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Report No. VJ-2849-B-1

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AN INVESTIGATION OF FACTORS AFFECTING DRIVER ALERTNESS

E. Donald Sussman, Dominic F. Morris
Cornell Aeronautical Laboratory
of Cornell University
Buffalo N.Y. 14221

AUGUST 1970

FINAL REPORT

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Prepared for
DEPARTMENT OF TRANSPORTATION
National Highway Safety Bureau
Washington D.C. 20591

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This report has been reviewed and is approved by:

John H. Doolittle

John H. Doolittle, Head
Avionics Department
Cornell Aeronautical Laboratory, Inc.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.
VJ-2849-B-1

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
An Investigation of Factors Affecting Driver Alertness

5. Report Date
August 1970

6. Performing Organization Code

7. Author(s)
E. Donald Sussman   Dominic F. Morris

8. Performing Organization Report No.
VJ-2849-B-1

9. Performing Organization Name and Address
Cornell Aeronautical Laboratory of
Cornell University
Buffalo, New York 14221

10. Work Unit No.

11. Contract or Grant No.
FH-11-7313

13. Type of Report and Period Covered
Final Report

12. Sponsoring Agency Name and Address
U. S. Department of Transportation
National Highway Safety Bureau
Washington, D. C. 20591

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The study consisted of a review of the literature concerned with driver alertness, and an experimental investigation of the effects of three variables: driving time, acoustic noise, and task complexity on driver performance. The findings were that during long-duration, low-event driving, drivers showed a linear increase in road position error; during emergencies such as a blowout, the driver's position error increased after four hours of driving, and this increase is most marked under high noise conditions. In addition, the study revealed no degradation in performance attributable to the use of a "speed controller" (a device which automatically maintains a preset speed). The study also includes suggestions for future research and possible methods of alleviating the effects of reduced alertness.

17. Key Words
Alertness, Driver Performance, Cognitive Processing, Control Precision, Electroencephalography, Pre-Attentive Processing, Vigilance, Fatigue, Work/Rest Period

18. Distribution Statement
Availability is unlimited. Document may be released to the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151, for sale to the public

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
100

22. Price

Form DOT F 1700.7 (8-69)

PREFACE

This research program was sponsored by the Department of Transportation, National Highway Safety Bureau under Contract No. FH-11-7313.

In the course of this effort, the authors were able to call on a number of individuals without whose efforts the successful completion of this project would have been impossible. Therefore, grateful acknowledgment is given to: Mr. James Knight for his able assistance in the operation and design of the simulator, assistance in monitoring the subjects, and aid in analysis of the data; Dr. Robert Sugarman for his assistance in subject monitoring, data analysis, editorial comment, and general good advice; Dr. Albert Zavala for his excellent technical and editorial contributions; and, Mr. Gilbert Gagne for his aid in the preparation of the simulator.

The authors also wish to express their appreciation to the contract manager, Mr. Rube Chernikoff of the National Highway Safety Bureau for his excellent technical contributions and aid throughout the program; and to Dr. P. Robert Knaff of the National Highway Safety Bureau for his aid, advice, and support throughout the program.

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LIST OF ABREVIATIONS

ANOV	Analysis of Variance, a technique for testing the significance of the difference among three or more means.
EEG	Electroencephalogram, a recording of the electrical activity of the brain.
EMG	Electromyogram, a recording of the electrical activity of muscles.
GSR	Galvanic Skin Response, a change in the electrical resistance of the skin surface.
Saccadic Movement	A quick jump of the eye from one fixation point to another.

1. INTRODUCTION AND SUMMARY

1.1 Purpose of the Project

The purpose of the project was (a) to identify interactions of the vehicle, driver, and the road environment which tend to reduce driver alertness; (b) to objectively measure these decrements in alertness; and, (c) to delineate a program of research aimed at the development of countermeasures to reduce decrements in alertness.

1.2 Phase I

Phase I consisted of a review of the literature. In general it revealed most of the work touching on driver alertness has been concerned with basic input and output factors such as studies of decision making and vigilance. The review points out the need for more effort to be put into "real world" studies of driving as opposed to laboratory studies of factors hypothesized to be critical to driving. The review pointed out a number of areas which should receive more emphasis.

Research is necessary into the nature and cause of variations in the driver's ability to process information with particular emphasis on the role of preattentive processing and selective attention. The review also identified a lack of research of research into the effect of motivation on driving performance. The Literature Review appears as Appendix A of this report.

1.3 Phase II

The Experimental portion of the study was concerned with the effects of task complexity, acoustic noise level, and duration of trip on measures of alertness. In the interests of economy, precision, and safety, the study was conducted using the CAL driving simulator.

The results of the study were as follows:

1. The driver's ability to maintain his vehicle on the road under nonalerting conditions decreases linearly with time over four hours.

2. The rate of steering wheel corrections made by the driver decreases linearly with time over four hours.

3. On a per subject basis, there is a significant negative correlation between position error and steering wheel correction frequency. This may be taken to indicate that either the subject perceptually samples his road position less frequently after driving a number of hours or he processes and reacts to his road position less frequently over long duration driving.

4. Measurements of position accuracy during a simulated emergency indicate that the driver is less likely to be able to control his vehicle accurately during an emergency after four hours of driving than after one hour of driving and that this decrease in control during the emergency is most severe when the driver has been exposed to a high level of acoustic noise.

5. Analysis of occipital EEG recordings reveal an increase in the occurrence of alpha bursts for all subjects.

1.4 Phase III

Implications of the research were discussed. Included were considerations of modification to the road markings or road surface to reduce road position error and the analysis control inputs to measure decreased alertness. The need for on-road validation of the study was discussed and a research plan for such validation outlined.

2. EXPERIMENTAL STUDY

2.1 Experimental Rationale

The research effort described below was aimed at the study of changes in driver alertness during long duration, low event driving. The phenomena measured fell into two basic classes: measures of changes in skills or ability thought to be basic to safe driving and measures of changes in physiological parameters which have been hypothesized to be correlated with decreased alertness.

2.1.1 Independent Variables

It was hypothesized that acoustic noise, task complexity and task duration were the independent variables that would affect the onset of decreases in alertness. These variables are discussed in turn below:

1) The level of acoustic noise

Acoustic noise may be considered a stressor in the driving condition. As indicated in the literature review above, extremely high noise levels lead to increased fatigue. However, it was necessary for the purposes of this study to determine if noise levels of the magnitude of those commonly encountered in on-road driving would lead to variations in alertness. Further, the effect of extremely low noise levels on alertness was of interest. In particular it was necessary to determine whether very low noise levels would tend to enhance alertness or degrade it in long-duration, low event driving.

To this end measurements were made in existing vehicles representing low, moderate and high acoustic noise environments. From the measured noise levels of these vehicles, noise contours were simulated and used to represent the three levels of an independent variable representing acoustic noise. With regard to the effect of noise, it was hypothesized that both high and low noise levels would have a detrimental effect on alertness: a high noise environment increasing the rapidity of the development of fatigue, a low noise environment lulling or soothing the driver into reduced alertness.

2) Task complexity

Task complexity was also of interest. While it was generally found in our literature review that drastic reductions in information input to an operator result in decreased alertness, the effects of decreasing output demands on the operator are not clear. To apply this to the on-road situation, the question is asked: does simplifying the driver's task by providing for automatic control of vehicle speed reduce the driver's alertness? In order to ascertain this, two levels of task complexity were examined: a low task complexity situation in which the speed was automatically controlled and could be overriden in emergencies, and a moderate task complexity situation in which the driver had to control speed throughout the simulated trip. It was hypothesized that a low task complexity situation would result in decreased alertness.

3) Duration

The effect of duration of drive is of great importance. While it is to be expected that the probability of degradations in alertness increase with time, it is the magnitude of this decrease and the relative rate at which this degradation increases which are of interest. Does degradation in alertness begin immediately or does it require hours to manifest itself? Do degradations quickly reach an asymptote or do a series of plateaus occur representing different components of a complex process? In short, it was hypothesized that there would be increased degradation of alertness along time and that the shape of the curve or curves representing such decreases in alertness and the magnitude of error decreases would be correlated with noise level and/or task complexity.

2.1.2 Dependent Variables

One may consider performance in a driving task to be dependent on a number of basic abilities or skills manifested by the driver.

Among these skills are:

1) The ability of the driver to perceive simple stimuli critical to driving. Such stimuli may include other vehicles, signs, warning devices, and features of the roadway.

2) The ability of the driver to control his vehicle. This ability presupposes a skill level sufficient to provide for accurate maintenance of lane position, relative speed, acceleration, and deceleration rates.

3) The ability of the driver to adapt and respond to emergency conditions. Critical are responses to changes in vehicle handling due to a blowout or brake fade, or abrupt changes in road conditions due to ice or mud.

4) The ability of the driver to respond appropriately to complex information. Here the ability of the driver to obey relatively complex instructions or make decisions based on a number of simultaneous events is important to his ability to drive safely.

While it is likely that any of these abilities or skills might show some degradation during long duration driving, it may be hypothesized that the driver's ability to perceive simple stimuli, precisely control his vehicle, and respond to emergencies would be of greatest importance in situations where loss of alertness resulted from boredom or a low event environment. Degradation of the ability of a driver to respond appropriately to complex situations would most likely result from the information overloading in a high traffic density, high event environment. Because the research effort was to apply to low event driving, changes in the fourth type of skill were not investigated in this project.

In view of the above, the following dependent variables were selected for evaluation:

1) The driver's ability to precisely control his vehicle during low event driving: This was measured by recording the integrated absolute road position error (using the center of the lane as zero error) from the center of the lane during normal driving over the course of the experiment.

2) The driver's ability to control his vehicle during an emergency. This was measured by recording the integrated road position error during a simulated blowout.

3) The number of control inputs per unit time which the driver made. This was measured by recording the number of 2° steering wheel reversals made by the driver.

4) The accuracy of control of simulated velocity by the driver. This was measured by recording the integrated absolute velocity deviations from a speed the driver was required to hold.

5) The latency of the driver's response to a stimulus of increasing amplitude (ramp stimulus). Here the driver was asked to make a response to a light representing the headlights of a distant but oncoming vehicle.

6) The occurrence of alpha bursts (8-12 Hz 50 smooth waves) in occipital EEG. The alpha bursts in cortical EEG records are thought to reflect a drop in alertness or lapse of attention. An alpha block (the absence of alpha) is thought to reflect an alert state,

7) Decreased occurrence of saccadic eye movements. This decrease may be hypothesized to be correlated with decreased alertness.

8) Measurement of changes in GSR (galvanic skin response) during emergency situations. As such, it was hypothesized that changes in measured GSR during emergencies might occur due to decreased alertness.

9) Measurement of changes in an EMG signal taken from the muscles supporting the head. It was hypothesized that EMG variation would occur to the extent that physiological fatigue accompanied decreased alertness and that the muscles most likely to exhibit such fatigue are those which maintain the neck in an erect position.

2.1.3 Use of CAL Simulator

In order to achieve the greatest economy and maximize experimental precision, it was decided to conduct all tests using the CAL driving simulator. Use of the simulator provided for complete control of traffic, roadway, and meteorological variables which might have reduced the precision of an on-road experiment. Such conditions might include variations in traffic density, road surfaces, ambient light and/or weather. The simulator provided for greater economy in that it did not require rotating or full-time observers or experimenters to accompany the driver during the experiment.

Because the simulator as well as the data recording devices were automated, it was possible for the observer to both monitor the experiment and work at other tasks such as the reduction of data previously gathered. Use of the simulator virtually eliminated possible safety hazards. Complete loss of control of the simulator by the subject resulted in an override shut-off by the computer and a manual reset by the operator. Such a loss of control on the road would have been disastrous. Finally it was possible to control the independent variables in the experiment (noise level, task complexity and duration of drive) more economically and precisely than would have been possible in an on-road testing situation. Figure 1 depicts a subject in the simulator ready for testing.

2.2 Methods

2.2.1 Subjects

Paid subjects were obtained from the following sources: the staff of CAL, the student body at The State University College at Buffalo, and the student body of The State University of New York at Buffalo. A total of 69 subjects were used in the various stages of the experiment. Of these subjects 11 were used in pretesting, adjusting, and modifying the simulator. The data from 10 other subjects were not complete and/or usable, due to equipment malfunction or due to subject discomfort or lack of their cooperation. Subjects were tested in the experiment until a total of 48 data runs, which were complete and relatively free from artifact, were available.

All subjects were male. The age of the subjects ranged from 20 years through 57 years old. All subjects had more than two years and 24,000 miles of driving experience and a currently valid driver's license. All subjects had normal uncorrected vision.

2.2.2 Apparatus

Subjects were tested using the CAL driving simulator. This is a computer based simulator which is capable of being driven by a subject and provides an auditory, visual, and motion environment similar to that encountered in "on-road" driving situations. The simulator consists of the following:

1. An hydraulically actuated base capable of ± 40 degrees in yaw (rotation about the Z-axis and ± 10 degrees in roll (rotation about the X-axis). The response of the base in both degrees of freedom is of 2 Hz bandwidth.

