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WINDSHIELD DAMAGE AND DRIVING SAFETY

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16. **Abstract**

Three tasks concerned with windshield damage and driving safety were completed. First, a review of the literature revealed abundant information on general problems of visibility and the assessment of windscreen optical quality, but little information specifically pertaining to windshield damage.

Second, the available accident data were analyzed. While the evidence is tenuous and sparse, there were no indications that windshield damage has been a causal factor in accidents. Only in the CPIR computerized accident file has windshield condition been coded, and in that file only two vehicles had pre-crash windshield damage. In neither case was it a causal factor.

Finally, in a two-choice response time experiment, sixteen drivers viewed slides of nighttime road scenes through four different windshields. Drivers were asked to indicate if it was "safe to proceed" (or not) by pressing buttons. Increasing the degree of windshield damage led to increases in response time, especially when a light simulating the glare of an oncoming vehicle's headlamps was present. This last result suggests to the authors that windshield damage is a visibility problem that should receive more attention from drivers and safety organizations.

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TABLE OF CONTENTS

LITERATURE REVIEW[1]

The relationship between windshield design and injuries from occupant impact with them has been a topic of considerable research, both at the Highway Safety Research Institute (HSRI) (Huelke, Grabb, and Dingman, 1964, 1966, 1967; Huelke, Grabb, Dingman, and O'Neal, 1968; Huelke, Grabb, and Gikas, 1966; Huelke and Sherman, 1975) and elsewhere (e.g., Patrick, 1967; Begeman, King, Weigt, and Patrick, 1978). This report focuses on a related and less well-researched question -- Do damaged windshields cause accidents by interfering with driver vision?

Three topics are addressed in this section: how windscreen optical quality has been measured, general and related problems of driver vision, and studies focusing specifically on windshield damage.

Measurement of Windscreen Optical Quality

The research literature offers several approaches to the evaluation of the optical quality of windshields, including driver acuity studies, subjective ratings, physical measures of similarity to standards, and modulation transfer function measures. Most of these approaches are more appropriate for wide-area distortions than localized windshield damage, the interest of this report.

The Chrysler Corporation proposed a method that combines subjective ratings generated by juries of engineers with some objective, quantitative measures (Anonymous, 1963). Two properties in which Chrysler expresses interest are "daytime distortion" (due to an image appearing displaced from its true position) and "dual vision" (resulting

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[1] This section is an expansion of the literature review contained in the proposal for this project (Green, 1980). The previous material has been revised, and recent research findings have been added.

from the internal reflection between the two surfaces of the windshield). While the optical issues are described in great detail, the mechanics of the rating procedure are unclear.

Kerkhof (1962) suggests that windscreen quality can be assessed by having subjects view Landholt C's, Snellen E's or some other acuity target directly through a windshield. The difference in subjects' performance in identifying targets through different windshields is a measure of their relative optical qualities.

A method proposed by Kohler (1973) requires photographs of a standard (reference) windshield and of a distorted (test) windshield. The similarity of the two photographs is the proposed measure of optical quality. However, the computation suggested for this similarity measure is difficult to understand.

Several other studies have looked at the optical qualities of non-automotive windscreens--in particular, those in the F-111 aircraft (Gomer and Eggleston, 1978; Ward, Defrances and Eggleston, 1979). In general, the researchers found no single objective measure that completely accounted for the variance of subjective ratings. They suggested that multiple, independent assessments were needed.

Finally, a quite different approach is to examine the Modulation Transfer Function (MTF) of a windshield (Merritt, Newton, Sanderson and Seltzer, 1978). Most often, the area under the MTF curve serves as a measure of the quality of the windshield. This function has been found to characterize quite accurately the quality of an image presented on cathode ray tubes and other types of electronic displays (Almagor, Farley and Snyder, 1978; Biberman, 1972; Snyder, 1976). Also, Merritt, Miller and Kerr (1980) found substantial relationships between contrast transfer values obtained with a real-time electro-optical system (the "Visibility Quality Meter" (VQM)) and those reported by individual subjects across several types of windshield degradation. Merritt et al. suggested that the VQM "stand in" for the average human eye in measurements of visibility. However, one of the assumptions of the theory underlying the MTF approach is that the visual field is homogeneous. Once again, as a cracked or damaged windshield is extremely heterogeneous, this approach is not appropriate here.

Related Problems of Driver Vision

Besides methodological studies, a wide range of studies deal with more substantive topics in visibility and field-of-view requirements for drivers. Relevant topics in the visibility literature include:

1. **The importance of driver position.** Allen (1962) reported that the average driver tends to sit very near to the left door. This lateral positioning increases the obstruction of the left A-pillar. It may also increase windshield distortions due to the increased angular displacement. Furthermore, in addition to lateral positioning, what drivers can see from a vehicle is greatly influenced by their height (Heath and Finch, 1952). An implication of these studies is that in experiments concerning visibility, driver head position should be measured and/or controlled.

2. **Mirror placement and design.** Mirrors can affect visibility in at least two ways. First, poor placement of mirrors (inside or outside) can obstruct the driver's line of sight significantly (Allred, 1978). Second, mirrors must be placed to minimize "blind spots" to the rear and sides of the vehicle, and thereby increase the overall field-of-view of the driver (Kaehn, 1976). To a limited degree, the vision problem of

windshield damage is similar to other problems that introduce blind spots in the field-of-view.

3. **Visibility loss due to spectacle frames.** Bewley (1969) claims the style and size of spectacle frames worn by drivers may reduce the field of vision below minimum safety standards. Furthermore, some frames may interfere both with peripheral and central vision (Smith and Weale, 1966). Neither the absolute or relative levels of this type of interference are known.

4. **Windshield wiping systems.** During rain the primary factor reducing visibility is the water film on the windshield (Morris, Mounce, Button and Walton, 1977). However, wiper mechanisms can also obstruct a driver's vision. They should be designed to avoid obstruction of certain "critical areas," particularly next to the left A-pillar and the central region of the windshield (Sutro, 1957; King and Sutro, 1954). The extent to which these factors interfere with vision relative to those mentioned previously has not been assessed.

5. **Heat-absorbing and tinted windshields.** Two studies performed at HSRI compared clear windshield glass with tinted glass (Bernstein, 1976; Filkins, 1979). In the first study, using a complex headlight visibility model, only small differences in detection distances were found between clear and heat-absorbing glass. Likewise, in his investigation of tinted windshield involvement in accidents, Filkins found little difference between the two windshield types. Damaged glass may be a greater hazard.

6. **Importance of zones surrounding the vehicle.** Smith, Bardales and Burger (1973) found that drivers attached greater importance to zones to the right of a driver than to the left. These zones included

areas to the sides and rear of the vehicle. The authors concluded that the higher weightings given to the right-hand zones were primarily due to the greater difficulty to see those zones (reduced field-of-view). This suggests that when evaluating the effect of damaged windshields, one must be concerned with the location of the damage relative to the driver's line of sight. (See also Smeed, 1953; Society of Automotive Engineers, 1973 for general information on field-of-view.)

7. **Efforts to develop a Figure-of-Merit for visibility.** Some attempts have been made to take field-of-view input variables and manipulate them to produce a single "Figure-of-Merit" describing the quality of the field. Baruoski, Maurer, and Kugler (1969) developed such a model and found that poor mirror/pillar placement, little head room, and high dashboard profile were frequent problems that decreased the Figure-of-Merit for forward visibility. However, Ponce (1973) found no association between paired rankings of visibility Figure-of-Merit and vehicle accident rates. In neither of these models is windshield damage a factor.

Windshield Damage and Degradation

Relatively little information exists on windshield breakage and its effects on driver performance (information which would be more directly relevant to the current issue). The few studies that have been performed are described in this section.

Although Rodloff and Breitenburger (1967) concentrated on the penetration resistance of various types of windshields, they noted that bright sunlight through cracked windshields impairs vision far more than headlights at night, though no data are presented. This suggests that glare angle should be manipulated in studies of driver performance with damaged windshields.

Hoffman (1973) reports two studies investigating situations where windshield breakage (caused by the impact of some external object) results in an immediate accident. In the first, 3 out of 305 windscreen-impact incidents resulted in accidents. In the second, 3600 incidents resulted in 4 cases of injury and 4 cases of property damage only. Thus, the impact of an object with the windshield rarely becomes the direct cause of an accident. However, Hoffman does not discuss the problem of "non-immediate" accidents that result from windshield damage interfering with vision.

A major survey of accident causation was conducted by Burger, Smith, Queen, and Slack (1977). Included in that study were several questions concerned with driver vision (the effects of inclement weather, glare from other vehicles' headlights, obstruction from mirrors, pillars, etc.). Conspicuous by their absence were any questions addressing the problem of windshield damage.

Treat (1980) provides an excellent summary of his Indiana Tri-level study, one of the few recent in-depth studies of accident causation. Vehicle-related vision obstructions were cited as a causal factor in about one percent of all accidents. Windshield damage was not implicated as a factor. "Windshield obstructions due to ice, frost, water, etc. on windows were the primary vehicle-related vision obstructions. In a small proportion of these accidents, deficient defrosters, wipers, and mirrors were implicated" (Treat, 1980, p. 16).

To understand the scope of the damage problem, it is important to know how often windshield damage occurs. Wright (1974) examined windshield breakage after British roads were resurfaced with a loose material (that could be picked up and thrown by the tires of passing vehicles). Estimates were that windshield breakage occurred at a rate of .33 per 100,000 vehicle kilometers. In a study by Millard (1970), referenced by Wright (1974), a rate of one per 480,000 vehicle kilometers is offered.

A somewhat more detailed examination of the windshield breakage problem appears in a study by Farr (1977). In that study questionnaires were completed by 1493 drivers who had damaged windshields. Shown in Table 1 are the reported causes of breakage.

TABLE 1

Causes of Breakage

STATED CAUSE OF BREAKAGE	LAMINATED WINDSHIELD	TEMPERED (Toughened) WINDSHIELD
"Stone"	76	836
"Hit something before breakage"	2	29
"Collided with something after breakage"	0	2
"Cause unknown"	23	479
"Other causes"	3	38
"No reply"	1	4
Total	105	1388

From Farr (1977).

Of the drivers questioned by Farr, 9 out of 10 experienced no difficulty in stopping safely immediately after a windshield fracture and only a fraction of a percent collided with anything after the windshield (tempered) was shattered. Most of the breakages occurred at high vehicle speeds either on divided or first class highways.

An interesting and important finding from the Farr study was that drivers tended to replace damaged windshields with tempered glass rather than laminated glass, because it cost half as much. Occupant impact injuries from laminated windshields are generally much less severe than those from tempered windshields, since laminated windshields are harder to penetrate (Olson, note 1). Clearly, this is one argument for including windshield replacement in full insurance coverage (and not only as a deductible item).

