCLUSIONS

The results of this experiment indicate that, by quantifying attentional demand, the VIA provides a measure of visual task difficulty to which conventional performance

Figure 1. Looking time as a function of goggle transmittance.

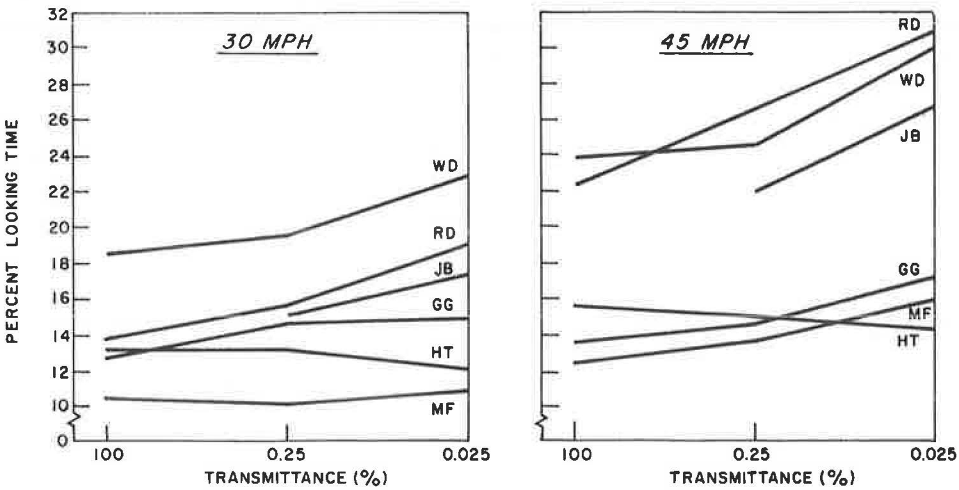

Figure 2. Lateral acceleration as a function of goggle transmittance.

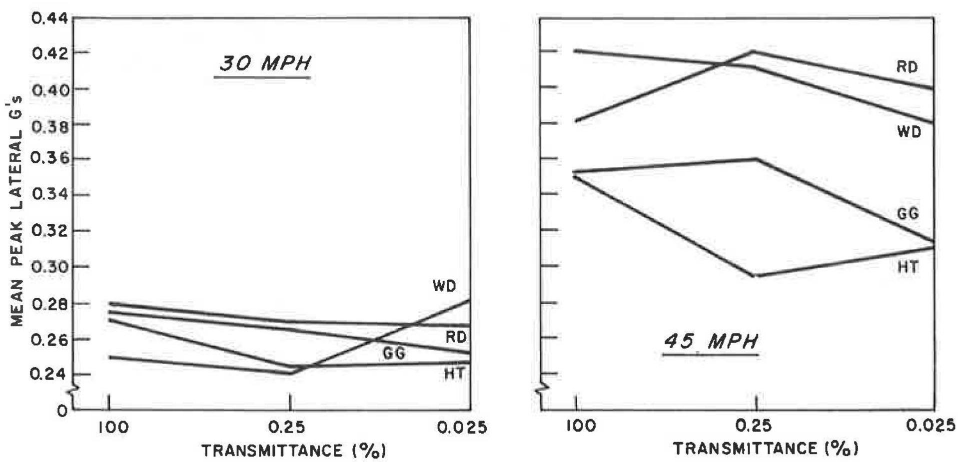

Table 1. Analysis of variance.

Source	SS	df	MS	F
Subjects	2,327	4	582	183.01
Goggles	205	2	103	32.38
Velocity	666	1	666	209.43
Subjects × goggles	162	8	20.25	6.36
Subjects × velocity	339	4	85	26.7
Velocity × goggles	26	2	13	4.09
Subjects × velocity × goggles	11	8	1.4	0.44[a]
Within	286	90	3.18	—
Total		119		

Note: Data for subject J.B. not included in analysis of variance.

[a]Not significant.

measures may be insensitive. More generally it is felt that the concept of attentional demand, as measured by the VIA or similar device, is applicable as a basic measuring tool to any research in which driver performance provides the criterion measure. In particular, the results of this study indicate that the VIA can be used to measure the influence of night visibility conditions on the difficulty of the driving control process.

REFERENCES

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DISCUSSION

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The authors conclude that their tests have demonstrated (a) that the VIA provides a measure of visual task difficulty and (b) that it provides a basic measuring tool for determining the loading effects of certain physical conditions on driver performance. Going one step further, this technique could provide a standardized measuring tool for comparing the difficulty of various driving tasks that relate strongly with attentional demand, e.g., traffic situations.

There are a few points that deserve special comment. There is the general problem of working with conditions that are both realistic and meet the experiment's requirement of having the drivers operate with some spare capacity in performance response. The authors say very little about the design of the experiment as it relates to this problem.

In connection with real roadway nighttime lighting conditions, it can be shown how the conditions used in the experiment relate to design requirements. The values listed below show that lighting conditions are roughly equivalent over a wide range.

Roadway	Design Illumination Range (ft-c)	Experiment Transmittance (percent)	Perceived Illumination (ft-c)
Local urban-major urban	1.0-2.0	0.25	2.5
Minor residential-rural freeway	0.2-1.0	0.025	0.25

From the fact that the low illumination condition (0.025 percent) is close to the recommended safe lower design limit (minor residential), it can be inferred that this condition used in the experiment represents a safe approach toward the lower limit of driving visibility.

Two results of the work point out that the subjects in fact were not operating close to their performance limits. First, an increase in speed did not require any increase in the number of looks. Second, extremely few cones were knocked down.

On the effect of velocity, it would seem that some further comments can be made. When based on the number of looks for the given distance of the course, there is no significant difference between the average obtained for the runs at 35 mph and that for 45 mph. Therefore, issue is taken with the authors' statement that attentional demand is greater at 45 mph. Their results show that total demand for both speeds is equal.

This difference in interpretation raises a related question. How does the ½-sec look compare with attention spans during various driving tasks? Some insights on this question might be gained by varying the length of the look from ½ sec.