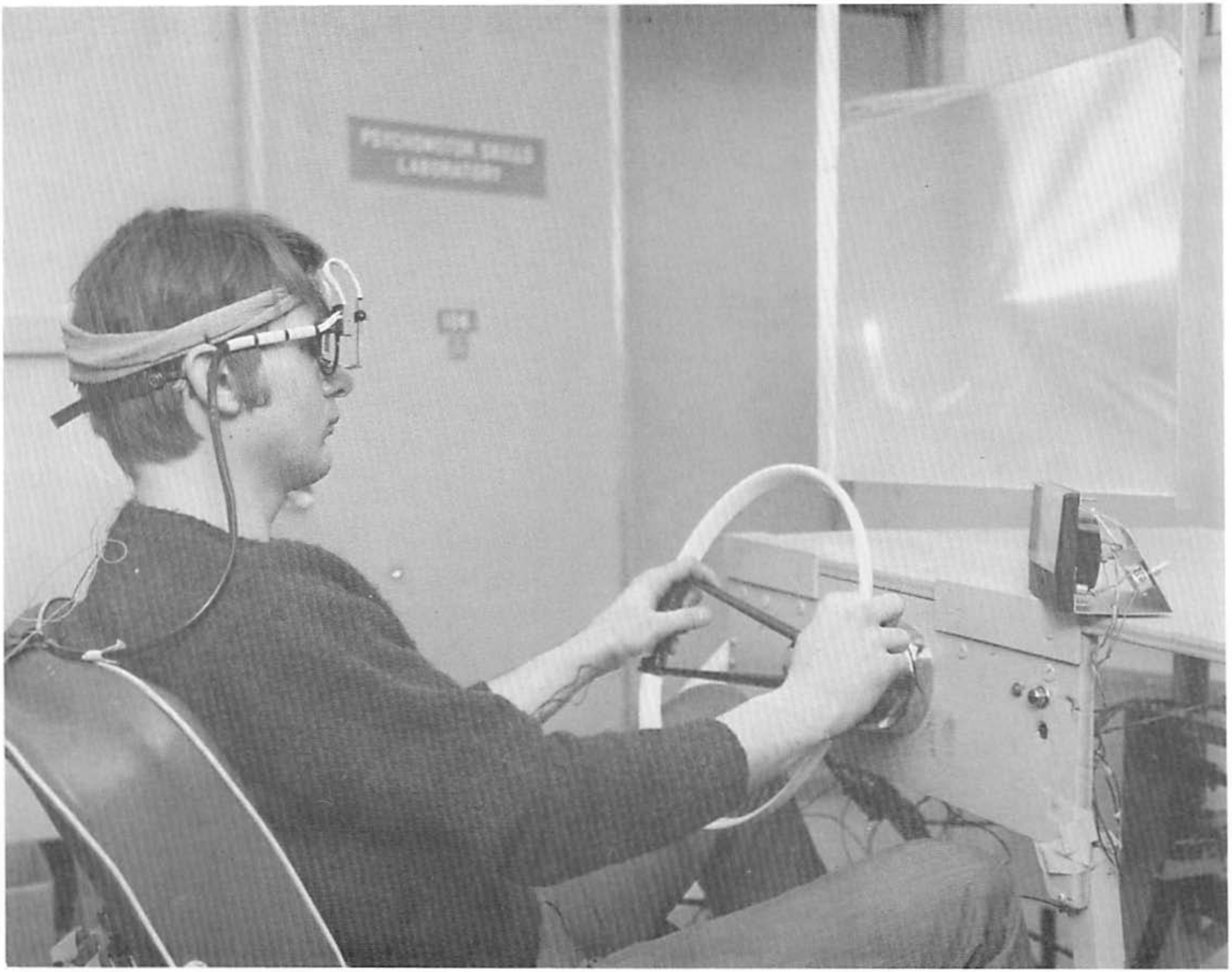


Figure 1 SUBJECT IN THE DRIVING SIMULATOR

2. A driver control station mounted on the base. The station includes an adjustable seat, a dashboard with a speedometer and a button for signaling the experimenter, a steering wheel, an accelerator pedal, and a brake pedal. The control dynamics are passive in terms of feedback and approximate power steering, power brakes, and an ordinary accelerator.

3. A visual display system composed of a four-channel Tektronix oscilloscope, a Schmidt projector, a rear projection screen, and a Fresnel collimating lens. The cathode ray tube (CRT) has been removed from the oscilliscope and mounted on the Schmidt projector. The projector has sufficient brightness to produce a clearly visible image in a darkened room. The rear projection screen is curved so that the image remains the same distance from the subject as the platform moves in yaw, and so that the image will stay more nearly in the curved surface of focus of the projector. The Fresnel lens is used to increase the apparent distance to the highway. The system provides a field of view of ± 25° horizontally and ± 20° vertically.

The signals which represent the highway are generated on the computer and modified to show correct perspective from the position and attitude of the vehicle. The highway is represented by three separate lines corresponding to the center and side lines and a filler or lighter area as the road surface. A variable graduated neutral density filter is used over the projection lens. This filter causes the image to be dimmest at the point where the road appears to converge, effectively enhancing the illusion of depth.

For the purpose of the present study, a second oscilloscope and lens are used to project various events to which the subject responds. The subject was provided with a light near the convergence point which appeared and brightened over a ten second interval. The effect of this was a light source which appeared to be approaching the driver. A second event was depicted by a diamond which appeared and both brightened and grew in size until it filled the road. The diamond shape appeared to be an obstacle which was moving at a slower rate than the driver.

4. An EAI model TR-48 analog computer. This computer performs three basic tasks. First, it accepts the driver's input signals and externally produced disturbance signals and produces output signals representing the motion of the vehicle that is being represented by a vehicle dynamics model. Second, the position servo loops for the motion platform are closed on the computer. That is, the compensating dynamics to make the closed loop servo sufficiently stable and fast are programmed on the computer. Third, the roadway signals for the projection system are generated on the computer. The motion platform servos and the display generator use the vehicle motion signals as inputs. The equations of motion programmed on the computer may be easily modified to represent changes in the vehicle parameters such as the steering ratio or roll axis position. Speed changes due to the use of the brake or accelerator are represented by changing the apparent speed of the road image, by changing the equations of motion, and by changing the reading on the speedometer.

The simulated speed may be controlled in either of two ways: 1) in the normal control mode, the driver can control the speed using his accelerator and brake; and 2) in the automatic mode, the computer controls the speed. The driver can disengage the automatic control by applying the brake. Release of the brake re-engages the speed controller. In both modes, the simulator is capable of speeds ranging between fourteen and seventy miles per hour .

5. Acoustic Display. Measurements of noise contours in selected vehicles was performed using a Hewlett-Packard octave band noise analyzer (Model 1558 BP). Figure 2 shows these contours. Acoustic noise contours similar to those measured in on-road operation were provided through filtering of the signal from Grason-Stadler white noise generator (Model 901B). The resulting filter output was amplified using a Dynaco preamplifier and Dynaco and MacIntosh amplifiers. The signal was reproduced using two AR-4 and one KLH-6 speaker systems. Figure 3 shows the sound contours used for the three noise levels.

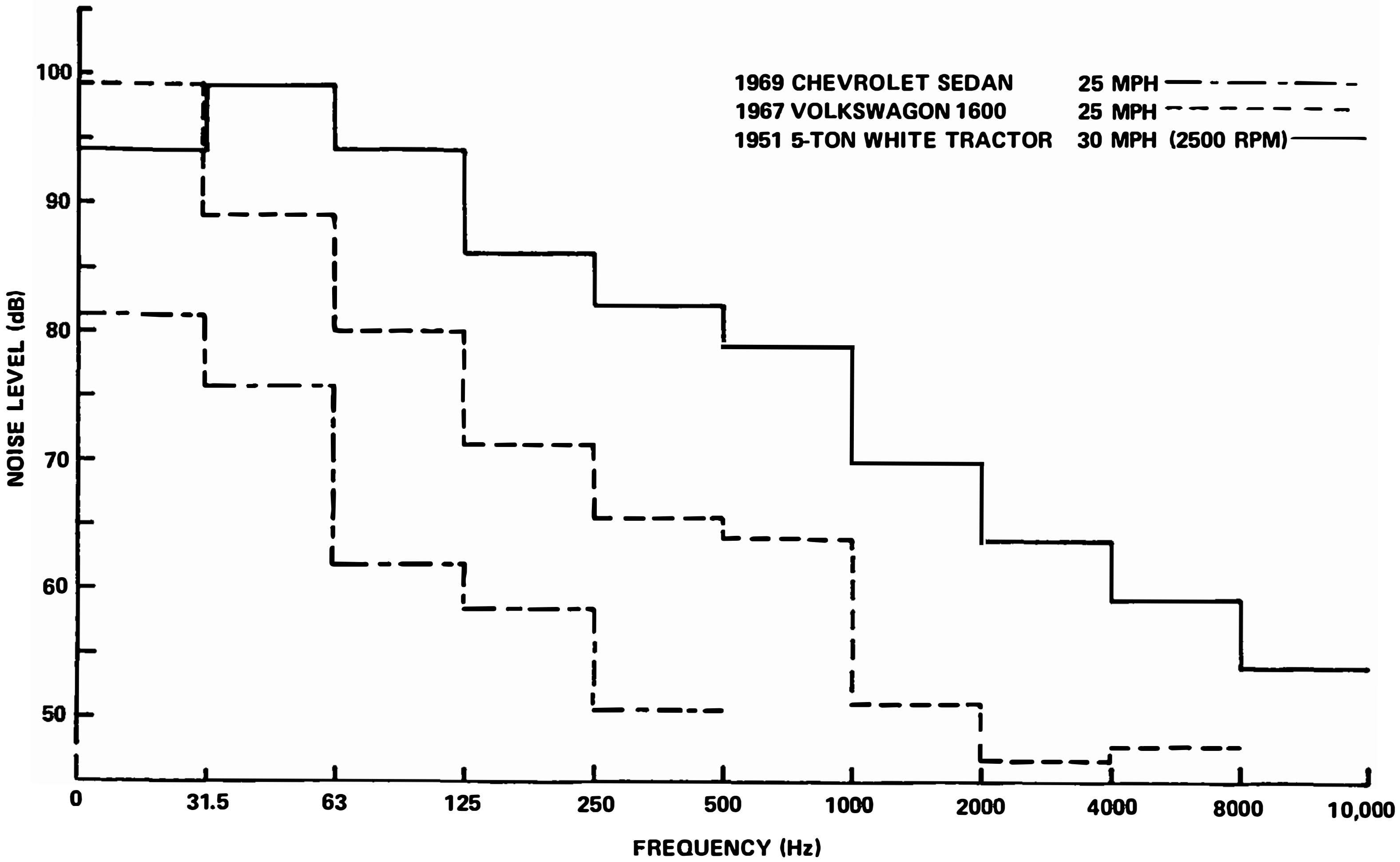


Figure 2 ACOUSTIC NOISE SPECTRA MEASURED IN THREE SELECTED VEHICLES

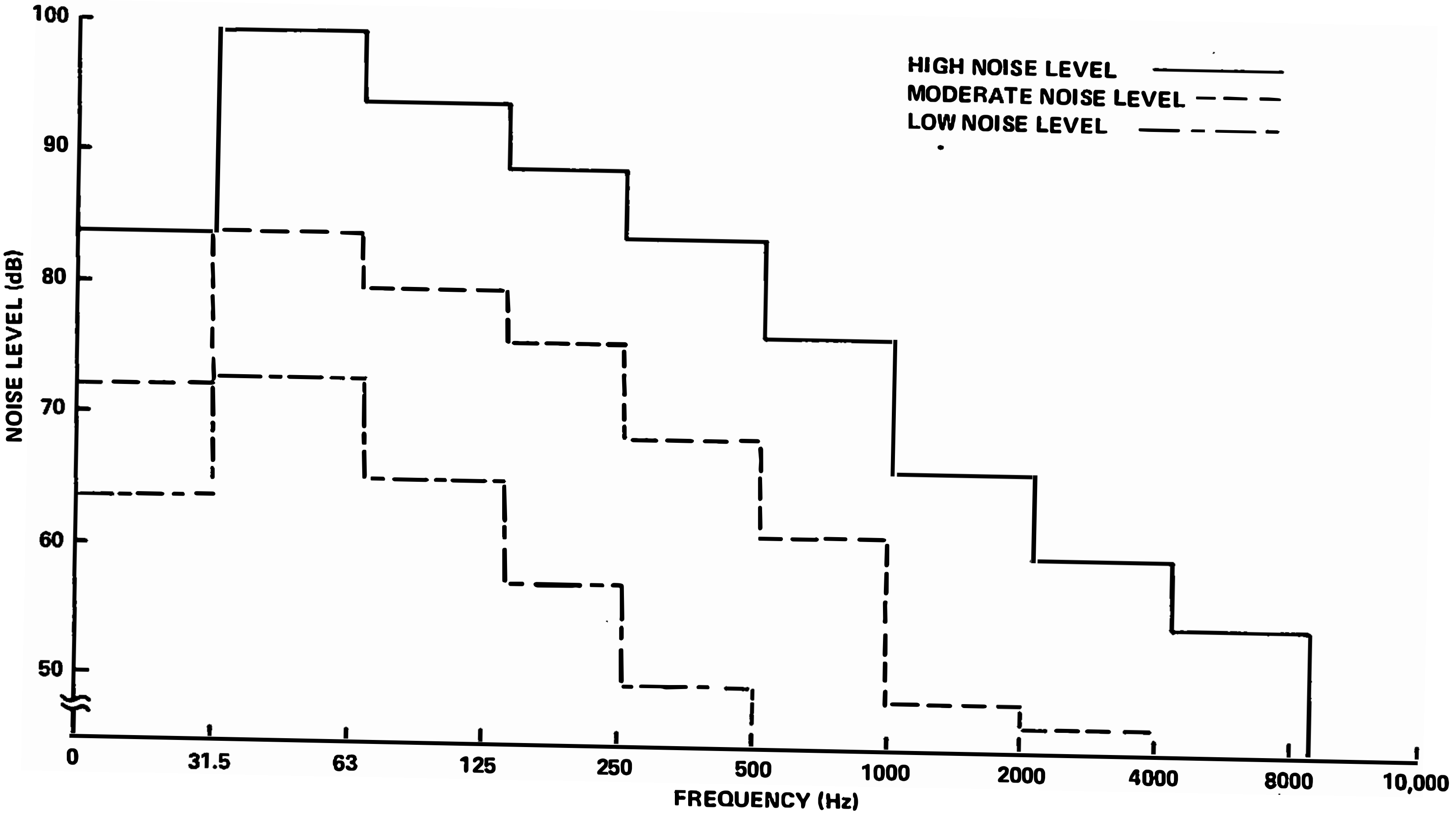


Figure 3 NOISE LEVEL CONTOURS USED IN THE STUDY

6. External Events. The EAI computer in conjuction with a Hewlett-Packard sequence noise generator (Model 3722A) provided external perturbations which were used to simulate external wind gusts and road irregularities. The disturbances were of low amplitude. They are provided in order to ensure that the driver makes periodic corrections in order to remain on the road (on the average at 55 miles per hour the vehicle would leave the road, if no corrections were made in 20 seconds). As the noise signals are derived from binary sequence, all subjects received the same perturbations at the same point in the experiment. The computer in conjunction with a Hewlett-Packard function generator provided a simulated blow-out. Using a d. c. offset in yaw and roll plus a 0. 5 Hz oscillation in roll and a 0. 5 Hz acoustic signal on the background acoustic noise, an event resembling a blow-out was achieved.