Glare is a common problem that can be intensified by windshield damage or obstruction. Allen (1974) performed several studies concerning the effects of windscreen dirt and surface scratches. In one, the veiling glare from 40 automobile windshields in the Melbourne community was recorded by using a sophisticated photographic procedure. (These windshields were exposed to abrasive dust from the brakes of the local trams, and surface damage was greater than normal.) Measurements were taken of both clean and dirty windshields and at several locations on each windshield. Mean veiling luminance indexes of .16 from hand-cleaned, .54 from dirty, and .82 from wiper-damaged windshields were reported. Allen suggests that a few deep scratches in a windshield are less of a visual problem then numerous fine scratches. This implies that for broken windshields, windshield-generated glare may be a serious problem only when the damage is substantial.

In subsequent static tests conducted by Allen, drivers counted the number of test targets visible while being subjected to the glare of an oncoming car's headlamps. While detection distances interacted with the distance of the glare vehicle, the windshield condition had a marked effect on performance. Detection distances for the test conditions were approximately 46 meters for no windshield, 43 meters for a new clean windshield, 40 meters for a new and dirty windshield, 36 meters for a scratched but clean windshield, and 30 meters for a scratched and dirty windshield.

In a third experiment, subjects approached targets while riding in a car and pressed buttons when they could just detect something in the roadway and when they were certain something was there. Detection thresholds were roughly 68 meters for the clean windscreen, 49 meters for the scratched one, 62 meters for dirty windscreens, and 50 meters for windscreens that were both dirty and scratched. Positive identification distances were typically 10 meters less than the detection threshold.

Finally, Allen measured windshields before and after they had been polished to remove surface scratches. Glare was reduced substantially after polishing. The central theme of Allen's paper is that normal conditions of use can result in windshield degradation that will cause substantial interference. In this and other works (1963, 1969), Allen found that the amount of light scattered by wiper patterns was related to an automobile's cumulative mileage. He suggests that glare related problems are severe enough to warrant windshield replacement every 50,000 miles.

Some of the effects of windshield damage on driver performance can be extrapolated from the general research on visibility described previously. For example, Sutro's (1957) study of critical areas for wiper-washer systems indicates that damage next to the left A-pillar and in the center of the windshield may be more critical than damage localized in other areas. Also, in developing their Figure-of-Merit model, Baruoski, Maurer, and Kugler (1969) found that driving environment affected field-of-view requirements. Visibility requirements (and, as a result, the importance of damage) are greatest in urban traffic and are reduced in rural or freeway situations. However, direct investigation of these parameters in cases of windshield breakage has not been performed.

In summary, there exists a general body of knowledge on driver visibility and specific requirements for an adequate field-of-view. However, there is little information in the research literature on windshield damage and breakage and its direct effects on driver performance. Limited frequency data do exist, but there are no data describing damage patterns or locations. Research on windshields has concentrated primarily on characteristics that will reduce vehicle occupant impact injuries and on the assessment of visibility loss when degradation is spatially homogeneous.

ACCIDENT DATA ANALYSIS

The only collection of accident data in which pre-crash windshield condition is coded is the Collision Performance and Injury Report (CPIR) Revision 3 (Highway Safety Research Institute, 1978). CPIR was originally developed in 1967 by General Motors and is now maintained by HSRI. The last major update was in 1979. The file is a collection of descriptions obtained at the accident sites by field investigation teams involving about 9600 vehicles. Over the history of the effort, no single consistent scheme to include accidents in the file has been utilized. This is due to the differences in investigation teams and changes in the interests of research sponsors. As a result, different types of accidents (such as fatal accidents involving trucks or pedestrian accidents) were, at times, disproportionately included or excluded from the file, depending on research priorities. Thus, CPIR is a **collection** of accident descriptions, and not a statistically representative sample of motor vehicle accidents.

CPIR is the most detailed of the accident data files at HSRI. It contains 647 variables, most of which describe the extent of injuries, vehicle damage, and parts of the vehicles that come into contact with the occupants. Many other variables deal with the environmental conditions present when the accident occurred and, in addition, a description of the vehicle prior to the accident.

Relevant to the present study is variable 37 - "Visibility Limitation." The ten codes for Visibility Limitation with their frequencies are shown in Table 2.

Table 3 presents a summary of the accident data for the 39 cases for which windshield condition was coded as a potential causal factor.

TABLE 2

Visibility Limitation Levels in CPIR

Level Tag	Number of Vehicles
Unknown	288
None	7571
Cloudy-Dark	630
Fog	165
Smoke	6
Windshield Condition	39
Glare	143
Other	44
Rain	203
Snow	129
Total n =	9218 (as of January, 1981)

Because of the differences in accident investigation teams, there are inconsistencies in coding. For instance, the one case reporting "glare" should have been coded in its own categorical level. Also, there are several cases of "rain" and "snow" reported at the windshield condition level rather than at their own levels. It is believed these cases are properly recorded, as they indicate a visibility problem, rather than other difficulties (such as skidding).

Appendix 1 contains a complete description of the pre-crash and post-crash windshield condition for the 37 vehicles as reported by the investigation teams. In 18 cases, there was no damage to the windshield after the crash. In 18 other cases there was at least some windshield damage. Occupant contact with the windshield was suspected or confirmed in 11 cases.

There were only two cases where the windshield was actually damaged <u>prior</u> to the accident. In both cases, the windshield condition was a

TABLE 3

Windshield Condition Prior to Accident

Condition	n (total = 39)
Fogged or icy windshield, not cleared by defroster	9
Washer-wiper system did not clear dirty or wet windshield	8
Slush or spray from other vehicle on windshield	7
Snow, sleet, blowing snow not cleared	6
Unknown - no definitive information	4
Pitted, chipped or damaged windshield	2*
Second vehicle - no damage	2*
Glare	1**

*These were the only 2 cases with windshields that were actually damaged (see text). The 2 cases identified as "second vehicles" were other vehicles involved in these 2 accidents. They were coded for this variable for their involvement in the accident, and did not themselves have a degraded windshield condition.

**This glare case was improperly coded by the accident team.

potential contributing cause, but was not felt to be the determining cause of the accident. Appendix 2 contains short descriptions of these two accident cases.

Appendix 3 contains short descriptions of 44 cases coded at the "other" level of visibility limitation. Once again, due to potential coding inconsistencies, a windshield condition problem might have been a factor in some of these cases. However, there were no cases reported among these 44 where the windshield was actually damaged prior to the accident.

In conclusion, there is no evidence from the CPIR file that windshield damage was the cause of any of the accidents coded. However, there are sampling and coding problems with the dataset, and consequently, that conclusion is suspect.

LABORATORY EXPERIMENT: NIGHTTIME DRIVER DECISION MAKING

The research literature provides little information on windshield damage and driving safety. Most of the previous studies were concerned with windshields containing gross, homogeneous distortions. Since most actual cases of windshield glass damage occur either at a point (such as a stone chip) or in a localized pattern (such as a fracture that "radiates" from an impact origin), most of these studies do not directly address the question of interest.

Likewise, the accident data analysis described in the previous section did not show a relationship between windshield damage and accidents. Although many of the vehicles in the dataset were suspected of having a degraded pre-crash windshield condition, there were only two cases with confirmed damage to the glass - not enough for sweeping conclusions about the entire population.

In response to this inadequate state of present knowledge, a controlled laboratory experiment was performed. The experiment collected response-time and error data from drivers who viewed simulated road situations through windshields, both damaged and undamaged. The rest of this section describes that experiment in detail.

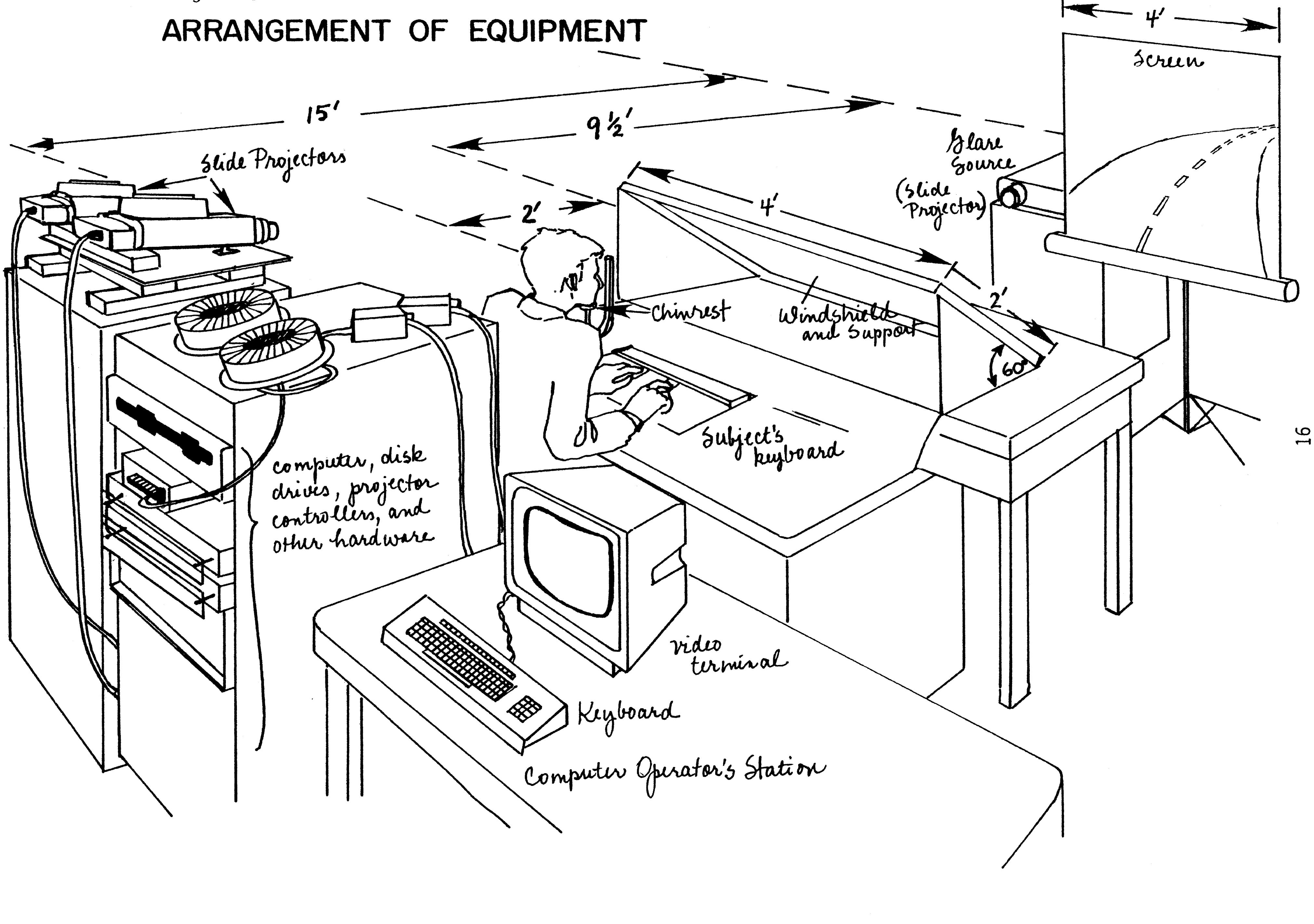
METHOD

Equipment and Materials

Three classes of apparatus were used in this experiment -- the computer system, the windshields, and the test slides. Each element is described in the following section. The general arrangement of the equipment is shown in Figure 1.

Figure 1.

ARRANGEMENT OF EQUIPMENT



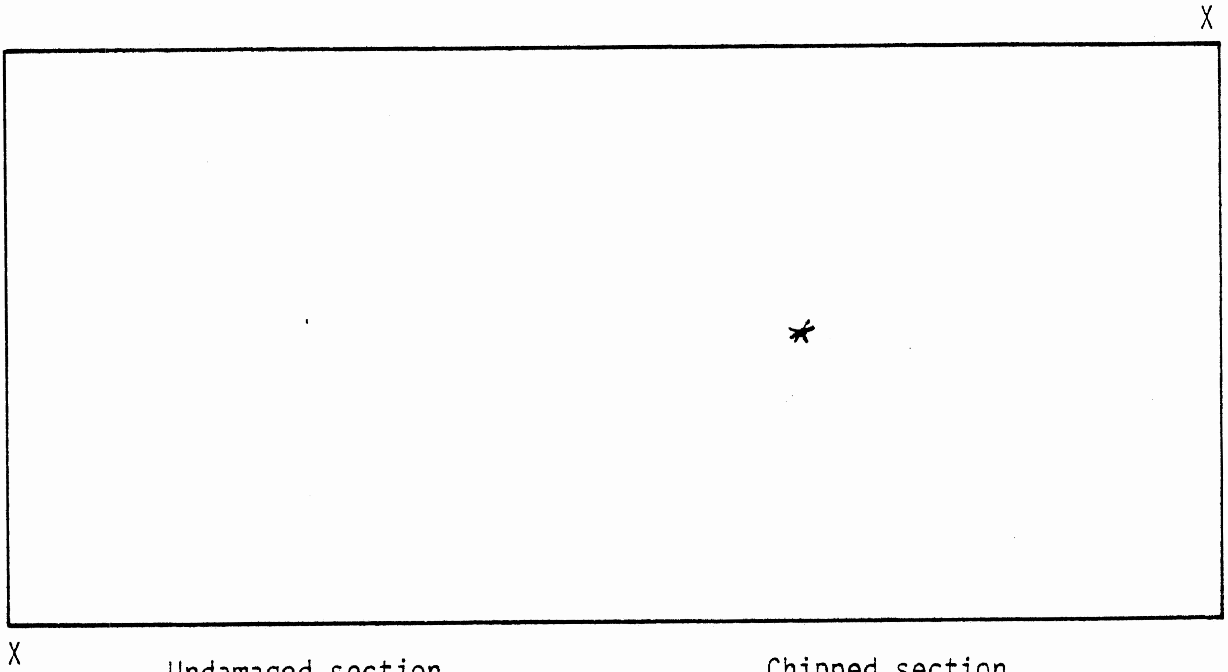
Computer System. The experiment was controlled by an ADAC model 1000 minicomputer which contained a Digital Equipment Corporation LSI 11/2 processor. The computer had 64K bytes of memory, a real-time programmable clock with up to one-tenth of a millisecond resolution, 32 bits for digital input/output, and both analog-to-digital and digital-to-analog converters. Five devices were connected to the computer:

1) Programs and data were stored on dual ADAC model 800 8 inch single-sided floppy disk drives.
2) Operator control of the computer was exercised via an Ann Arbor Terminals model 531E video display unit.
3) Slides of test scenes were presented to subjects by 2 Kodak RA-960 35 mm random-access slide projectors. Those projectors were connected to the computer via 2 Lafayette Instrument model 12910 projector controllers which were modified for rapid carousel movement.
4) Exposure control of the slides was obtained bv two Lafayette model 43016 external shutters, one per projector lens. The shutters were interfaced to the computer via custom-made drivers.
5) Subjects responded via a specially made, 10-key "Fitts type" piano-like keyboard. A response required key depression of less than 1 mm and only a few ounces of force. It too was connected to the computer via a custom-made interface.

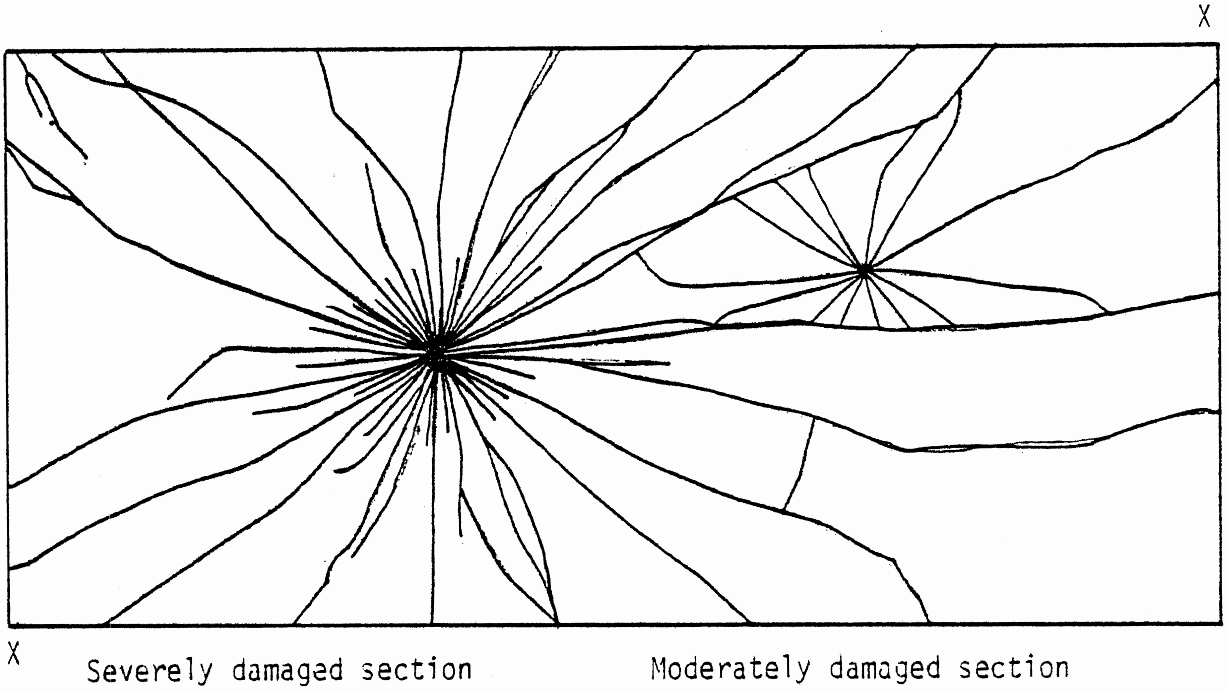
Operating independently of the computer was a Kodak model 650H serial access 35 mm slide projector which was aimed at the subject and served as a glare source. The illumination level was adjusted to .08 footlamberts measured in the plane of the subject's eyes using a variac which regulated the voltage to the lamp circuit. Those levels were measured with a Photo Research 1970 PR Pritchard photometer. They are equivalent to glare levels experienced by drivers when facing U.S. low-beam headlamps from several hundred feet away.

Windshields. Two pieces of laminated flat auto glass provided by Libbey-Owens-Ford (2 feet high x 4 feet wide x .230 nominal inches thick) served as the test materials. Each piece was composed of 2 panes of clear float glass (.100 nominal inches thick) separated by a high penetration resistance PBB interlayer. The pieces were supported by wooden frames and placed at arms length in front of the subject, angled 60 degrees from the driver's line of sight. (See Figure 1.) Each pane can be thought of as having two 2-foot-by-2-foot viewing sections. On one piece, one section was left undamaged while the other had a centrally located simulated stone bruise (made by dropping a ball bearing from several feet). The other piece had severe damage on one half and moderate damage on the other, achieved by forceful hammer blows by the project technical monitor. Shown in Figure 2 are sketches of the damaged glass.

Slides. Forty-eight 35 mm slides of simulated nighttime road scenes from a driver's point of view in four configurations were used: 12 left curves, 12 right curves, 12 straightaways, and 12 intersections. Within each group of 12 there were 6 "safe to proceed" and 6 "slow down" slides. Slides were divided into 2 groups of 24, with each projector carousel containing an equal number of road type by response type combinations. To prevent the sounds of the projector movements from introducing response biases, slides were randomly ordered within each carousel. (A descriptive listing of all slides appears in Appendix 4.)



Undamaged section Chipped section



Severely damaged section Moderately damaged section

Figure 2. Sketches of Damaged Windshields

Note: The windshields are shown as they would appear to the subject looking towards the screen. Each windshield could be mounted in two ways. The "X" indicates the position of the lower left corner. The subject's line of sight was directly behind the damage center in the severe and chipped conditions and just above it in the moderate condition.

Road scenes were constructed using "Matchbox" size (roughly 1:64 scale) vehicles which were positioned on a simulated two-lane paved road on a simple terrain board. To make them appear more realistic, all vehicles were painted with "dull coat" to reduce the paint reflectivity, and most grill work was blackened. The reflectivity of all luminaires was enhanced by covering them with 3M reflective sheeting, white for headlamps and red for taillamps and marker lamps. The camera position was fixed so that it simulated a passenger car driver's view of the road. Primary illumination of the road was achieved by a Ray-O-Vac rectangular throw-away "Brite-Lite" flashlight, which was positioned beneath and slightly to the right of the camera lens. Its intensity distribution made the scene appear as if the road was being illuminated by a car's headlights. Other illumination was provided by Eveready AA size pocket flashlights (placed behind crossing vehicles to simulate their headlamp patterns) and by a desk lamp (located several feet from the scene and aimed away from it to provide general scene illumination). In the post-experiment debriefing subjects stated they believed the scenes were real. ("Did you know the slides were pictures of toy cars?" "No, really? You're kidding.")

People Tested

Sixteen licensed drivers were tested, 8 "young" individuals (ages 17-33, mean 26) and 8 "old" people (ages 56-76, mean 69). Within each age group there were an equal number of males and females. The young drivers were University of Michigan employees and all but one worked at the Highway Safety Research Institute. The old subjects were mostly retired people living in Ann Arbor, Michigan. All of the old subjects were paid $10.00 for their time, as was one HSRI employee who was tested after normal working hours. All drivers were in good health, though one of the older subjects had slightly decreased mobility in his right wrist. All young subjects had a Snellen far acuity of 20/25 or better (corrected) while, except for one driver (20/70), all of the older drivers were 20/50 or better (corrected). All drivers were color normal.