7. System Programming. All events during the four hours of the experiment were controlled sequentially and timed using a Grason-Stadler behavioral program system. The experiment was programmed on a 375 contact sequential stepper and controlled through electromechanical relays.

8. Recording Equipment. A brush eight-channel polygraph (Mark 200) was used to record the following variables: 1) GSR; 2) EEG; 3)EMG; 4) /EMG/ ; 5) vertical eye-movement; 6) horizontal eye movements; 7) steering wheel position; and, 8) programmed events.

A Hewlett-Packard physiological amplifying system was used to obtain signals for GSR, EEG, EMG, and integrated absolute EMG. Signals for horizontal and vertical eye-movements were obtained by using a Space Sciences Inc. Eye-Movement Monitor (SGH-V-2). Signals for the steering wheel motion and programmed events were obtained from the EAI TR-48 analog computer. The Brush recorder was programmed to record 25 one-minute samples during the experiment as well as during the practice and post-test period. The inter-sample interval averaged ten minutes.

A CAL-developed six-channel FM tape recorder was used to record the following signals: 1) simulated road position; 2) steering wheel position; 3) accelerator position; 4) simulated velocity; 5) programmed events; and, 6) a null signal used in playback. All of these signals were obtained from the EAI TR-48 computer. The FM tape recorder was programmed to record the same 25 one-minute selected samples as the Brush recorder, as well as the practice and post-test periods.

A Grason-Stadler three-channel printing counter (Model E4500A-1) was used to record the following: 1) integrated absolute road position error; 2) absolute velocity error; and 3) two degree steering wheel reversals. Integrated absolute road position error and absolute velocity error were obtained from the EAI TR-48 analog computer. Two degree steering wheel reversals were obtained directly from a CAL fabricated steering wheel sensor. The printer provided an on-line, real-time continuous record of the data as it printed scores for each of the 240 minutes of the experiment, as well as the practice and post-test periods.

A Sanborn two-channel graphic recorder was used to record the following: 1) 12° steering wheel reversals; and 2) integrated absolute road position error (a backup measure). The 12° steering wheel reversals were obtained from a CAL-fabricated sensor. The integrated absolute road position error was obtained from the EAI TR-48 computer. Due to programming error data representing 12° steering wheel reversals was unanalyzable.

A Hewlett-Packard Electronic Counter (524C) and Digital Recorder (560A) were used to time and print-out the subject's response latency to the brightening light.

All programming and recording equipment which were likely to provide acoustic cues to the subject were kept in an Industrial Acoustic Sound Isolation chamber (Model 1204A).

2.2.3 Experimental Design

The effect of two independent variables on the subject's performance over time was examined using a three-factor design (two levels of task complexity x three levels of acoustic noise x time and with repeated measures over time). As data from forty-eight subjects were used, each of the six treatment groups contained eight subjects. The following dependent variables were measured: integrated road position error, integrated absolute velocity error, number of two and twelve degree steering wheel reversals (these were measured continuously and means computed for each half-hour); EEG, EMG, GSR, horizontal and vertical eye movements, road position, velocity, steering wheel position, and accelerator position (these variables were sampled twenty-five times during the experiment); response latencies to a ramp stimulus (recorded 17 times).

2.2.4 Procedure

Upon arrival at the experimental station, subjects were briefed on the experiment. They were told that the experiment was designed to evaluate the efforts of long distance driving. They were then given consent forms to read and sign. A sample form is found in Appendix A.

Next, electrodes for EEG and EMG recording were applied using surface electrodes of the "bandaid" type. The skin surface was prepared by washing with alcohol and rubbing with "Redux" electrode paste. Electrodes were then tested for impedance. In general, a d. c. impedance of less than 6000 ohms was achieved resulting in signals of relatively high quality. A single bipolar EEG placement was used for all subjects. The placement was the bipolar parietal-occipital placement ($P_3 - 0_1$ according to the "10-20" system) with the left ear lobe (A_1 according to the "10-20" system) as a reference.

EMG placement was the standard neck placement as recommended in Davis (1959). This is a bipolar placement from the semispinalis-capitis muscle to the splenius capitis muscle. The reference here was again the left ear lobe (A_1 "10-20" system).

The GSR measurement utilized a pair of electrodes on the surface of the left palm. Electrodes here were Ag - AgCl "cup types". The electodes were packed with cotton which had been moistened by a physiological saline solution.

It was suggested that as the subject was to spend several uninterrupted hours in the simulator, it would be wise for him to relieve himself and/or get a drink before the experiment began. After the subject returned, he was seated in the simulator and the seat was adjusted. All sensors and electrodes were then adjusted and/or corrected and gains and filters adjusted.

The EEG signal was adjusted so that 50µV gave a 1 cm pen deflection. As the purpose of the EEG recording was only to detect the occurrence of the alpha rhythm, a 1.5 Hz to 20 Hz bandpass filter was used.

The EMG signal was adjusted so that 100µV gave a 1 cm deflection. Here only a 1.5 Hz high pass filter was used. The GSR recording utilized no filtering. The gain was adjusted so that a 1 cm pen deflection was equivalent to 25 ohms change in skin resistance.

The subject was next fitted with the eye-movement sensors which are part of the eye-movement monitor. Subjects were then given instructions as to their role in the experiment. The instructions for the subjects in the moderate task complexity group differed slightly from those of the low task complexity group.

The moderate task complexity group was told the following:

"On the screen you will see a two-lane road. The road will be defined by three lines representing the right border, the center of the road, and the left border. Your job will be to drive on the right lane. We would like you to drive as smoothly as possible in this lane."

"You have control of your speed through the use of your accelerator and brake pedal. Your speed will be indicated on the speedometer. The simulator has a speed range from 14 to 70 miles per hour. We would like you to operate it at between 50 and 60 miles and to try and keep as close to 55 miles per hour as you can."

"At times you may feel that you are going up a hill, you will notice a speed drop in the road and on your speedometer. When you sense a hill, adjust your accelerator to maintain your speed at 55. You may see a blue brightening light at the point where the road converges. This will represent an approaching driver's high beams. As soon as you see this light, press the switch to the left of the brake. The switch is similar in placement and function to a dimmer switch. When you press it, it will click. Just as in a real vehicle, the switch will not turn off the approaching vehicle's lights. You will be timed on this response, so make it as rapidly as possible."

"You may see a diamond shape approach you in the road. It will begin as a small dot and grow to fill your lane. This shape will represent a slow moving truck. If the shape appears, attempt to avoid it by changing into the left lane. When the diamond disappears, you should re-enter the right lane."

"You may experience what feels like a "blow-out". Here the simulator will begin to roll, vibrate, and pull to the side of the road. If this should occur, stay in the right lane and try to maintain control of the vehicle. Slow the vehicle down and remain in your lane until the "blow-out" is over."

"There is a red button below the speedometer. PUSH IT! As you can hear, the button operates a gong. If something should go wrong with the simulator or if you feel sick, you can use this button to signal the observer. Do you have any questions?"

"You can now practice for a few minutes before the experiment starts."

In the low task complexity condition, the instructions were the same with the following exception; instead of being told they could control their speed the operator said: "Your speed will be controlled by the computer. It will remain at a speed between 50 and 60 miles per hour (approximately 55 miles per hour). While you will not be able to exceed the preset speed, application of your brake will disengage the speed controller and allow you to slow the simulator to its minimum speed of 15 miles per hour. Release of the pedal will re-engage the speed controller and return you to the preset speed." After the instructions were given, the subject was then given about four minutes of practice. During the practice period, the subject experienced the brightening light. At this time, the experimenter was able to ascertain if he was responding correctly and also correct him if he did not.

After the practice period was finished, the subjects were asked if they had encountered any problems. If they indicated that they had no problems or questions, the experiment proceeded.

The experiment proceeded for 240 minutes. During this period, the driver experienced 17 brightening lights, three obstacles, three hills, and one simulated blow-out. Table 1 details the events and the times at which these events occurred.

After the 240 minutes, the simulator was turned off. The subject's electrodes and sensors removed, and the subject allowed to walk around, relieve himself and/or get a drink of water. After the subject had been out of the simulator for four minutes he was requested to drive it for about two more minutes to allow for posttest measures. During this posttest, no measures of EEG, GSR, EMG, or eye-movement were recorded.

Not all subjects were able to last for the entire 240 minutes. In cases where the subject indicated that he felt ill, the experiment was terminated and the subject debriefed and paid. In cases where the subject indicated that he was bored, he was told that this was not uncommon and encouraged to continue. If he still was reluctant after encouragement, the subject was released, debriefed, and not paid.

During the experiment, the subject encountered the following kinds of events:

1. Ramp stimulus. This was a brightening light which appeared at the convergence point of the road. The subject was expected to respond to it much as he would to the high beams of a car approaching on the highway. The subject encountered this once during practice, 17 times during the experiment, and once during the posttest.
2. Avoidance emergency. Here the subject was asked to avoid an object which appeared to be approaching him. This occurred three times during the experiment.
3. Hills. These were only encountered by subjects in the moderate task complexity condition. Hills were indicated by a slowing of the projected display and change in the speedometer. Subjects were expected to correct speed changes, due to the hill, through use of their accelerator. The simulated hill occurred four times during the experiment.
4. Blow-out. Here the subject encountered an abrupt change in the motion parameters of the simulator similar to a blow-out. The subject was expected to maintain control of the vehicle during the blow-out. This occurred once during the experiment.

Table 1 represents the scheduled occurrence for each of these events. It should be noted that there are four orders of occurrence. These orders provided counterbalancing of the emergency condition. Using such counterbalancing, 12 of the 48 subjects encountered the emergency condition during hour one (minute 18), 12 during hour two (minute 79), 12 during hour three (minute 159), and 12 during hour four (minute 228).

TABLE 1

SCHEDULE FOR SAMPLING PERIODS AND PROGRAMMED EVENTS

		Time in Minutes																								
		2	10	18	28	40	50	59	69	79	89	100	108	119	128	139	150	159	170	178	188	199	208	220	228	240
All Orders	Road Position, Velocity, Accelerator Position, EEG, EMG, GSR, Eye Movements	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Ramp Stimulus	x			x	x		x			x	x	x	x		x	x		x	x	x	x	x	x		x
Order 1	Avoidance									x								x							x	
	Blowout			x																						
Order 2	Avoidance			x														x							x	
	Blowout									x																
Order 3	Avoidance			x						x															x	
	Blowout																	x								
Order 4	Avoidance			x						x								x								
	Blowout																								x	

2.2.5 Recapitulation of Experimental Method

Three independent variables were used: task complexity, acoustic noise level, and time.

Two levels of task complexity were used. In the low task complexity situation, the simulator speed was maintained by the computer. In the moderate task complexity situation, the driver was required to control the speed.

Three levels of acoustic noise were used. The noise levels represent noise frequency contours obtained through the measurement of actual vehicles. Figure 2 depicts the noise contours encountered in three representative vehicles. From examination of contours, artificial contours were derived to represent low noise vehicle, moderate noise vehicle, and a high noise vehicle. Figure 3 represents the actual noise contours presented to the subjects in the experiment.

By considering the six treatment conditions and the four orders of emergency presentation, 24 treatment-order combinations are possible. The sequence in which the treatment-order combinations were tested was obtained by randomly assigning treatment-order to test dates. A random permutation of the 24 test dates was applied to the treatment-order combination. The randomized order was repeated twice in order to provide a sequence of all 48 subjects. Table 2 shows the treatment-order combinations and the sequence in which they were tested.

TABLE 2

EXPERIMENTAL TREATMENT COMBINATIONS AND SEQUENCES

Task Complexity	Noise	Order	Sequence
Moderate	High	Order 1a	2, 32
		Order 2a	14, 40
		Order 3a	4, 28
		Order 4a	3, 27
	Moderate	Order 1a	1, 35
		Order 2a	21, 46
		Order 3a	26, 30
		Order 4a	18, 43
	Low	Order 1a	24, 34
		Order 2a	15, 41
		Order 3a	20, 45
		Order 4a	7, 31
Low	High	Order 1b	19, 44
		Order 2b	23, 48
		Order 3b	9, 36
		Order 4b	8, 33
	Moderate	Order 1b	37, 10
		Order 2b	29, 5
		Order 3b	11, 6
		Order 4b	42, 17
	Low	Orber 1b	39, 13
		Order 2b	22, 47
		Order 3b	16, 25
		Order 4b	12, 38

3. RESULTS

3.1 Analysis of Results

The data to be analyzed, with one exception, represent repeated measures on subjects over time. An analysis of differences between the curves representing the performances of subjects within treatment groups was performed. In such tests, if the data are parametric, coefficients of orthogonal polynomials representing various order polynomials (linear, quadratic, and cubic) and fitted to the data for each subject.

A coefficient representing the degree to which each subject's data fit the trend under test is computed. An analysis of variance on the coefficient representing the fit of each subject's score to the polynomial under question is then performed for each trend analysis. As the study under discussion was intended to measure the effects of two levels of task complexity and the levels of acoustic noise on various measures of alertness over time, the summary tables include the following entries:

Within Subject -- variation attributable to a subject.

Time -- variation attributable to the effects of time at the task

Time x Task -- variation due to differences in performance over time between groups receiving different levels of task complexity.

Time x Noise -- variation due to difference in performance over time between groups receiving different levels of noise.

Time x Task x Noise -- variations attributable to differences between groups differing in both task complexity and level of noise.

Time x Subject Within Groups -- variation attributable to within group differences over time (residual variance).

It was hypothesized that the decreases in alertness accompanying long-duration driving could be manifested in various ways.

The ability of the driver to accurately maintain his vehicle within his lane could be expected to deteriorate as alertness decreases. To measure this, the extent to which the vehicle deviated from the center of the lane, integrated absolute road position error was recorded. An analysis of the recordings revealed that road position error increased in a linear fashion during the four hours of the experiment. An analysis of variance of the data revealed that the probability of the linear trend being due to chance was less than 0.01. Table 3 is an analysis of variance summary table representing this data.

TABLE 3

ANOV SUMMARY TABLE FOR LINEAR TRENDS IN INTEGRATED ABSOLUTE ROAD POSITION ERROR

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Within Subjects	3240.11	48		
Time	436.80	1	436.80	7.58**
Time x Task	11.03	1	11.02	0.20
Time x Noise	197.01	2	98.50	1.70
Noise x Time x Task	165.31	2	82.65	1.43
Time x Subject Within Group	2429.96	42	57.85	

**$P < .01$; $F_{crit.\ (.01)}(1,40) = 7.31$

Tests for higher trends, quadratic and cubic, yielded no significant differences.

As there were no differences between groups due to the effect of task complexity or noise over time, the data for all six treatment groups were pooled. Figure 4 represents the change in integrated absolute road position

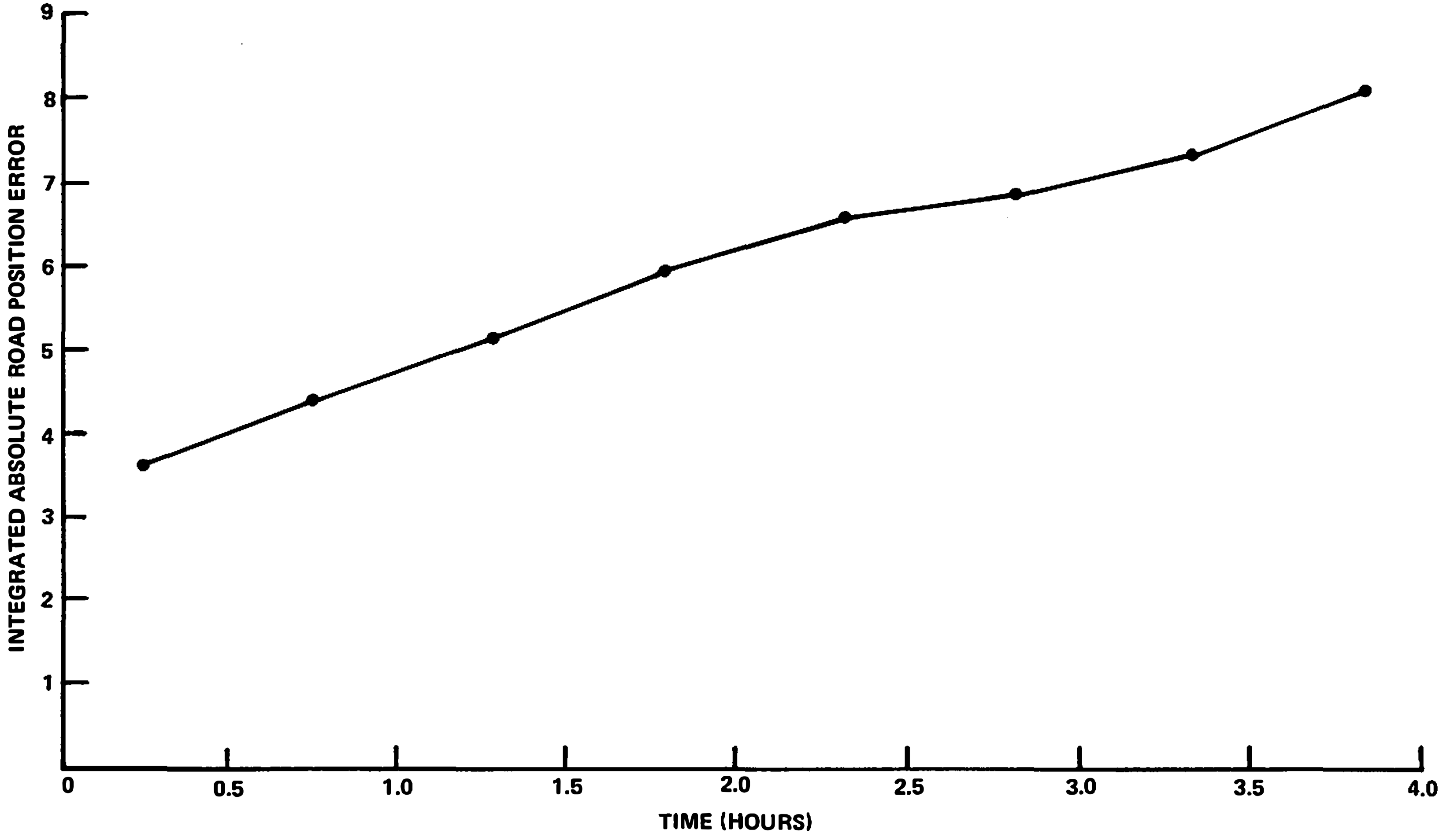


Figure 4 INTEGRATED ABSOLUTE ROAD POSITION ERROR AVERAGED OVER HALF HOUR PERIODS

error over time. Integrated absolute road position error scores were also obtained during a one-minute post test. The mean score for the post test was 4.23 with a standard deviation of 1.87. A comparison of this score with road position error scores obtained during the four hour driving period indicates that performance in the post test was similar to performance obtained in the second half hour of driving.

It was hypothesized that changes in the rate of steering wheel movements or corrections would occur with decreased alertness. Analysis of fine steering wheel corrections made (two degree steering wheel reversals) indicated that there was an overall linear decrease in the number of fine steering wheel corrections made by the driver over the four hours of the experiment. The probability that this linear decrease in correction was due to chance was less than .01. Table 4 is an analysis of variance summary table for the linear trends in the steering wheel data.

TABLE 4

ANOV SUMMARY TABLE FOR LINEAR TRENDS IN 2° STEERING WHEEL REVERSALS

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Within Subjects	1880.51	48		
Time	603.25	1	603.25	22.17**
Time x Task Complexity	12.35	1	12.35	.45
Time x Noise	19.73	2	9.87	.73
Time x Noise x Task	103.29	2	51.64	1.90
Time x Subject Within Groups	1142.24	42	27.20	

**P $<$ .01; $F_{crit.\ (0.1)}$ (1,40) = 7.31

Tests on higher order trends, linear and quadratic, revealed no significant differences. Figure 5 shows the changes in fine steering wheel reversals over time. As the analysis revealed no differences due to the effects of task complexity or noise, the data for all six treatment groups were pooled.

As would be expected, comparisons of dichotomized data for each subject using a contingency table revealed a significant negative correlation ($p < .001$ $X^2 = 18.33$) between error score and steering wheel correction. Using Guilford's (1954) formula for the ϕ coefficient of correlation $\phi = -.54$.

It was hypothesized that a decrease in the driver's ability to accurately maintain a constant speed would occur with reduced alertness. However, analysis of integrated absolute velocity error for the 24 subjects in the moderate task complexity group revealed no differences due to time or noise level which could not be attributed to chance.

Figure 6 graphically depicts the data for integrated absolute velocity over time. As there were no differences between the three treatment groups, the data were pooled for all 24 subjects.

It was hypothesized that the latency of response to a stimulus of increasing amplitude would be expected to deteriorate with decreased alertness. An analysis of response latencies to the ramp stimuli was performed for linear, quadratic, and cubic trends. No significant difference due to noise, task complexity, or time were revealed. Figure 7 represents response latencies to a ramp stimulus as a function of time.

Decreased alertness had been hypothesized to affect the operator's ability to cope with a sudden emergency. To measure this, a simulated "blowout" was provided during the first, second, third, or fourth hour of the experiment. The indicant of the driver's ability to cope is road position error during the duration of the simulated "blowout." It should be noted that the scores taken during the simulated "blowout" were not included in the overall analysis of road position described above. An analysis of the data suggested that road position error during the emergency occurred during the fourth hour.