Procedure

Subjects were tested individually. Test sessions lasted between 1-1/2 and 2 hours. Before the main experiment, the subject's vision was checked with a Titmus model OV-7M Professional Vision Tester. Also, their color vision was checked with Dvorine Pseudo-Isochromatic Plates.

Subsequently, the subject was seated in front of the test apparatus and allowed to dark adapt for ten to fifteen minutes. During that period biographical information was collected, the chin rest was adjusted, and the instructions were read. In addition, subjects were shown all of the test slides and told the correct response for each one.

The experimental session consisted of about 1000 trials. On each trial a slide was shown to which the subject responded by pressing a key depending upon whether or not it was safe to proceed. Subjects were instructed to imagine they were driving on a rural road at night at high speed, had been distracted from looking ahead, and then suddenly saw the scene presented. The decision rule was that if anything was in their lane or about to enter it (regardless of distance), they were to press the left key (slow down or brake). If it was safe to proceed, subjects pressed the right key (the accelerator). This rule was used to make the correct decision for each slide uniform across subjects. Subjects were instructed to respond as rapidly and accurately as possible. (The complete instructions are in Appendix 5.)

Trials were organized into blocks of at least 96 trials, with each slide originally scheduled to be shown twice per block. The test sequence was random within subjects and blocks, but counterbalanced across age groups and sex (except for practice blocks, for which the same random sequence was always used). During the test blocks, unknown to the subjects, the last 2 slides scheduled for that block were shown in reverse order as the first trials of the block. These served as unscored practice trials. Also, test trials with response times that were clearly unreasonable were repeated automatically at the end of each test block. These included:

1) Trials with response times less than 150 msec, indicating that the subject guessed wildly rather than following the decision instructions. Only one trial was repeated for this reason.
2) Trials with response times greater than 3500 msec. These trials do not reflect a true response to the stimulus. Rather, they probably indicate a breakdown of the decision process, such as simply forgetting the correct response to the slide. Forty-nine trials were repeated for this reason.
3) Trials with no response in at least 10 seconds. When 10 seconds elapsed, the computer terminated the trial and moved on to the next slide. This occurred 4 times (when the slide projector jammed).

The cutoff points for defining unreasonable responses were chosen based upon experience with response time / keypress experiments as well as an examination of data obtained from pilot subjects in this experiment.

Each subject responded to 10 blocks of trials, two practice blocks without a windshield in place and eight test blocks. The eight test blocks represent all possible combinations of the four levels of damage (undamaged, chip, moderate, severe) with the two glare levels (no, yes). The damage and glare levels were counterbalanced across subjects. To minimize handling of the damaged glass, both glare combinations were run in sequence for each damage level. (See Table 4 for the complete experimental design.)

TABLE 4

Experimental Design
Glare (Yes/No) by Windshield Damage by Subject

SUBJECT	SEX	AGE	PRACTICE		TEST BLOCKS							
			1	2	1	2	3	4	5	6	7	8
1	M	29	No Windshield		Undamaged		Chip		Moderate		Severe	
			No	No	No	Yes	No	Yes	No	Yes	No	Yes
2	F	31	No Windshield		Severe		Undamaged		Chip		Moderate	
			No	No	No	Yes	No	Yes	No	Yes	No	Yes
3	M	33	No Windshield		Moderate		Severe		Undamaged		Chip	
			No	No	No	Yes	No	Yes	No	Yes	No	Yes
4	F	26	No Windshield		Chip		Moderate		Severe		Undamaged	
			No	No	No	Yes	No	Yes	No	Yes	No	Yes
5	F	28	No Windshield		Undamaged		Chip		Moderate		Severe	
			No	No	Yes	No	Yes	No	Yes	No	Yes	No
6	M	22	No Windshield		Severe		Undamaged		Chip		Moderate	
			No	No	Yes	No	Yes	No	Yes	No	Yes	No
7	F	22	No Windshield		Moderate		Severe		Undamaged		Chip	
			No	No	Yes	No	Yes	No	Yes	No	Yes	No
8	M	17	No Windshield		Chip		Moderate		Severe		Undamaged	
			No	No	Yes	No	Yes	No	Yes	No	Yes	No

TABLE 4 (continued)

SUBJECT	SEX	AGE	PRACTICE		TEST BLOCKS							
			1	2	1	2	3	4	5	6	7	8
			No Windshield		Undamaged		Chip		Moderate		Severe	
9	M	72	No	No	No	Yes	No	Yes	No	Yes	No	Yes
			No Windshield		Severe		Undamaged		Chip		Moderate	
10	F	59	No	No	No	Yes	No	Yes	No	Yes	No	Yes
			No Windshield		Moderate		Severe		Undamaged		Chip	
11	M	76	No	No	No	Yes	No	Yes	No	Yes	No	Yes
			No Windshield		Chip		Moderate		Severe		Undamaged	
12	F	56	No	No	No	Yes	No	Yes	No	Yes	No	Yes
			No Windshield		Undamaged		Chip		Moderate		Severe	
13	F	64	No	No	Yes	No	Yes	No	Yes	No	Yes	No
			No Windshield		Severe		Undamaged		Chip		Moderate	
14	M	75	No	No	Yes	No	Yes	No	Yes	No	Yes	No
			No Windshield		Moderate		Severe		Undamaged		Chip	
15	F	72	No	No	Yes	No	Yes	No	Yes	No	Yes	No
			No Windshield		Chip		Moderate		Severe		Undamaged	
16	M	75	No	No	Yes	No	Yes	No	Yes	No	Yes	No

RESULTS AND DISCUSSION

Errors

Each response was placed automatically into one of seven categories: correct response (acceptable response time, too fast, too slow), incorrect response (acceptable, fast, slow), or no response. The overall frequencies for each error category are shown in Table 5. A total of 54 trials were repeated due to response times out of the acceptable range. These 54 trials represent only 0.44% of the total number of trials presented.

An analysis of the error counts indicated that subjects and subject-related variables (age and sex) influenced the number of errors made. There are large differences between subjects. Males made fewer errors than females, and younger subjects made fewer errors than older subjects. Table 5 shows error counts by subject, age, and sex.

Errors decreased slightly with practice. The number of keypress errors on trials with acceptable response times were 64, 62, 45, 53, 58, 50, 45, and 50 for blocks 1 through 8, respectively.

Table 6 shows error counts by windshield condition and glare levels for acceptable responses. Neither factor significantly affected error rates and, in fact, more errors were made when no glare was present. However, errors were somewhat more frequent with a severely damaged windshield, especially when glare was present.

In general, it appears that response errors were not a function of windshield damage and glare levels, but were significantly affected by subject variation. Errors represent a subject-specific problem with learning the correct responses for each slide, rather than a visibility degradation. Also, several "more difficult" slides produced

TABLE 5

RESPONSE TYPE COUNT BY SUBJECT

		Within Deadlines		Fast (<150 msec)		Slow (> 3500 msec)		No
Group	Subject	Correct	Error	Correct	Error	Correct	Error	Response
Young Females	2	736	32	0	0	0	0	0
	4	766	2	0	0	0	0	0
	5	759	9	0	0	0	0	0
	7	721	47	0	0	0	0	1
Young Female Subtotal		2982	90	0	0	0	0	1
Young Males	1	762	6	0	0	0	0	0
	3	763	5	0	0	0	0	0
	6	753	15	0	0	1	0	1
	8	745	23	0	0	0	0	0
Young Male Subtotal		3023	49	0	0	1	0	1
Young Subj. Subtotal		6005	139	0	0	1	0	2
Old Females	10	753	15	0	0	16	4	0
	12	734	34	0	0	18	4	0
	13	721	47	0	0	4	0	0
	15	709	59	0	0	0	0	0
Old Female Subtotal		2917	155	0	0	38	8	0
Old Males	9	753	15	0	0	0	0	0
	11	729	39	0	0	1	0	2
	14	728	40	0	1	1	0	0
	16	729	39	0	0	0	0	0
Old Male Subtotal		2939	133	0	1	2	0	2
Old Subject Subtotal		5856	288	0	1	40	8	2
Female Subj. Subtotal		5899	245	0	0	38	8	1
Male Subject Subtotal		5962	182	0	1	3	0	3
Total		11861	427	0	1	41	8	4

TABLE 6

Keypress Errors by Windshield and Glare Levels
(Acceptable Response Times Only)

WINDSHIELD DAMAGE	GLARE No	GLARE Yes	Totals
Undamaged	60	45	105
Chip	54	49	103
Moderate	57	44	101
Severe	54	64	118
Totals	225	202	427

disproportionately high error rates, which supports the learning hypothesis. The error data show that damaged windshields and glare levels do not cause an increase in incorrect responses to driving situations. However, taking too long to make a decision can be just as dangerous as making an error (Wolf and Barrett, 1978). The next section describes the effects of windshield damage and glare on response times.

Response Times

The primary dependent measure in the nighttime driving study was decision or response time, the time in milliseconds from when the projector shutter opened until a key was pressed. Only those trials with times within the 150 and 3500 millisecond deadlines were examined. The data were analyzed in a stepwise fashion. First, practice effects were examined. Then, once practice effects were removed from the data, all remaining factors were considered. In a one-way Analysis of Variance the effect of trial block was very highly significant ($F(7,12280)=8.68$, $p <.001$). The mean response times for each subject by block are shown in Figure 3 for the young subjects and Figure 4 for the old subjects. In general, even though subjects had two blocks of practice prior to the test sessions, they continued to improve until roughly three test blocks had elapsed, after which much smaller reductions in response time occurred. Much of the variability in those curves reflects the between block changes in glare and windshield type.

Once practice effects were removed (by adding or subtracting the deviation of each block mean across subjects from the grand mean), the data were examined further via Analysis of Variance. Specifically, an 8-way analysis was employed with Age (young versus old), Sex (male versus female), Windshield damage (undamaged, chipped, moderate, severe), Glare (no versus yes), correct Key (or decision type - left [slow down] versus right [safe to proceed]), Slide nested within a key (48 total slides) and Subject nested within Sex and Age as the main effects. The analysis is summarized in Table 7.

With regard to people, there were significant differences due to Age ($F(1,9279)=26.70$, $p <.001$), Sex ($F(1,336)=5.08$, $p <.05$), and Subjects nested within age and sex ($F(12,552)=42.46$, $p <.001$). There was no interaction between Age and Sex ($F(1,45)=1.90$, $p >.1$). Young drivers were faster in responding than old ones (778 versus 1,044 milliseconds). Males responded more rapidly than females (853 versus 969 milliseconds). Overall, subject mean response times varied from 679 to 1,222 milliseconds. (See Figures 3 and 4 for further details of between driver differences.)

Figure 3.