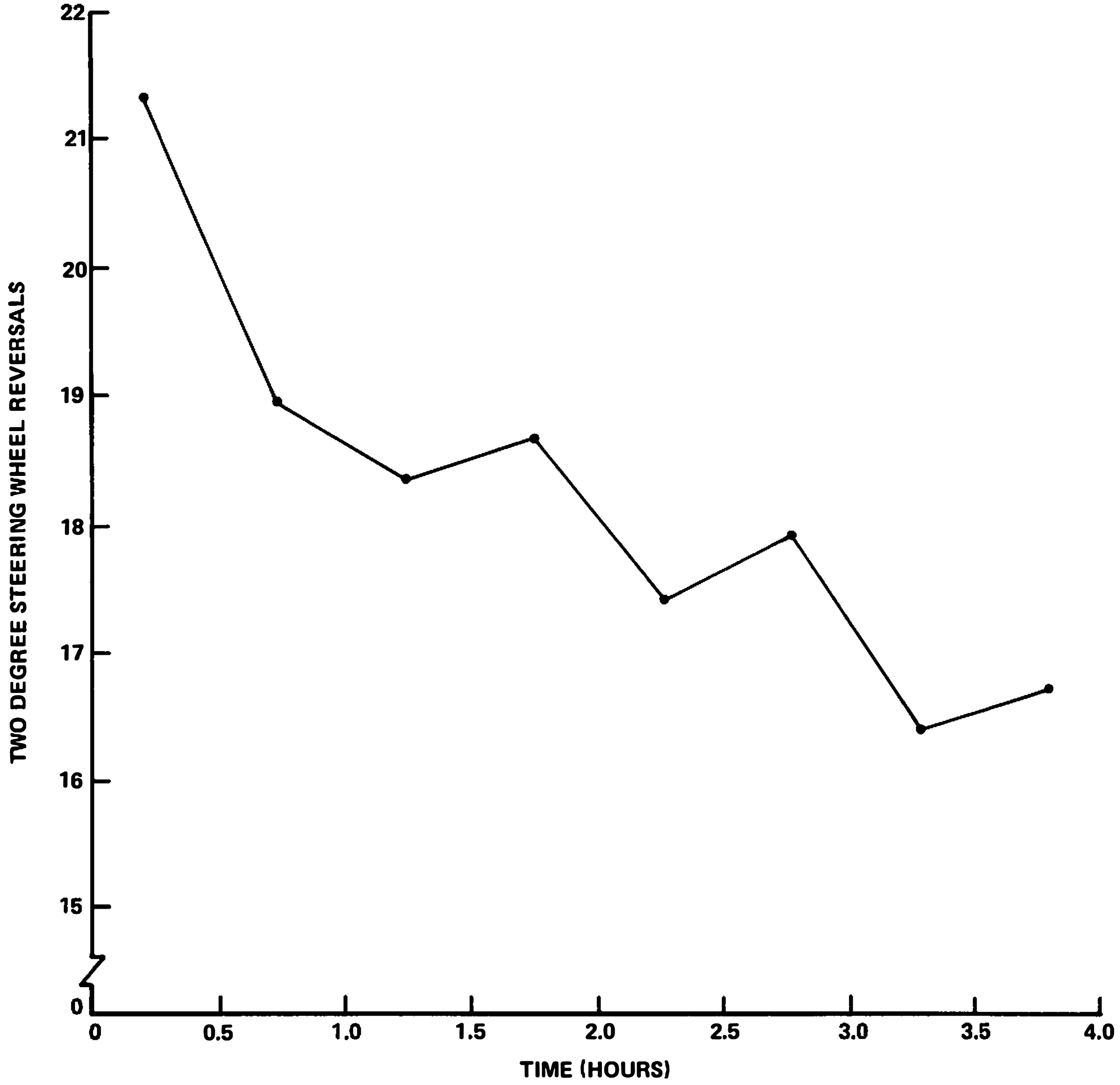


Figure 5 2° STEERING WHEEL REVERSALS AVERAGED OVER HALF HOUR PERIODS

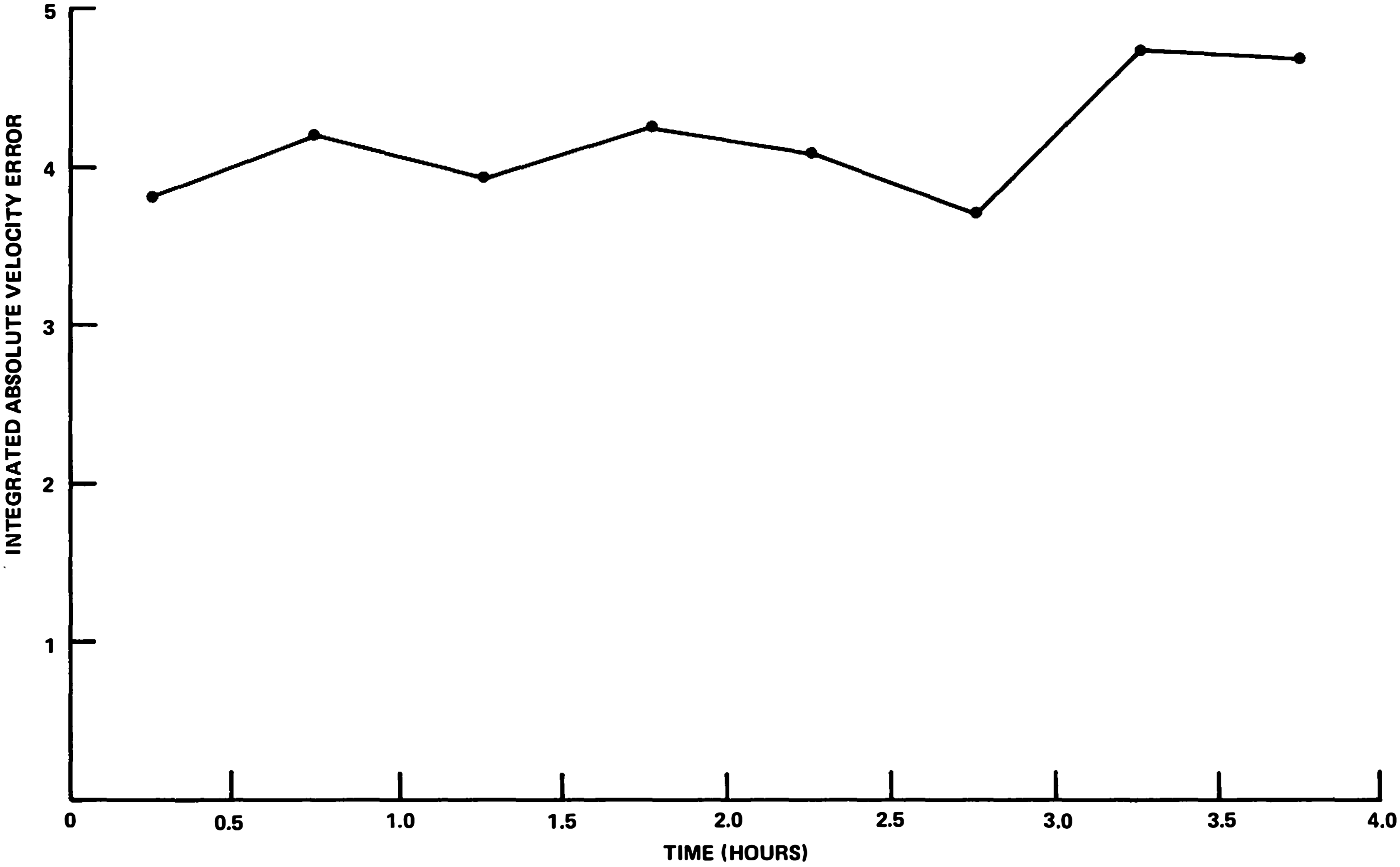


Figure 6 **INTEGRATED ABSOLUTE VELOCITY ERRORS AVERAGED OVER HALF HOUR PERIODS**

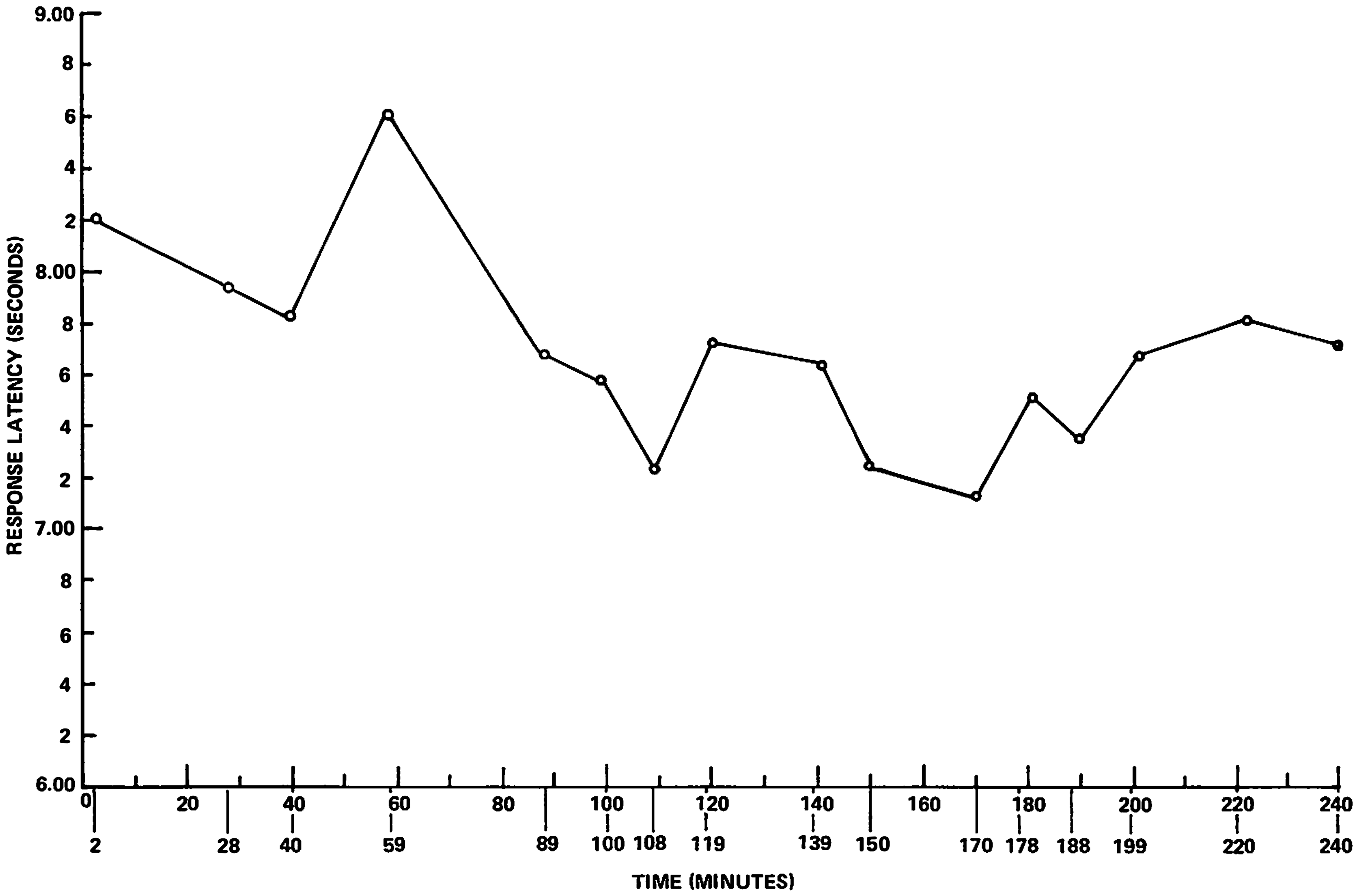


Figure 7 RESPONSE LATENCY TO A RAMP STIMULUS

Each subject encountered the blowout only once during the course of the experiment. Therefore, it was not possible to utilize a repeated measure design and evaluate relative changes in performance. Instead, a simple non-repeated measures factorial analysis of variance was performed. This analysis suggested that there was an effect due to time ($p < .05$).

Table 5 is the analysis of variance summary table for road position error during the blowout.

TABLE 5

ANOV SUMMARY TABLE FOR ROAD POSITION ERROR DURING THE BLOWOUT

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Time	244.50	3	81.50	3.01*
Noise Level	35.22	2	17.61	0.65
Task Complexity	8.33	1	8.33	0.31
Time x Noise	191.45	6	31.91	1.17
Time x Task	20.84	3	6.95	0.26
Noise x Task	51.12	2	25.56	0.93
Time x Task x Noise	262.21	6	43.70	1.61
Within Group	652.00	24	27.07	
Total	1465.67	47		

$^{*}P < .05$; $F_{\text{crit. } (.01)}^{(3,24)} = 3.01$

Figure 8 is a graphic representation of this data. Examination of the graph reveals that the greatest error occurred during hour four.

An analysis of simple effects was performed which revealed that the increase in integrated absolute road position error at hour four could be attributed to increases in the scores of subjects receiving the high noise level R ($P < .05$ $F_{\text{cit. } 05}$ $(2, 36) = 3.60$). Figure 9 illustrates the performance differences between noise levels as a function of time.

An analysis of the frequency of occurrence of alpha bursts in the occipital EEG data was performed. For the purposes of the analysis, a judge was trained to recognize alpha bursts as they occurred in the polygraph

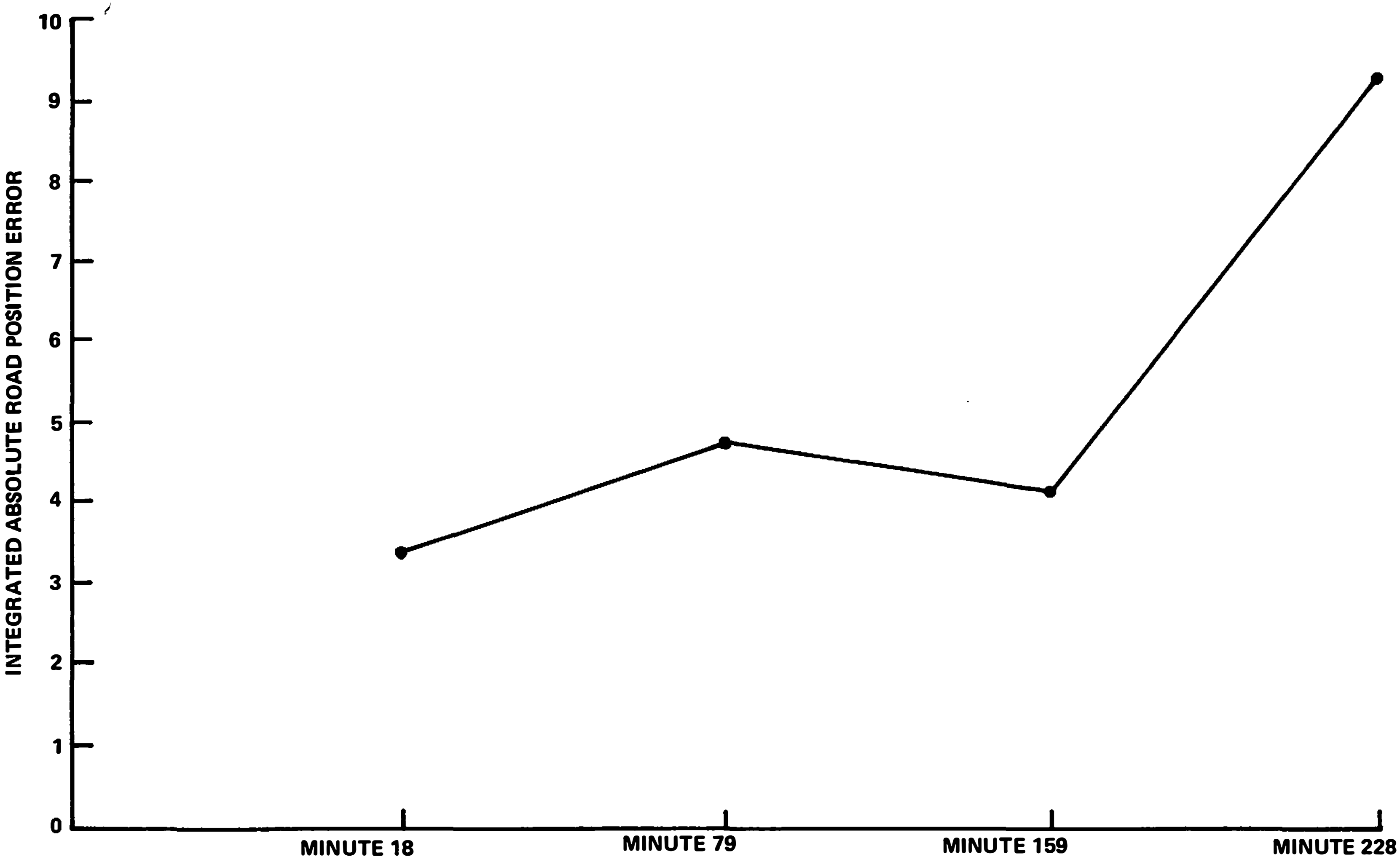


Figure 8 INTEGRATED ABSOLUTE ROAD POSITION ERROR FOR ALL SUBJECTS DURING BLOWOUT

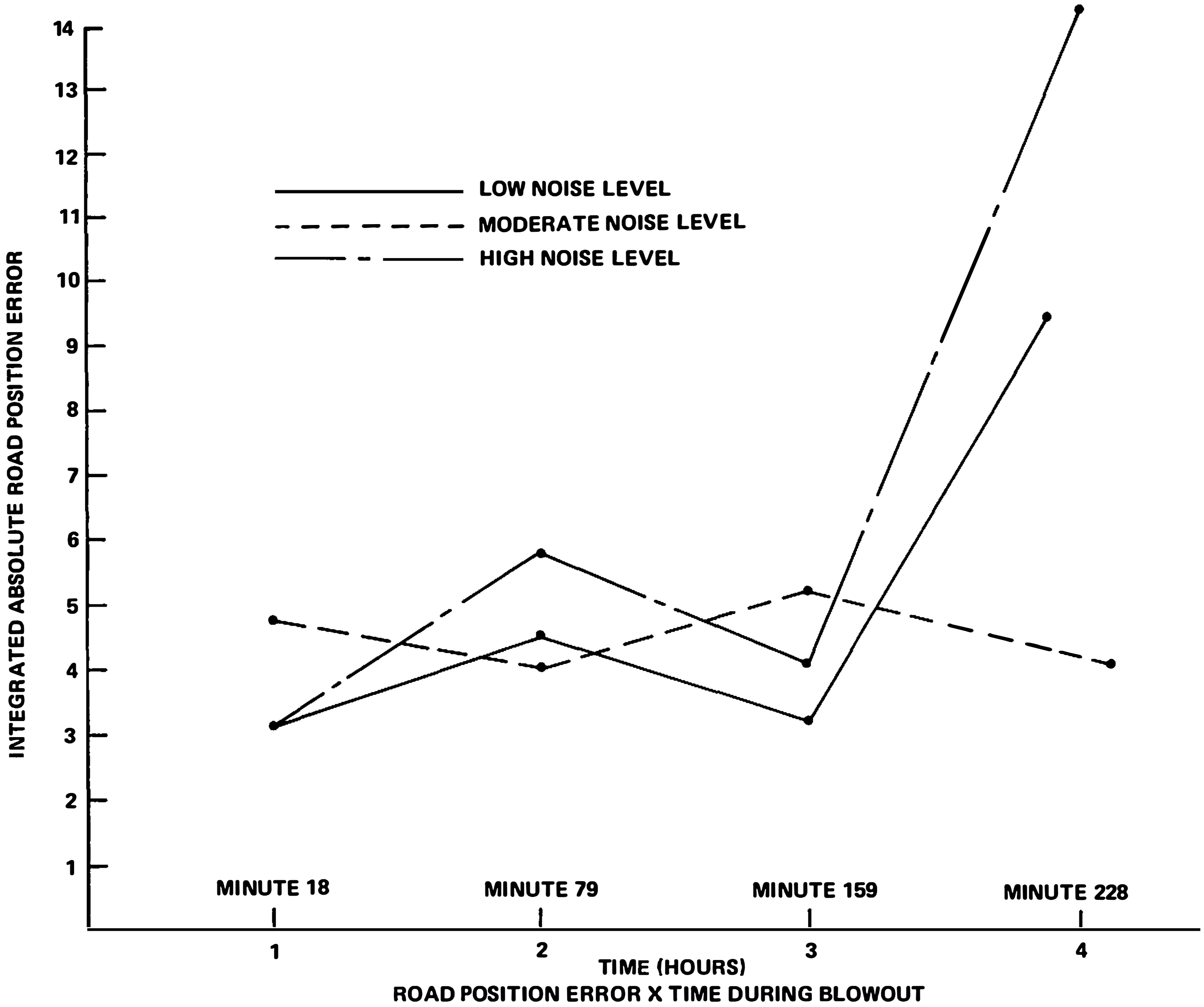


Figure 9 INTEGRATED ABSOLUTE ROAD POSITION ERROR FOR LOW, MODERATE OR HIGH NOISE TREATMENT GROUP

record. This judge then recorded the frequency of occurrence of the bursts for each of the 24 samples taken during the course of the experiment. As the frequency of alpha burst could not be considered to have parametric qualities, the median number of alpha bursts for each subject for each of the four hours of the experiment was computed. An analysis of changes in frequency of occurrence using a Wilcoxson Matched-Pair signed Ranks Test testing differences between medians for hours one and four revealed a significant increase ($p < .004$). Overall analysis of the changes in frequency of occurrence for treatment groups revealed significant increases in the frequency of occurrence for the low noise, low task complexity group ($p < .05$); high noise, low task complexity group ($p < .05$); and the low noise, moderate task complexity group ($p < .05$).

An examination of the polygraph records for changes in horizontal and vertical eye movement revealed no changes which could reliably be attributed to any of the dependent variables.

As hypothesized in the rationale, changes in emotional reactivity of subject, if present, could be reflected in relative changes in GSR across the various treatment conditions. To assess this, the frequencies of GSR shifts during the avoidance task were recorded. No changes which could reasonably be related to the dependent variables were revealed.

Finally, EMG from the neck muscles was recorded in an effort to determine to what extent muscular fatigue was correlated with changes in alertness. Examination of the polygraph record provided no evidence of systematic changes due to the treatment conditions.

To summarize, the analysis indicated the following:

1. The driver's ability to maintain his vehicle on the road under non-alerting conditions decreases linearly over a four-hour interval.
2. The rate of steering wheel corrections made by the driver decreases linearly over a four-hour interval.
3. There is a significant negative correlation between position error and steering wheel correction frequency. This may be taken to indicate that either the subject perceptually samples his road

position less frequently after driving a number of hours, or he processes and reacts to his road position less frequently over long-duration driving.

4. Measurements of position accuracy during a simulated emergency indicate that the driver is less likely to be able to control his vehicle accurately during an emergency after four hours of driving than after one hour of driving and that this decrease in control during the emergency is most severe when the driver has been exposed to a high level of acoustic noise.
5. Analysis of occipital EEG recordings revealed an increase in the occurrence of alpha bursts for all subjects between hours one and four.

3.2 Discussion

The analysis of the results demonstrated that there was a significant decrease in the ability of the subject to accurately maintain his vehicle in the center of the lane. Further, the decrease in position accuracy was linear along time. In low event driving then, decreases can be expected to begin to appear within the first hour of driving, and increase at a constant rate for at least four hours.

Measures of integrated absolute road position error made during the posttest returned performance to approximately the level found after one hour of driving. As it was not within the scope of the experiment to determine the rate of increase in road position error, it is not possible to state whether the improvement noted after the rest period would be followed by quick return to the lower performance characteristic of the fourth hour or, whether the improvement noted will be followed by a rate of performance decrease which is similar to that encountered in the four hours driving task. Thus, these results suggest that rest pauses have some value in improving performance of drivers temporarily.

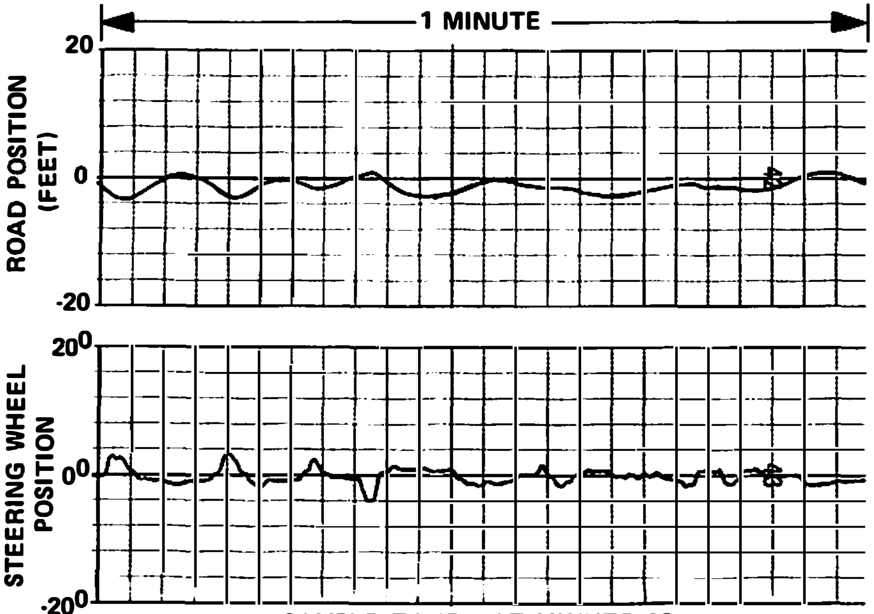
Analysis of the results revealed that two-degree steering wheel reversals decreased linearly with time over the four hours. This finding is consistent with that of Greenshields (1966), which was discussed in the Literature Review contained in Appendix A.

A linear increase in road position error accompanied by a linear decrease in fine steering wheel corrections at first seem paradoxical, because low steering wheel correction rate is generally taken as evidence of smooth or skillful driving. Under long duration driving, however, a decrease in sampling of road position by the driver and/or a decrease in the frequency of corrections can be expected to lead to increased road position error (assuming the accuracy of each correction does not increase and the level of vehicle and road perturbations, necessitating corrections, does not decrease). This process becomes evident in the extreme case when the driver makes no correction for a number of seconds (minimizing steering wheel reversals) and runs off the simulated highway (maximizing position error).

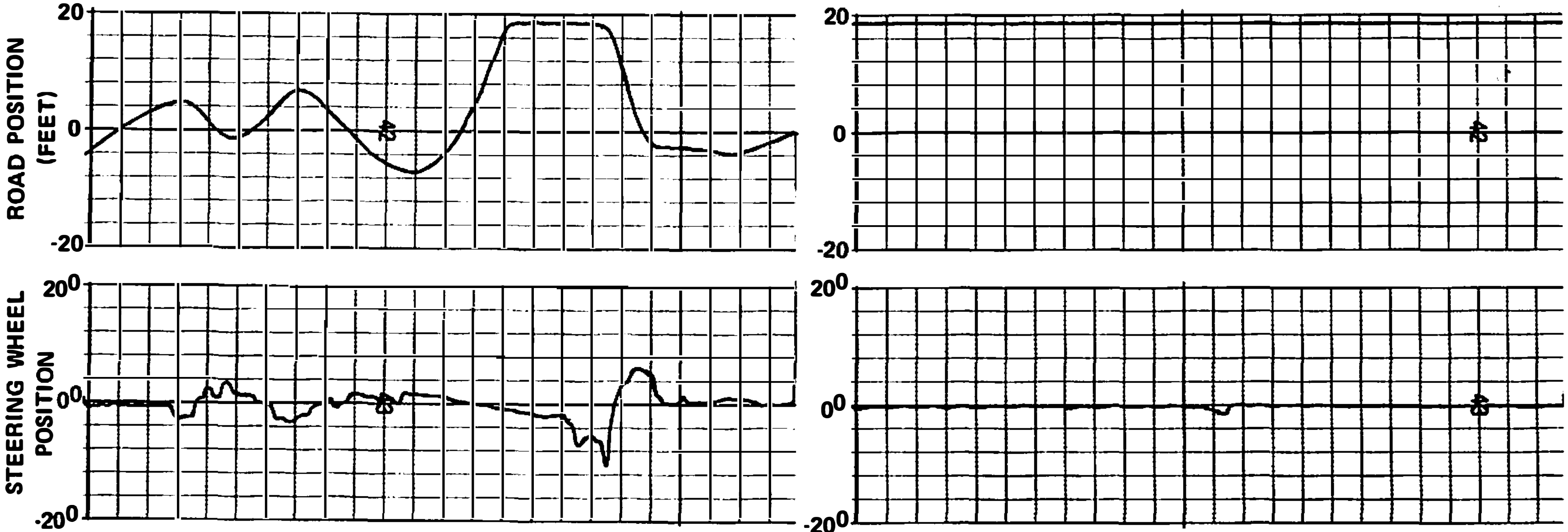
Figure 10 is a reproduced polygraph record which illustrates the above phenomenon. Note that in an early sample taken at minute 28, road position is maintained smoothly and the frequency of steering wheel movements is relatively high. In the sample taken at minute 108, the frequency of steering wheel movement has decreased and the driver is making large excursions over the simulated road. At minute 220 the driver has made no steering wheel inputs for at least one minute and the vehicle is off the simulated road for the entire period.

It is of interest to speculate on the nature of the mechanism which results in the decreased steering wheel input rate. One possible candidate for such a mechanism is reduction in the frequency of "perceptual sampling" of the environment by the driver. Changes in sampling rate might be expected to be manifested in two ways. It is likely that a decreased sampling rate could lead to increased reaction time latencies to the ramp stimuli. In other words, if the subject checks his visual environment less frequently he will have less of a probability of seeing the stimulus when it first appears and his reaction times will be higher. Analysis of latencies to the ramp stimuli revealed no evidence of increased latency.

Second, it would be reasonable to expect that reduced visual sampling would be accompanied by an increase in the presence of the alpha rhythm at the occipital cortex. Alpha rhythms in the occipital area (the primary visual association area of the brain) are generally a sign that the individual in question is not attending to any particular stimulus. In fact, the presence of alpha rhythms usually indicate a "drowsy awake" state. Perception of a visual stimulus by a subject exhibiting alpha usually results in a phenomenon called "alpha blocking" when the alpha abruptly disappears. There was evidence of an overall increase in the occurrence of alpha for all subjects as would be expected if reduced steering wheel corrections had been caused by a reduced frequency of visual sampling.



SAMPLE TAKEN AT MINUTE 28



SAMPLE TAKEN AT MINUTE 108

SAMPLE TAKEN AT MINUTE 220

Figure 10 A COMPARISON OF ROAD POSITION AND STEERING WHEEL MOTION FOR A SINGLE SUBJECT AT 28 MINUTES, 108 MINUTES AND 220 MINUTES

The response to the ramp stimulus is relatively simple and infrequent. It demands little from the subject. The responses necessary to maintain the vehicle in the center of the lane require more processing and greater attention and a considerably more complex response. If the decrease in position accuracy were a result of a degradation in the functions such as cognitive processing or response precision, it would follow that decreased performance would be most marked in the maintenance of position accuracy. Therefore, one may speculate that degradation of the processing of information rather than in the sampling of stimului could account for the reduced position accuracy.