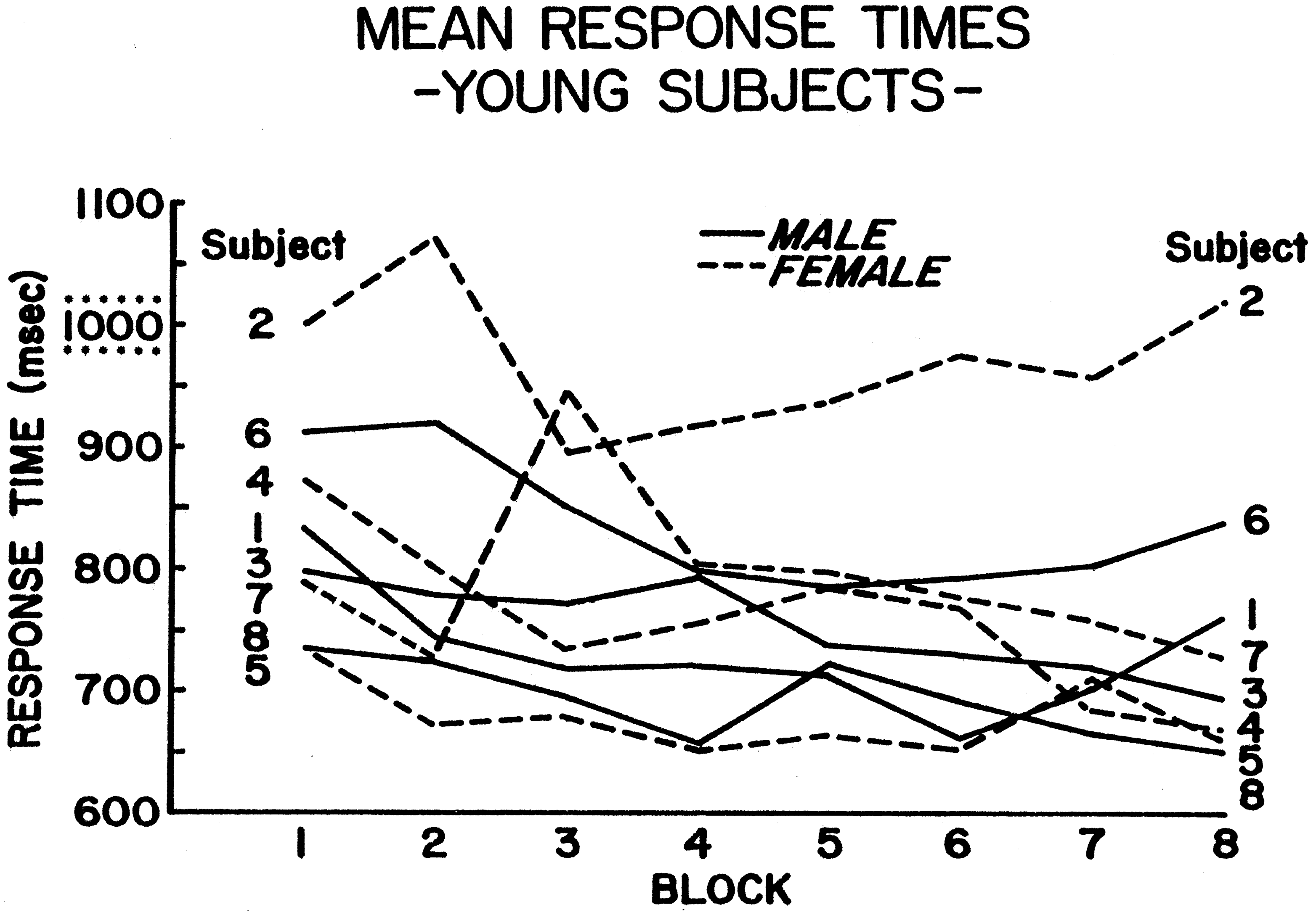

MEAN RESPONSE TIMES
-YOUNG SUBJECTS-
RESPONSE TIME (msec)
1100
1000
900
800
700
600
BLOCK
1
2
3
4
5
6
7
8
Subject
2
6
4
1
3
7
8
5
MALE
FEMALE
Subject
2
6
1
7
3
4
5
8

Figure 4.

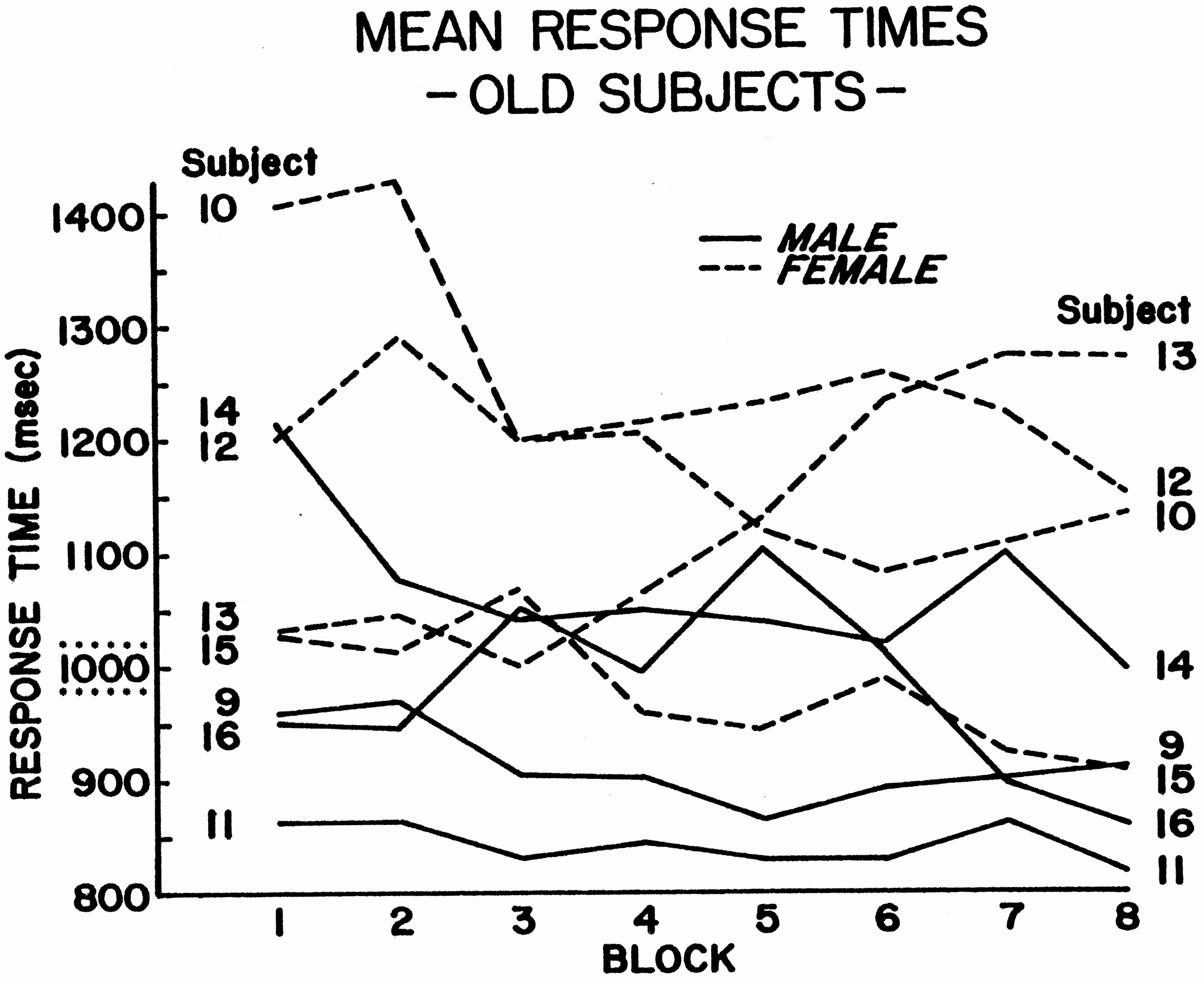

MEAN RESPONSE TIMES
-OLD SUBJECTS-
— MALE
--- FEMALE
Subject
10
14
12
13
15
9
16
11
Subject
13
12
10
14
9
15
16
11
RESPONSE TIME (msec)
1400
1300
1200
1100
1000
900
800
1
2
3
4
5
6
7
8
BLOCK

TABLE 7

ANALYSIS OF VARIANCE OF RESPONSE TIMES

FACTOR	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	P
A [Age]	216231279	1	216231279	26.70	<.001
X [seX]	41175286	1	41175286	5.08	<.05
W [Windshield]	12088273	3	4029424	10.01	<.001
G [Glare]	682736	1	682736	5.16	<.05
K [Key]	18279705	1	18279705	1.98	>.1
L(K) [Slide]	391145593	46	8503165	46.49	<.001
AX	15005517	1	15005517	1.90	>.1
AW	1826547	3	608849	1.50	>.1
XW	1646052	3	548684	1.41	>.1
AG	2133	1	2133	<1	>.1
XG	1584	1	1584	<1	>.1
WG	1238800	3	412933	6.03	<.001
AK	1171562	1	1171562	<1	>.1
XK	3774548	1	3774548	3.18	<.1
WK	965636	3	321878	1.89	>.1
GK	35411	1	35411	1.35	>.1
S(AX)[Subject]	93257904	12	7771492	42.46	<.001
AL(K)	23516430	46	511226	2.79	<.001
XL(K)	23119789	46	502604	2.74	<.001
WL(K)	8088105	138	58609	<1	>.1
GL(K)	1936458	46	42096	<1	>.1
AXW	1232536	3	410845	1.03	>.1
AXG	734982	1	734982	5.90	<.05
AWG	90672	3	30224	<1	>.1
XWG	2993	3	997	<1	>.1
AXK	85524	1	85524	<1	>.1
AWK	927048	3	309016	<1	>.1
XWK	197329	3	65776	<1	>.1
AGK	75892	1	75892	1.82	>.1
XGK	385947	1	385947	9.81	<.001
WGK	241639	3	80546	1.76	>.1
SW(AX)	14588731	36	405242	6.61	<.001
SG(AX)	1686736	12	140561	2.78	<.001
SK(AX)	10403043	12	866920	4.74	<.001
AXL(K)	13796997	46	299934	1.63	<.01
AWL(K)	8497777	138	61578	1.00	>.1
XWL(K)	5971000	138	43268	<1	>.1

TABLE 7 (continued)

FACTOR	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	P
AGL(K)	1774744	46	38581	<1	>.1
XGL(K)	2545456	46	55336	1.09	>.1
WGL(K)	5658314	138	41002	<1	>.1
AXWG	310732	3	103577	1.35	>.1
AXWK	468179	3	156059	<1	>.1
AXGK	34200	1	34200	1.85	>.1
AWGK	67776	3	22592	<1	>.1
XWGK	97543	3	32514	<1	>.1
SL(AXK)	100972104	552	182920	4.29	<.001
SWG(AX)	2676306	36	74341	1.58	<.05
SWK(AX)	6204227	36	172339	2.81	<.001
SGK(AX)	413448	12	34454	<1	>.1
AXWL(K)	7378044	138	53464	<1	>.1
AXGL(K)	1582348	46	34398	<1	>.1
AWGL(K)	4714263	138	34161	<1	>.1
XWGL(K)	8697033	138	63021	1.34	<.01
AXWGK	30284	3	10094	<1	>.1
SWL(AXK)	101487224	1656	61284	1.43	<.001
SGL(AXK)	27845212	552	50444	1.18	<.05
SWGK(AX)	1854594	36	51516	1.09	>.1
AXWGL(K)	6779517	138	49126	1.04	>.1
SWGL(AXK)	77651404	1656	46890	1.10	<.1
R(AXSWGKL)	261826078	6144	42614	1.10	<.1

With regard to experimental conditions, there were very highly significant differences between Slides (*F*(46,552)=46.49, *p* <.001). Response times ranged from 662 msec for slide 12 (semi crossing the road) to 1381 msec for slide 25 (oncoming semi rounding a curve). Subjects had the greatest difficulty with scenes showing curved roads and/or multiple vehicles. (The mean times by slide for all responses within the deadlines by are included in Appendix 4.) As is usually the case, response times were correlated with the number of errors per slide (*r*(46)=.59, *p* <.001). (See Figure 5.)