The lack of evidence for increased latencies deserves comment. As noted in Appendix A, studies of vigilance which involve detection latency and probability of detection of a weak stimulus have generally shown decreased performance over time. The response to a ramp stimulus uses an indicant of alertness which is different from the classic vigilance task in a number of ways. In the interest of realism, subjects were told to look for a brightening light resembling the high beams of an oncoming vehicle. Response latency in such a situation is a product of a number of distinct factors: the sensitivity of the receptor to the stimulus, the time the subject requires to make the decision that the stimulus is indeed present, and the probability that the subject is attending to the stimulus situation.

Measures of latency to a ramp stimulus therefore confound such factors and such confounding may obscure or obliterate changes in any one of the processes. It must be emphasized that while such confounding obscures the underlying factors, the task of responding to a ramp stimulus is appropriate for such a study as it represents the type of task commonly found in on-road driving.

Tests of data representing the driver's ability to maintain a constant speed revealed no effects which might reliably be attributed to task complexity, noise level, or time. Only one possible explanation suggests itself: the simulation of velocity changes was of insufficient fidelity. Differential velocity was simulated using variations in the apparent speed of our projected display, correlated variations in the speedometer reading, and correlated variation in the equations of motion for roll and yaw. In an on-road situation, drivers may sense speed changes through the use of a number of cues not available in the simulation. Among these might be auditory cues (including variations in engine, wind, and tire sounds), motion cues (including sensations of lateral acceleration, pitch, and small variations in vehicle acceleration due to variations in road surface).

The measure of the subject's ability to respond to a sudden emergency were of interest in that they revealed a decrease in control accuracy in the fourth hour of testing. They further revealed that the greatest decrease in control accuracy occurred when the subject had been tested in the high noise environment. This finding has direct relevance to on-road driving. It strongly suggests that acoustic noise below the level that is physiologically injurious, can be detrimental in terms of its effects on the ability to respond to emergencies. Further, it is clear that in the case of drivers or operators of machinery or pilots such degradation could dangerously degrade the operator's level of performance in an emergency.

Measures of occipital EEG revealed increases in the occurrence of alpha overall treatment conditions. This indicates that the duration of the drive affects neurological function, and may indicate that one cause of reduced position accuracy is reduced sampling due to decreased brain activity.

Examination of the measures of occipital EMG revealed no reliable changes due to time, task complexity or noise level in the electrophysiological function of one of the muscle systems which maintains the head in an erect position. This may be taken to indicate that the performance of subjects in this study cannot readily be attributed to muscular fatigue. This position is further supported by the marked improvement in performance shown by subjects after about a four-minute rest period. It is doubtful that such a short time would be sufficient to alleviate four hours of physiological fatigue.

Examination of the polygraph recording representing horizontal and vertical eye movements revealed no effects which might be reliably attributed to noise level, task complexity, or time. The data appeared highly variable and the variability may have been in part a function of the wearing of the eye movement sensors. These sensors resemble, but are considerably heavier than, an ordinary pair of eyeglasses and are worn in place of spectacles. Their use precludes the wearing of eyeglasses by subjects who normally use them for driving. It may be that the use of the eye movement sensors tends to serve as an annoying factor and the resulting variations due to discomfort obscured any changes due to treatment conditions.

Examination of GSR shifts during the blowout and avoidance tasks for each subject revealed no systematic increase or decrease in GSR due to treatment conditions. One reason for this may be that the simulator as prepared is not a particularly interesting situation and may not necessarily lead to any change in emotional values. If causes for change in emotional state are lacking, there is little opportunity for manifestations of differences in emotional reactivity. Another reason, as is noted in the introduction, indicants such as GSR may represent autonomically conditioned responses to stress and be idiosyncratic to the individual,leading to large inter-individual variance.

Finally, as noted in Section 1.2.1 a number of subjects (three) were unable to complete the experiment due to nausea or discomfort. All three of these terminations occurred under the low noise condition, two under low task complexity, one under moderate task complexity. Although no statement regarding the generalizability of such data is warranted it is interesting to note this effect.

3.3 Recommendations

In light of the findings of the Literature Review and of the experiment it would be imperative to validate the findings obtained in this study in an on-road study.

It is important to recognize that the data are the product of laboratory experimentation and should be validated on the road using actual vehicles. The data represent changes of human performance in a highly sophisticated driving simulator. By definition, every simulation involves some lack of fidelity. In driving simulations in particular, the sensory environment is to some extent impoverished when compared to the real world. This impoverishment may yield more rapid deterioration of driving performance than can be expected in actual driving. Therefore, it may be that the same effects exhibited in the simulator study will occur in on-road driving but over a greater time scale. If the usefulness of the findings of the simulator study are to be maximized, attempts should be made to validate the findings and provide realistic time parameters for the effects recorded.

The following is a brief description of such a validation study.

Experimental Method

It is anticipated that either a non-public closed course such as the Watkins Glen Grand Prix Race Course or a course which includes segments of public roads closed to traffic could be used for this study. Such courses would allow an assessment of the effects of those variables found to have a significant probability of affecting driver safety (duration of drive and acoustic noise level) which is more generalizable to real world driving than the assessment provided by the simulator. Further, use of a closed road track or closed road sections will allow for far more rigorous standards of safety and more experimental control than possible on roads open to traffic.

Subjects would be drawn from the staff of CAL and/or local universities. All subjects would be at least 21 years of age and have had at least two years of licensed driving experience.

An instrumented automobile, equipped to record at least the following, would be used as the test vehicle:

- Steering wheel motion
- Brake and accelerator motion
- Force and frequency of application
- Forward and lateral acceleration
- Forward speed and distance
- Lateral road position
- Elapsed time

In the interest of safety, the vehicle should be equipped with a service brake pedal for the experimental observer. An acoustic pick-up and amplification system will be installed in order to provide for variations in noise level.

The following classes of measures should be collected:

1. Accuracy of control during "low-event" driving.
2. Latency of reaction to unexpected events (such as detours or conditions requiring emergency maneuvers).
3. Precision of control of vehicle during such events or maneuvers.
4. Comprehension of unexpected road signs.

Each driver would be subjected to one of three noise levels corresponding to those used in the simulator study.

Subjects would be instructed to drive as normally and smoothly as possible, maintaining speed limits as posted. Subjects would be asked to read and obey all traffic signs and explain them at the observer's request. Each subject would drive steadily for five hours stopping only to change observers every thirty minutes. The change, which will require less than one minute, will be done in order to reduce decreases in observer alertness.

During the drive, various road signs could be presented to the driver and the driver could encounter without warning detours and situations requiring precision driving (e.g., an emergency avoidance of rubber pylons).

Two other research topics are suggested by the results of this study:

The first involves research into the effects of information overload. Information overload may be expected in areas which have any or all of the following characteristics: heavy traffic flow, complex intersections, high traffic signal density, and/or high informational sign density. Overload may occur even on roads with moderate levels of the characteristics if the driver is unfamiliar with the area.

The effects of overloading the driver with information to be processed are probably as serious as those associated with loss of alertness through boredom. A study of the effects of information overload would involve an effort similar to the present study. Various levels of information could be presented to the subject for processing. The effect of the amount of information processing over time on measures of performance critical to driving would be analyzed. Such an effort could be provided most economically using a simulation approach supplemented with on-road validation.

The second is concerned with the development of better measures of driver performance with regard to the development of measures of driver alertness, the most direct and valid measure would involve continuously sensing lateral road position. However this is not feasible. In the study, fine steering wheel movements were found to be highly correlated with road position error ($\phi = -.54$). Such a measure would make a fair indicant of alertness. Perhaps a direct analysis of steering wheel movements would be more satisfactory than the counting of reversals. It would seem research efforts aimed at establishing the correlations of various types of steering wheel motions with driver performance would be of value. Such a program could be relatively straightforward. Subjects could be tested on a simulator or get judged ratings for on-road driving. During this test period all steering wheel motions would be recorded. After spectral analysis of the recorded steering wheel signal, a factor analysis could be performed to find those portions of the spectrum most closely associated with documents in driving performance.

The simulator study indicated that a major effect of long duration driving is a decrease in position error. The ramifications for traffic safety are as follows: if this finding can be generalized to the on-road situation, then a reduction in accident rate on long, straight featureless roads might be achieved by a number of direct methods:

1) <u>Widening the lanes</u>. This method would reduce the effect of increased position error. However, its cost is probably prohibitive. Further, this will only be of value if the increase in position error represents some absolute change in the subject's ability to position his vehicle, if the degradation is a function of the driver's relative tolerance to position error, widening the road may only result in the driver beginning with a less stringent position error criterion. In such a case, increased tolerance for position

error will lead to dangerous deviations in about the same time frame as would be expected on lanes of normal width.

2) Mark lanes so that they appear narrower. This would force the driver to set his criteria for deviations requiring corrections at a lower level. If the assumption can be made that requiring this higher level of performance does not change the rate of decrease in performance, then making the lane appear narrower will allow the driver to operate his car for a longer period before he reaches a dangerous magnitude of position error. Also, making the lane perceptually smaller could alert the driver to his increased position ppsition error before it became dangerous. The efficacy of such a program could be easily tested by marking a candidate roadway and measuring the mean deviation from the center of the lane of normal traffic. This measurement would then be compared to measurements of an unmarked segment of the road or a similar road.

3) Use textured median strips, shoulders and interlane boundaries. The design of textured boundary markings has been used in urban and suburban roadways. It is reasonable to consider the use of this sort of marking for rural roads. The use of textured boundaries would provide the driver with auditory and tactile cues when his position error becomes so great that his wheels leave the lane. These cues would tend to alert the driver as they would occur infrequently in normal driving. If feasible, consideration should be given texturing of the entire lane with the goal of providing an acoustic and/ or tactile position feedback. As envisioned, the texture could be graduated so that correctly positioning the vehicle in the center of the lane would result in the least road noise or vibration. Such a system might cause drivers to better maintain their position within the lane.

Finally, the study revealed that noise levels of the magnitude commonly found in vehicles in current use can cause degradations in the driver's ability to respond to sudden emergencies. Assuming that this finding is generalizable to on-road driving, careful consideration should be given to the establishment of maximum interior noise levels for vehicles. These levels would have particular relevance to long distance trucking operations.

4. APPENDIX A - Review and Discussion of Pertinent Literature

Alertness usually is defined in terms of the observer's response to stimulus inputs which are considered critical within the framework of the task he is performing. The term alertness has been used in reference to activities ranging from signal monitoring tasks in which stimulus inputs are rare and relatively weak ("vigilance" tasks) to complex tasks in which the information processing capabilities of the observer are severely taxed. Measures of alertness include simple detection, detection rate, reaction time and appropriateness of the response.

The purpose of this discussion is to present a representative sampling of research efforts that are relevant to alertness and to the task of driving a vehicle. An important consideration is the applicability of the research data to actual driving situations since, particularly in vigilance type tasks, the applicability of the laboratory data to field conditions has been seriously questioned (Elliot, 1960; Kibler, 1965).

In this report the relatively narrow approach of looking only at driver vigilance is not followed. Instead, the driver is discussed more broadly in terms of the way that he processes the information available to him in various driving environments. A basic assumption underlying this discussion is that the driver has a limited capability for processing that information. The main concern is with those mechanisms by which the driver selects and attends to those information inputs of the environment which he considers to be critical to the driving task. Basic problems include the determination of how many inputs can be attended to at one time and how these inputs are selected from among all those possible. The studies reviewed here include both basic studies aimed at the development of theories and models of human information processing, and applied studies primarily aimed at obtaining quantitative data regarding driver performance under actual field conditions.

From this report the basic studies are grouped into three large and somewhat overlapping areas of attention, decision making, and vigilance, plus other relevant topics such as driving considerations, task load, long-term driving, lack of sleep, ambient temperature, noise, and physiological measures. The plan of this review is to examine the findings of these basic studies from which to develop some general conclusions about driver alertness and the directions which further research should take. The applied studies have been grouped according to considerations directly relevant to automobile driving.

4.1 Attention

4.1.1 Selective Attention

The number of information inputs present at any given time often far exceeds the capacity available for processing them. Some sort of selection must be made to determine which of the inputs will undergo further analysis. The concentration of the analytic mechanism on the selected inputs can be termed the process of selective attention. A number of important questions arise with regard to this process. First, at what point in the processing of the inputs is the selection made? Second, on what basis are inputs selected for attention? Third, how much information can be attended to at one time? Finally, what happens to those inputs on which attention is not focused?

An experience common to most persons with normal hearing is the so-called "cocktail party effect." This effect refers to the ability to listen to only one of a number of simultaneous conversations while the others are ignored. The work of Cherry (1953) was instrumental in stimulating a large amount of research on selective listening. He used a method of shadowing, where the subjects repeated out loud a spoken message as it was presented. They were instructed to follow as close behind the spoken message as possible. Cherry conducted one series of shadowing experiments in which the subjects were required to repeat out loud one of two dichotically presented verbal messages where a different message was presented to each ear. He found that the unshadowed (unselected) input was effectively ignored and little material from that input could be recalled following cessation of the message. Subjects noted very gross events in the unshadowed message, such as the change from a male to a female voice, but could not recall the content of the message nor even that a different language was being spoken. Moray (1959) repeated a short list of words numerous times in the unshadowed message and reported that subjects later recognized those words only at a chance level. If the shadowing task is disrupted momentarily, however, attention can be diverted to the second input (Mowbray, 1964).