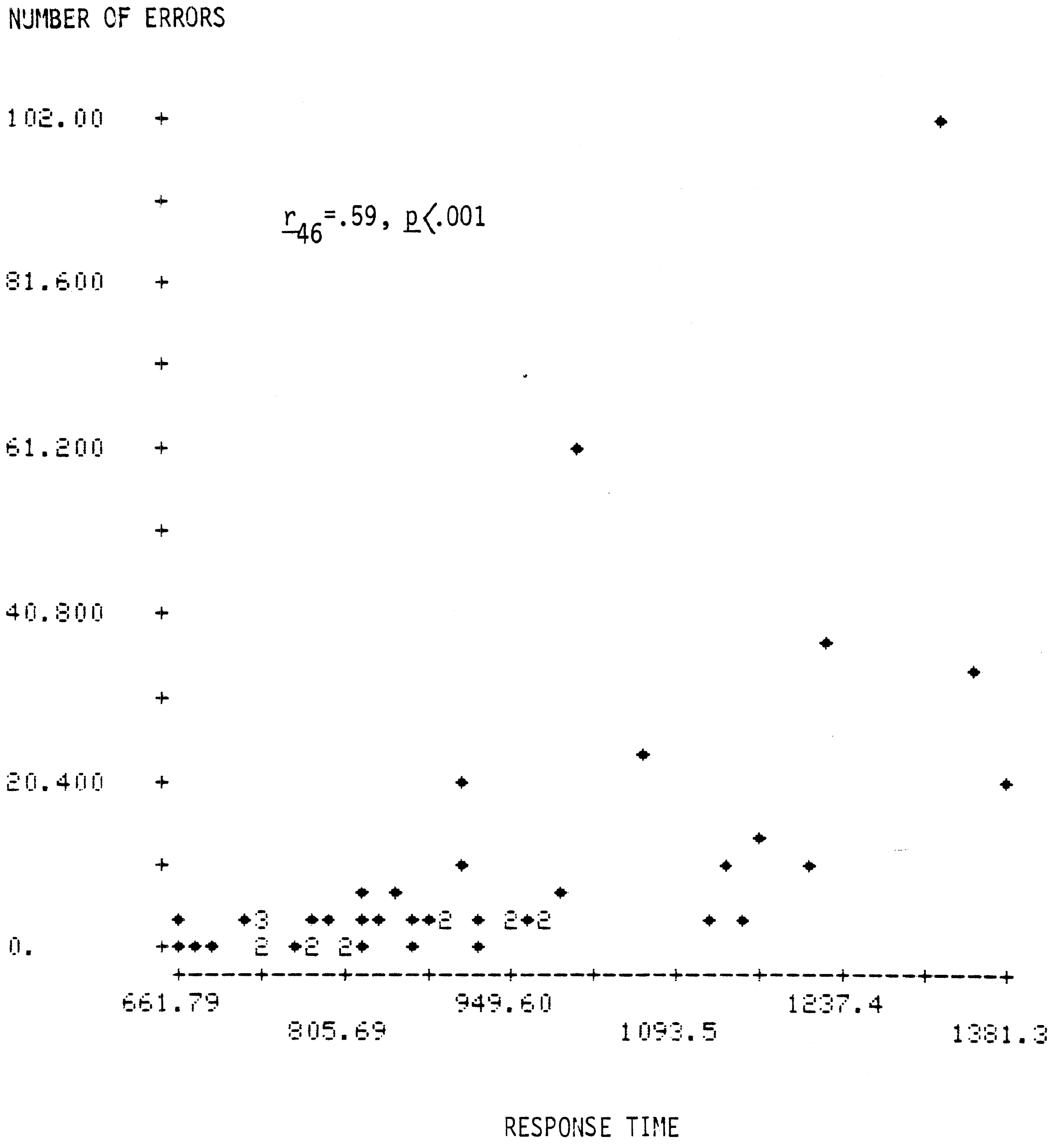


Figure 5.

Response Time Versus Number of Errors for Each Slide

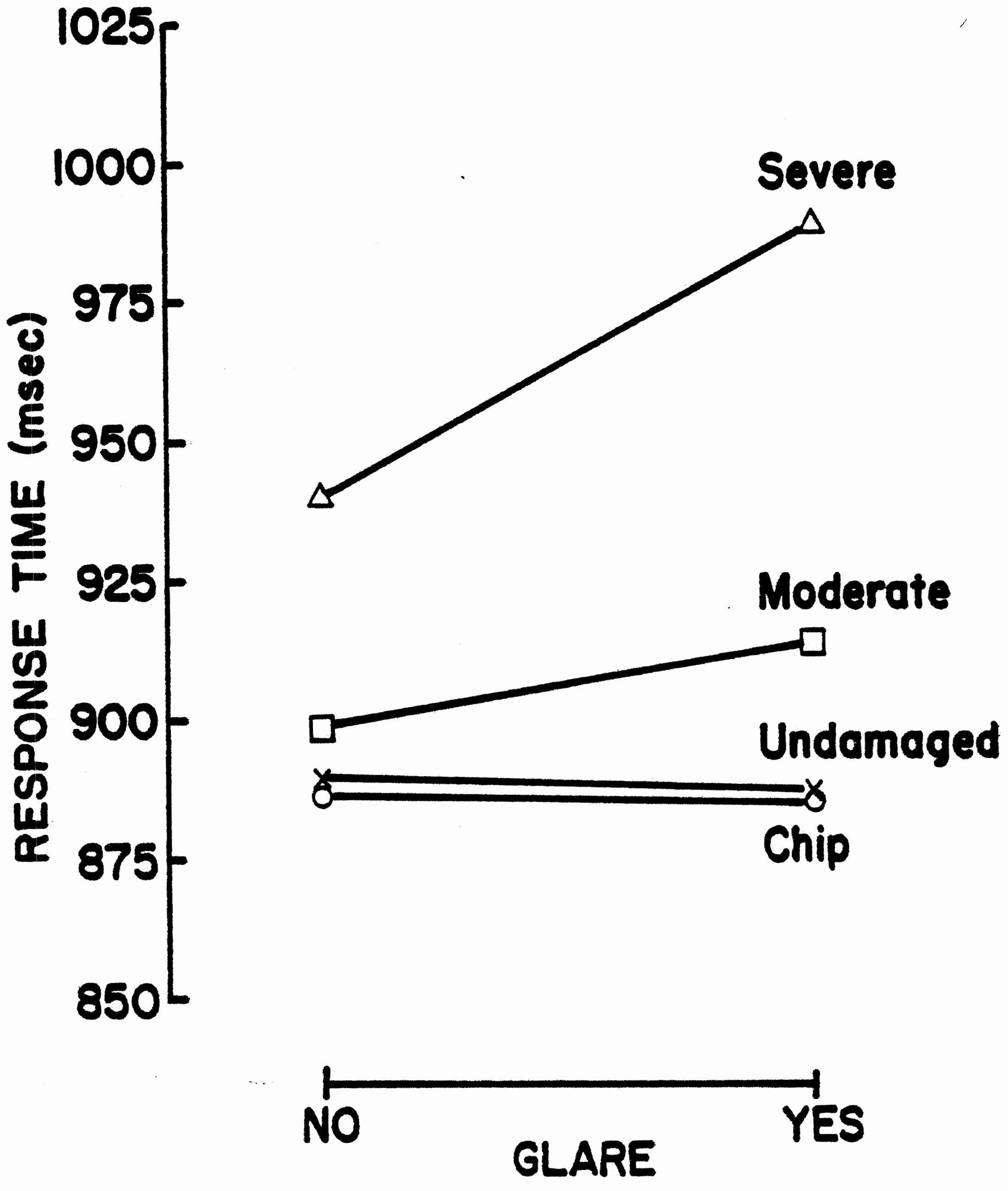
On the other hand, the difference between decisions (slow down or safe to proceed--the response key) was not significant ($F(1,2044)=1.98$, $p > .1$), although the difference in the means was large (slow down = 872 msec, safe to proceed = 949 msec). When choosing to slow down, drivers may terminate the decision process as soon as the obstacle is recognized. Deciding it is safe to proceed requires an exhaustive search, a more time-consuming process. This difference was not significant, however, because there was considerable variability between slides, driver-slide, and driver-key combinations. All three of these factors were in the error term for the F test for the Key (decision type) effect.

Most important, however, are the effects of Windshield damage and Glare. Both factors were statistically significant ($F(3,360)=10.01$, $p < .001$, $F(1,28) = 5.16$, $p < .05$). Increasing damage generally resulted in longer response times (undamaged = 888 msec, chip = 886 msec, moderate = 905 msec, severe = 964 msec), as did the presence of glare (no = 903 msec, yes = 918 msec). (The two millisecond advantage for the chipped windshield over the undamaged windshield is probably a measurement error.) Also, an interaction between glare and windshield damage was revealed by this analysis ($F(3,1021)=6.03$, $p < .001$). When acting together their combined effect was greater than their simple additive effect. Particularly potent was the glare-severe damage combination. (See Figure 6.)

There were several significant 2-, 3-, and 4-way interactions. Only the significant 2-way interactions need be mentioned here. In addition to the interaction between windshield damage and glare, there were interactions between slide and age ($F(46,552)=2.79$, $p < .001$) slide

Figure 6.

WINDSHIELD BY GLARE INTERACTION



and sex (_F_(46,552)=2.74, _p_ <.001), and slide and subject (_F_(552,6144)=4.29, _p_ <.001). All three effects reflect specific problems of different drivers with particular slides.

Also present were interactions of subjects with windshield damage (_F_(36,1656)=6.61, _p_ <.001), with glare (_F_(12,552)=2.78, _p_ <.001), and with response key--decision type (_F_(12,552)=4.74, _p_ <.001). Thus, drivers _within_ age and sex groups are affected to differing degrees by windshield damage and glare and differ in the way they make decisions. However, since none of the 2- or 3-way interactions of windshield damage or glare with sex or age was significant, it does not appear that windshield damage presents a disproportionate problem for any particular segment of the driving population. It was thought at the outset it would for older drivers.

Thus, this response time study has shown that many factors influence the time to make decisions in a simulation of nighttime driving. Differences among drivers (between sexes, between age groups and between people within age-sex groups) influenced their response times as did the particular road scene presented (test slides). Most important, however, there were differences due to windshield damage with increasing damage resulting in an increase in response time. The difference between the severe and undamaged condition was 76 milliseconds, an 8 1/2 % increase over the baseline undamaged condition. While this is not an overwhelming difference, it is very highly significant in a statistical sense. Furthermore, the experiment was not constructed to exaggerate differences by examining human performance at its absolute limits, but rather to examine ordinary practiced decision-making. Thus, differences of this size are meaningful.

Also of interest was the effect of glare. Adding small amounts (simulating low beam headlamps at several hundred feet) increased response times significantly, especially when coupled with the severely damaged windshield. Surprisingly, both glare and windshield damage had equal effects on all age groups. It was thought they would present greater problems for the elderly.

SUMMARY AND CONCLUSIONS

1) The literature concerning windshield damage and driver vision was reviewed. The research fell into three broad categories -- studies concerned with the evaluation of the optical quality of windscreens, studies focusing on more general issues of visibility, and several miscellaneous reports concerned specifically with windshield damage. In the first category, several methodological approaches were described, including the use of driver acuity measures, subjective ratings, physical measures of similarity to standards, and modulation transfer function measures. While such approaches are appropriate for evaluating homogeneous distortions, they are less useful for windshield damage. With regard to general research on visibility, no studies were discovered which addressed squarely the damage question, although some were relevant as ancillary references. Finally, there are a few reports dealing specifically with windshield damage. They:

   a) provide limited data on the causes of breakage,
   b) indicate there are few cases in which breakage is an immediate cause of an accident, and
   c) suggest that glare angle is a critical factor in vision through damaged windshields.

2) The CPIR accident file was reviewed to see where windshield damage was a causal factor. For the roughly 40 vehicles for which windshield condition was flagged, only two of them had windshields that were damaged prior to an accident. In neither case was the damage believed to be a causal factor. Since the

CPIR data base is not a statistically representative sample of accidents, this outcome should not be viewed as conclusive.

3) In a laboratory study simulating nighttime driver decision making, windshield damage was an important factor. Sixteen drivers (ages 17-76) were shown slides of a two-lane rural road which they viewed through 4 different levels of windshield damage both with and without simulated glare. As soon as each slide appeared, drivers pressed one of two buttons to indicate if they should "slow down" or if it was "safe to proceed." Both response times and errors were recorded. Neither the damage level nor the simulated glare affected error rates. However, increasing levels of windshield damage were associated with increases in response time, with decisions made with the severely damaged windshield taking 8.5 percent longer, on the average, than with the undamaged windshield. Adding glare to windshield damage resulted in further increases in response time. While these differences are not enormous, they are very highly statistically significant.[2] Furthermore, considering the relatively unstressful nature of this experiment, differences in response times would tend to be understated. In addition, increasing the level of windshield damage and adding glare had the same relative effects on both age groups and sexes. It was thought that these manipulations would create greater problems for the elderly. While additional converging evidence is desired, this study

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[2] In analyzing experiments one is interested both in the size of differences between conditions and how consistently differences were obtained (how confident one is there are differences). "Very highly statistically significant" is a common scientific phrase for expressing extreme confidence that differences between conditions exist.

indicates that windshield damage is a safety issue that is of concern to drivers, as well as to organizations that monitor, regulate, or affect motor vehicle safety.

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APPENDIX 1

37 Cases of Windshield Condition in CPIR

37 Cases of Windshield Condition in CPIR

CASE #	PRIOR CONDITION	CONDITION AFTER CRASH
AA 165/ UM 189	slush kicked up by passing truck momentarily blinded driver	cracked / deformation 23% bond separation
AA 168	w/s fogged on inside; heater -defroster had not yet cleared it	undamaged
AA 169/ UM 598	w/s dirty	cracked / occupant contact
AA 325	slight fogging of w/s; defroster set on low	cracked / occupant contact 100% separation
MVD 1	raining; w/s wipers did not work	undamaged
MVD 24	misting rain; w/s wipers in degraded condition; rt. wiper, improper replacement	cracked /probably by occupant contact
MVD 26	rainy, w/s dirty; wiper blades in bad condition and on at time of accident	cracked and broken / occupant contact
4 ME 9	w/s dirty; w/s washer broken--had not rained enough to clear w/s	undamaged
CAL 71 15A	slush splashed on w/s by passing vehicle	cracked / probably occupant contact 100% separation
CAL 71 52A	unclear explanation; probably sleet on w/s	undamaged
CAL 71 73A	unknown / no information in narrative	cracked / occupant contact
CAL 71 107A	sleet	undamaged
CAL 71 109A	presumably sleet on w/s	cracked and broken by roof loading
CAL 71 119A	snow, sleet	cracked / occupant contact
CAL 71 126A	snow	undamaged
CAL 71 130A	blowing snow	undamaged
CAL 72 56A	spray from water in ice puddle	cracked and broken / occupant contact
CAL 72 224A	road wet / spray from passing car	stress cracked / deformation

CASE #	PRIOR CONDITION	CONDITION AFTER CRASH
CAL 72 9B	slush kicked up on w/s by car in front	cracked / deformation
CAL 73 322	w/s fogged	undamaged
CAL 74 11	heavy frost on w/s; driver didn't clean adequately	undamaged
HSRI 926	iced and fogged w/s	undamaged
HSRI 1365	frost on w/s	undamaged
MGU 009 71	rain, snow on w/s; wipers in 1st position (not fast enough)	cracked / occupant contact
MGU 100 75	unknown / no mention in narrative	cracked and broken / deformation
MIAMI 72 213	dirty windows / inoperable w/s washer system / defective wiper	undamaged
ML 71 12	water sprayed up on w/s by passing truck	cracked / deformation
UNM 98	w/s fairly badly pitted along the lower half (attributed to sand storms)	cracked / occupant contact
OK 188	icy w/s	undamaged
RAI 74	slush splashed on w/s	undamaged
SRI 8096 08	glare (incorrectly coded)	undamaged
SWRI 7107	w/s heavily soiled / w/s chipped and pitted in several locations on driver's side	undamaged
UM 040 68	snow from hood blew on w/s	undamaged
UM 171 69	frost on inside of w/s	cracked / deformation
UOK 72 2	extremely dirty windows	undamaged
SWRI 7139	fogged	cracked, broken / occupant contact
UM 300 70	missing data	missing data

APPENDIX 2

2 Cases of Damaged Windshields

2 Cases of Damaged Windshields

CASE#: SWRI 7107
ACCIDENT DATE: 3-2-71

This accident involved the case vehicle, a 1969 Ford Chateau Club Wagon, hitting the rear of an abandoned car parked in lane # 1 of a six lane divided limited access freeway. The windshield of the case vehicle was chipped and pitted in several locations on the driver's side. Although the major cause of the accident was inattention, (the driver was looking for roadside guide signs for an exit ramp), it was felt by the investigator that the heavily soiled and pitted windshield probably presented a minor visual obstruction affecting the driver's perception of the stopped vehicle ahead.

CASE #: UNM 98
ACCIDENT DATE: 7-12-73

This accident involved the case vehicle, a 1969 Chevrolet Nova, and an intersection accident with a 1972 Volkswagen. The driver of the case vehicle, with a BAC (Blood Alcohol Content) of 0.29%, failed to stop for a stop sign and impacted vehicle 2 (entering the intersection from his left) on the passenger side. The windshield of the Nova was fairly badly pitted along the lower half. This pitting is commonly caused by driving in the sand storms prevalent in the Southwest. The high alcohol content of the driver, impeding his ability to drive effectively, was the cause of the comprehension error leading to the accident. The condition of the windshield is not mentioned anywhere as a contributing cause.

APPENDIX 3

44 CPIR Cases with "Other" Visibility Code

44 CPIR Cases With "Other" Visibility Code

CASE #	EXPLANATION OF "OTHER"
BU 71 9	heavy rain
CA 71 32A	blowing snow, visibility reduced
CA 71 44A	heavy snow, near zero visibility
CA 71 51A	snow
CA 71 66A	snow, visibility fair
CA 71 76A	blowing snow, visibility fair
CA 71 85A	MISSING DATA
CA 71 106A	heavy snow, visibility poor
CA 71 123A	snow, visibility poor
CA 71 125A	MISSING DATA
CA 71 132A	snowfall, visibility fair
CA 71 137A	blowing snow, blizzard conditions
CA 71 138A	precipitation, snow showers
CA 71 141A	rain or snow (conflicting comments)
CA 71E 23A	ground fog
CA 72 88A	hazy
CA 72 345A	sleet storm, visibility reduced but not a factor
CA 72 362A	snow, visibility reduced
CA 71 8B	blowing snow, visibility somewhat limited
HSRI 002	bright headlights on oncoming car
HSRI 504	blowing snow
MCR 69 7	rain, vision restricted
MGU 007 71	exhaust vapor (emitted by row of idling parked cars)
MGU 076 74	change in light conditions (drove into tunnel)
MGU 125 77	shadow (struck car was in a shadow)
MI 697004	poor lighting in construction area
MI 697010	drizzling rain
MI 697018	location of rearview mirror obstructed view
MI 697027	location of rearview mirror obstructed view
MIAMI 105	night time (no street lighting)
MI 331	sudden change in lighting (from area with street lights to area without lights)
OK 068	no headlights on other vehicle
USC 73 15	inadequate lighting
SU 011	wet side windows, light rain

CASE #	EXPLANATION OF "OTHER"
SWRI 73 08	dust (kicked up by a truck)
UC 852D	bushes
UM 043 68	dust and gravel
UM 299 70	MISSING DATA
UM 426 71	blowing snow
UM 428 71	blowing snow
UM 835 73	patches of ground fog
UTAH 009 69	snowing
UOM 039 75	dust (kicked up by other cars)
UOS 017 73	blowing snow

APPENDIX 4

Test Slides: Content, Response Times, and Number of Errors

TEST SLIDES: CONTENT, ERRORS AND RESPONSE TIMES

Slide	Projector Slot	Road Configuration	Correct Response	No. of Errors	Response Time(msec)	Content
1	1,1	straight	slow	3	727	Semi ahead, same direction & lane as subject
2	1,2	left curve	proceed	3	985	Car, camper & car oncoming in opposite lane
3	1,3	straight	proceed	0	813	Car parked on right shoulder
4	1,4	right curve	proceed	11	1202	Car, small truck & car oncoming in opposite lane
5	1,5	intersection	proceed	2	794	Small truck stopped at left waiting to cross
6	1,6	left curve	slow	23	1058	Car, camper & car oncoming in opposite lane and car ahead partially hidden by camper
7	1,7	straight	slow	4	724	Police car roadblock across subject's lane
8	1,8	right curve	slow	3	928	Two cars oncoming in opposite lane; 1 ahead around curve
9	1,9	right curve	slow	12	1159	Camper, small truck, semi oncoming in opposite lane; oncoming car in subject's lane passing semi
10	1,10	straight	proceed	1	862	Car & small truck oncoming in opposite lane
11	1,11	right curve	proceed	3	774	No vehicles in scene (empty road)
12	1,12	intersection	slow	1	662	Semi across middle of intersection
13	1,13	right curve	proceed	9	1135	Three cars oncoming in opposite lane
14	1,14	left curve	proceed	2	886	Car oncoming in opposite lane & very distant
15	1,15	straight	slow	1	676	Accident ahead blocking both lanes
16	1,16	left curve	slow	3	738	Car, camper & car ahead in subject's lane
17	1,17	straight	proceed	1	769	Semi oncoming in opposite lane, very close
18	1,18	intersection	slow	6	821	Car, small truck oncoming in opposite lane; car well ahead in same lane as subject; 1 car on left and 1 on right waiting to cross

Slide	Projector Slot	Road Configuration	Correct Response	No. of Errors	Response Time(msec)	Content
19	1,19	left curve	proceed	4	956	Car parked on right shoulder
20	1,20	intersection	proceed	4	828	Small truck on right waiting to cross
21	1,21	left curve	slow	62	1004	Car, camper & car oncoming in opposite lane; semi ahead in subjects lane partly hidden by camper
22	1,22	intersection	slow	0	729	Semi making left turn coming from left into subject's lane
23	1,23	right curve	slow	4	894	Camper ahead
24	1,24	intersection	proceed	6	844	Car waiting on right to cross
25	2,1	right curve	proceed	19	1381	Semi oncoming in opposite lane, somewhat distant
26	2,2	intersection	slow	0	692	Train crossing (gondola ahead, red caboose off to right)
27	2,3	intersection	proceed	2	876	Car oncoming in opposite lane; small truck waiting to cross from right
28	2,4	right curve	slow	3	966	Car, camper & small truck oncoming in opposite lane, car ahead in subject's lane around curve
29	2,5	left curve	slow	4	953	Two cars ahead in subject's lane around curve
30	2,6	intersection	proceed	0	922	Car & small truck oncoming in opposite lane; 1 car on left and 1 waiting on right about to cross
31	2,7	straight	slow	3	735	Car very close & ahead in subject's lane
32	2,8	left curve	slow	102	1323	Two cars oncoming around curve, 1 passing other, only headlamps visible
33	2,9	straight	slow	1	739	Semi oncoming in opposite lane (close), car ahead (close)
34	2,10	right curve	proceed	33	1349	Car oncoming in opposite lane rounding curve
35	2,11	left curve	proceed	8	990	Camper oncoming in opposite land rounding curve
36	2,12	right curve	slow	3	868	Semi ahead in subject's lane rounding curve
37	2,13	intersection	slow	19	911	Semi partially in intersection, entering from right

Slide	Projector Slot	Road Configuration	Correct Response	No. of Errors	Response Time(msec)	Contents
38	2,14	straight	proceed	0	818	Small truck oncoming in opposite lane
39	2,15	straight	slow	2	665	Semi ahead in subject's lane (close)
40	2,16	left curve	proceed	2	1148	Three cars oncoming in opposite lane (1 quite distant)
41	2,17	left curve	slow	3	824	Semi ahead in subject's lane rounding curve
42	2,18	intersection	proceed	0	805	Car waiting to enter from left
43	2,19	straight	proceed	1	779	Two cars, small truck & semi oncoming in opposite lane
44	2,20	right curve	proceed	4	1118	Vehicle oncoming in opposite lane rounding curve (distant)
45	2,21	intersection	slow	11	913	Camper oncoming in opposite lane, car on right entering intersection
46	2,22	left curve	proceed	0	773	No vehicles (empty scene)
47	2,23	right curve	slow	36	1224	Two oncoming vehicles around curve, 1 passing other (only headlamps visible)
48	2,24	straight	proceed	3	979	One vehicle oncoming in opposite lane (distant)

APPENDIX 5

Instructions to Subjects

INSTRUCTIONS TO SUBJECTS

THIS IS AN EXPERIMENT TO EXAMINE NIGHTTIME DRIVER DECISION-MAKING. BEFORE WE BEGIN I WOULD LIKE TO CHECK YOUR VISION. (walk over to Titmus Tester) I AM GOING TO SHOW YOU A PICTURE THAT HAS SEVERAL IMAGES IN IT LIKE THIS ONE. (show Titmus illustration). YOU ARE TO TELL ME WHICH OF THE RINGS IS (TOP, RIGHT, LEFT OR BOTTOM) UNBROKEN. (IN THIS EXAMPLE THE RIGHT RING IS SOLID.) LOOK IN THE DEVICE AND BEGIN WITH IMAGE 1. WHICH RING IS UNBROKEN? IMAGE 2?....

(record performance)

NEXT, I WOULD LIKE TO CHECK YOUR COLOR VISION. ON EACH OF THE FOLLOWING PAGES IS A NUMBER CONSTRUCTED OF DOTS. TELL ME WHICH NUMBER YOU SEE. THIS ONE FOR EXAMPLE IS 48. OK? HOW ABOUT THIS ONE?

(fill out form)

THIS EXPERIMENT TAKES ABOUT AN HOUR AND A HALF. I WOULD LIKE TO COMPLETE IT WITHOUT INTERRUPTION. IF YOU WANT A DRINK OF WATER OR WANT TO USE THE BATHROOM, NOW IS THE BEST TIME. OK? IF YOU ARE READY TO BEGIN PLEASE HAVE A SEAT HERE. WHILE YOU ARE ADAPTING TO THE DARK, I WILL RECORD SOME BIOGRAPHICAL INFORMATION, TELL YOU ABOUT YOUR TASK, AND THEN ANSWER ANY QUESTIONS YOU MIGHT HAVE.

(complete biographical form)

IN THIS EXPERIMENT YOU ARE TO IMAGINE YOU ARE DRIVING YOUR CAR AT NIGHT AT HIGH SPEED AND YOU SUDDENLY LOOKED AHEAD. I WILL SHOW YOU SLIDES OF A LARGE NUMBER OF ROAD SCENES. YOUR TASK WILL BE TO DECIDE WHETHER YOU CAN CONTINUE AT THE SAME SPEED OR SHOULD SLOW DOWN. YOU SHOULD SLOW DOWN WHENEVER THERE IS ANOTHER VEHICLE IN YOUR LANE OR ABOUT TO ENTER IT REGARDLESS OF HOW DISTANT. INDICATE YOUR DECISION BY PRESSING ONE OF THE 2 KEYS IN FRONT OF YOU. PRESS THE LEFT KEY TO SLOW

DOWN, THE RIGHT KEY TO CONTINUE AT THE SAME SPEED. (THINK OF THE LEFT KEY AS THE BRAKE AND THE RIGHT AS THE ACCELERATOR.) WHEN YOU RESPOND JUST GIVE THE KEY A QUICK TAP LIKE SO. (show the subject how.) WHEN THIS KEY CLICKS THE COMPUTER KNOWS YOU PRESSED IT. DON'T HOLD THE KEY DOWN AFTER YOU RESPONDED AND, PLEASE, DON'T TRY TO DESTROY IT. ALSO, IF YOU MAKE A MISTAKE, DON'T CORRECT IT. THE COMPUTER ONLY ACCEPTS YOUR FIRST RESPONSE.

BEFORE WE BEGIN I WOULD LIKE TO SHOW YOU ALL OF THE TEST SLIDES AND TELL YOU WHAT THE CORRECT RESPONSE IS FOR EACH ONE. DON'T PRESS ANY KEYS JUST YET. LET ME FIRST GET THE PROJECTOR PROGRAM GOING.

```
(put practice floppy in drive 1
set clkres=10, set current time
RUN RA-TEST3.L
command 0 - set projector times to 2,2,24
command 1 - step through slides for both projectors
when done move projectors to position 12 and
close shutters (2,0,0) and command 4)
```

FOR THIS SLIDE THE CORRECT RESPONSE IS.... ETC.

NOW LET ME ADD A FEW WORDS ABOUT THE EXPERIMENT. I AM GOING TO SHOW YOU THE SAME SET OF SLIDES IN A RANDOM ORDER IN GROUPS OF ROUGHLY 100. THERE WILL BE A TOTAL OF 10 GROUPS, 2 PRACTICE SETS AND 8 TEST SETS. BETWEEN EACH GROUP THERE WILL BE A 30 SECOND REST BREAK.

PLEASE SIT WITH YOUR CHIN IN THE CHIN REST DURING THIS EXPERIMENT. IT IS VERY IMPORTANT THAT YOUR EYE POSITION BE IN A FIXED POSITION RELATIVE TO THE WINDSHIELD. I CAN ADJUST THE THE CHIN REST IF NECESSARY. IS IT OK NOW?

LET ME LOAD IN THE TEST PROGRAM AND THEN I WILL ADD A FEW MORE REMARKS.

```
(RUN RT24.L
enter subject number and name, date, block, etc.
enter sr sequence
trials = 0,0)
```

SO, I AM GOING TO SHOW YOU ABOUT 100 SLIDES AT A TIME IN A RANDOM ORDER. LOOK AT EACH SLIDE AND DECIDE IF IT IS SAFE TO PROCEED. IF THERE IS ANOTHER VEHICLE IN YOUR LANE OR ABOUT TO ENTER IT PRESS THE LEFT KEY (THE BRAKE), IF IT IS CLEAR, PRESS THE RIGHT KEY. PLEASE RESPOND AS RAPIDLY AND ACCURATELY AS POSSIBLE BY TAPPING A KEY.

FINALLY, LET ME NOTE THAT THERE IS A CONSTANT 2 1/2 SECOND DELAY BETWEEN SLIDES TO ALLOW FOR THE PROJECTOR TO MOVE. DON'T USE THE PROJECTOR NOISE AS A CUE FOR WHEN THE NEXT SLIDE WILL APPEAR. SOMETIMES YOU WON'T HEAR THEM MOVE.

ANY QUESTIONS? OK, CHIN DOWN.

THIS IS A PRACTICE, READY?

Turn glare on and off as required.

Change windshields as required.

For test put data floppy in drive 1 - trials = 2,0