To explain such results, Broadbent (1958) suggested that the nervous system acts as a single communication channel of limited capacity. In his model sensory inputs are initially processed in parallel but at an early stage of processing the inputs are selectively filtered on the basis of physical features of the input, such as intensity, pitch and location. This filtering serves to block irrelevant inputs from further processing. The filter thus is tuned to pass information from only one of many input channels (e. g., one particular voice out of many different voices). Information about unselected inputs is held in a short term store for possible future processing, but if not passed by the filter it is soon lost and cannot be remembered.

One problem with the original Broadbent model is that under certain conditions, meaningful inputs from the rejected input channels are perceived and attended to. Moray (1959) found that subjects receiving dichotically presented inputs heard their names on the irrelevant channel. Gray and Wedderburn (1960) found that in a situation where two messages were simultaneously presented, subjects readily perceived words in which the different syllables of each word in a message were alternately presented to each ear. Deutsch and Deutsch (1963) suggest that filtering does not take place until all the inputs have been analyzed for meaning. Under this concept, all inputs reach the same perceptual and discriminatory mechanism whether they are being attended to or not. They propose a shifting reference standard which reflects the level of the most important input. Shifts in attention occur when a signal of higher importance is input to the system. Deutsch and Deutsch relate this mechanism of selection to a general arousal theory. The problem with this approach, as Neisser (1967) notes, is that it does not explain why so little of the unattended input makes an impression even though it all has been analyzed.

In another approach, Treisman (1960, 1964) suggests that the irrelevant channels are attenuated rather than filtered out completely. The attenuator serves to reduce the signal-to-noise ratio of the unattended inputs. Broadbent and Gregory (1962) accept this view. Like Broadbent, Treisman views attention as a passive process accomplished through analysis of the input.

Treisman suggests that all inputs undergo some form of hierarchical testing by the analytical mechanisms. Thus, most irrelevant inputs would fail the tests early in the hierarchy and would receive no further processing. In this testing, signals are differentiated on the basis of physical features, e. g., intensity) where possible and on higher order features (e. g., grammer) where necessary. This testing is carried out sequentially, proceeding from the simpler tests to the higher order tests. Those inputs that fail the tests at the lower levels are rejected as noise.

To account for those signals in unattended messages which are perceived despite the attenuation, Treisman suggests that inputs which are highly important or relevant to the subject (e. g., his name) could be perceived provided the test criteria were sufficiently low, i. e., the organism could be attuned or sensitized for those inputs. Factors such as contextual probability, recent use and importance lead to reductions in the level of the test criteria.

Hernandez-Peon, Scherrer and Jouvet (1956) found that a sound produced far less electrical activity in the cochlear nucleus of a cat when the cat was looking at a mouse than when the mouse was not present. These data support an attenuation concept, at least across sensory modalities. However, humans can exert selective attention within a single modality, so the pertinence of these data is not without question.

Treisman's approach overcomes many of the objections raised concerning the filter model, but presents a very complex model of information processing. Norman (1968) criticizes Treisman's model on the basis that the underlying mechanisms are unduly complex. Neisser (1967) contends that the hypothesis that unselected messages are attenuated cannot be correct. He notes that even though the unattended message may be ignored as to content, it is no less loud than if it were the attended message. Neisser further points out that messages can be selected on the basis of relative loudness alone, a fact he finds difficult to reconcile with an attenuation model. In response, Treisman (Neisser, 1967) argues that it is the information content and not the loudness that is attenuated. Neisser states that this approach forces the hypothesis of attenuation to give up much of its content at the expense of satisfying his criticisms.

Norman (1969) presents a somewhat different approach to a model of attention. In his model the initial analysis of signal inputs is performed automatically and consists of matching the physical characteristics of each signal with those of representations stored in memory. All inputs receive a simple analysis for meaning. Selection of an input for further processing is based on a consideration of such cues as context, grammar and meaning, in addition to the physical characteristics of the inputs. Norman suggests that some measure of the pertinence of each of these properties of the inputs is a critical factor in the selection process. Pertinence reflects expectations regarding possible future inputs and the properties of the presently attended chennal of information. The pertinence inputs and the sensory inputs both operate on the items in storage. Those items which are most highly activated by the combination of sensory and pertinence inputs are the items then selected for further processing. Unattended inputs remain only partially interpreted. Norman's model differs from the attenuation models in that changes in performance are considered a result of changes in bias, i.e., pertinence, and not a change in sensitivity.

Sperling (1967) demonstrated that the information presented in a brief visual presentation is stored by the observer for a short period of time following the offset of the stimulus material. The observer is able to continue processing this material as long as it is in storage and subjects reported that they could still see the stimuli after they were no longer displayed. Storage time typically is one second or less, although it can extend to five seconds, depending on the values of such factors as the intensity of the input, the exposure time and the pre- and post-exposure illumination (Sperling 1960, 1963). Verbal material undergoes a somewhat similar process.

Neisser (1967) uses the term iconic memory to refer to the visual store and echoic memory to refer to the auditory store. Neisser (1967) suggests a two-stage model of attention. The material in iconic or echoic storage first undergoes perliminary analysis which serves to grossly segregate the sensory inputs on the basis of global, nonspecific features of the inputs. This is followed by a focusing of attention on certain of these items which then undergo extensive analysis.

In the case of verbal material, the first stage consists of a passive filter system which performs preliminary identification of words and other cognitive units based on a gross analysis of features. This stage can establish localization, form crude segments, and in a limited way, direct responses. Operations in this stage can be conducted in parallel, i. e., independently of each other. The second stage consists of an active process of analysis-by-synthesis in which the listener synthesizes a series of linguistic units based on stored representations which match the inputs he is currently receiving. This constructive process is considered by Neisser to be the basic mechanism of auditory attention. It is in this stage that detailed analysis of the input is conducted. Neisser stresses the point that unattended inputs are neither "filtered out" nor "attenuated" but instead are analyzed only by the passive mechanism which he terms preattentive. These preattentive mechanisms operate only in a crude, global way. However, some hierarchical depth is assumed in that these mechanisms can serve to pick out certain simple units, e. g., one's own name, even if the input is not in the message undergoing analysis by synthesis.

Neisser also proposes a model of visual attention. Again, a two-stage model is assumed. The first stage, the preattentive stage, accomplishes the gross division of inputs into those that will be processed further and those that for the moment will receive no further processing. This is a passive stage in which gross analysis of input features is conducted in parallel, thus allowing inputs to be processed independently of each other. Only those items which are actively processed can be recalled later although all inputs are held in a sensory store for a very short period of time. The second stage of processing is one in which the selected inputs undergo detailed analysis. This stage operates on the gross distinctions determined in the first stage and represents a focus of attention on those inputs.

Lettvin, Maturana, McCulloch and Pitts (1959) and Hubel and Wiesel (1962) report neurophysiological evidence that there are detector arrays in the visual system which respond only to relatively specific inputs. Lettvin et al found fibers in the optic nerve of the frog which responded only to the movement of small dark objects, e.g., bugs, in the visual field. Once activated, the receptors continued to respond as long as the object remained within the visual field. Hubel and Wiesel found specialized receptors in the visual system of the cat that responded differentially to inputs depending on such rather complex features as the orientation and movement of the stimulus in the visual field. The preattentive mechanisms conceivably could operate in this way, but Neisser (1967) stresses the point that recognition of a complex visual input is a much more involved operation than this and requires processing well beyond the stage of simple neurological response.

Neisser (1967) points out that certain response activities can occur directly as a result of the preattentive processes without the need for higher order processing. One of these activities is the redirection of attention itself. Neisser notes that attention is not randomly allocated but rather is often guided by cues such as motion extracted directly from the visual input. Thus, many common activities that occur in daily life can be ascribed to the preattentive level. These include both cognitive activities and guided movements such as those involved in driving or walking or other similar activities. The driver who suddently becomes aware that he has driven his automobile for a long period of time without actually focusing attention on the driving process is one example of how one might function at the preattentive level. The driver in such a situation may have his attention focused elsewhere, perhaps on a daydream, yet can maneuver his automobile along the roadway, particularly a roadway with which he is familiar. As Senders, Kristofferson, Levison, Deitrich and Ward (1967) have noted, a curved roadway becomes perceptually straight to the driver as he becomes familiar with it. It can be assumed, in this case, that processing of events that once served an alerting function in that they required focal attention to some aspect of the driving task, has become so simple and well learned that the preattentive processes are sufficient to conduct the task. As long as the events are such that they are within the group of familiar and expected events, the driver can handle a large number of these events at the preattentive level. When confronted with a situation in which the crude mechanisms of preattentive operation will not suffice, the driver must shift to a more alert mode of operation. Such a shift takes time, and in some instances may be critical to the safety of the driver. However, just how this shift would operate to influence driving performance has yet to be determined.

4.1.2 Divided Attention

An area of attention research of particular interest to driver alertness has to do with the division of attention. Frequently, the driver is confronted with situations in which several demands are simultaneously placed on his attention mechanisms. It is important to know how well he can handle such situations. Treisman (1969) reviewed a number of experiments on attention and concluded that division of attention between two or more sensory inputs (e.g., messages to both ears) and between two or more targets (e.g., different words) is accomplished through alternation of attention or serial analysis. However, division of attention between two or more analyzers (e.g., those concerned with shape and color) is relatively more efficient. With regard to focusing of attention, Treisman concludes that focusing is readily accomplished for different targets or for inputs from different physical sources that reach a single analyzer as occurs when a different message is input simultaneously to each ear. Focusing of attention on a particular analyzer seems to be much less efficient, particularly when the distinction to be made is along dimensional characteristics of a single input (e.g., color).

Liebowitz and Appelle (1969) investigated the effects of varying the difficulty of a central task on the luminance thresholds for peripherally presented light signals. They found that threshold levels were influenced by the characteristics of the central task. Peripheral stimuli were presented at visual angles ranging from 20° to 90° on either side of the fixation light. In conditions in which a centrally located light was extinguished and the subject had to actuate a switch to reactivate the light, thresholds were generally higher than those obtained in the condition where the subjects simply fixated on a steady central light. They interpret their findings as reflecting the effects of the attention demands of the central task on the size of the functional visual field. A slow interruption condition had a more deleterious effect on peripheral thresholds than did a high interruption condition. This finding was interpreted as showing the lack of a simple relationship between required rate of response and peripheral threshold.

Liebowitz and Appelle stress the point that the data from their study present strong evidence against the simple extrapolation of laboratory data regarding thresholds, acuity, motion perception and other such functions to situations in which the perceptual motor load is not the same. The data of a number of other researchers (Easterbrook, 1959; Gasson and Peters, 1965; Mackworth, 1968; and Sanders, 1963) also indicate that a functional visual field exists which varies in size according to the processing demands placed on the observer. Jenkins (1958) reported that the reaction times to peripherally presented light signals were affected by changes in the central task requirements. Bahrick, Noble and Fitts (1954) found that the payoff associated with a central task affected detection of peripheral signals; and Weltman and Egstrom (1966) found that in physically dangerous situations, some subjects showed an increase in reaction time to peripherally presented light signals. The results of these studies clearly indicate a need for further research to determine the effects of field conditions on information processing functions determined in the laboratory. These results suggest that the driver who is focusing his attention on some demanding task, such as lane changing or distance keeping on a crowded highway, is less likely to detect a weak, but critical sign that appears along the side of the road than is the driver who is driving along an uncrowded highway and need devote relatively little attention to on-road activities.

Aseyev (1960) found that factory workers employed in tasks defined as monotonous showed a progressive increase throughout the work day in reaction time to irregularly presented light signals whereas subjects employed in tasks defined as not monotonous demonstrated no such degradation. These reaction time data were obtained when the subjects were not actively engaged in work. Haider (1963) had subjects perform a detection task while actively working at their jobs. Similar results were obtained. Based on these results, one can speculate that in situations in which the driver's task is simple and undemanding, e.g., when driving on an uncrowded freeway in a car, the driver will show a progressive deterioration in the speed with which he responds to external signals such as a blowout.

Recently, Peterson (1969) has developed a model that is primarily concerned with concurrent activities. While directed towards verbal activities the model is applicable to other cognitive or symbolic activities in which attention must be divided among two or more inputs.

Peterson suggests three levels of classification of symbolic activity based on the degree of attention required to maintain an ongoing activity. An important determinant in the attentional demand of the activity is the stage of training and proficiency in that activity. At the lowest level, Peterson groups a class of activities which he labels emission activities. These activities are characterized by self-guidance and freedom from environmental cues. As examples of emissive activities, Peterson cites the reciting of the alphabet and counting.

At an intermediate level, Peterson groups activities he labels reproduction activities. These activities are characterized by direct correspondence between input and output as occurs in reading and shadowing tasks. Since these activities are not self-guided, a degree of uncertainty exists because of the relative unpredictability of the input.

The third level of activity suggested by Peterson is one in which some type of problem solving is necessary before an appropriate output can be effected. The examples cited for this level are arithmetic computation and anagram solution.

Peterson conducted a series of experiments in which subjects performed these activities in various combinations. The results supported his hypothesis that performance would reflect the relative degree of attention required by the concurrent activities. Thus, when solving anagrams, performance was best when the concurrent activity was an emission task (counting), intermediate when the second task was a reproduction task (shadowing) and poorest when the second task was a problem-solving task (adding). However, Peterson notes that performance was still quite efficient when performing any two of the concurrent activities.

Peterson proposes a four-stage information processing system. In the first stage information is held in various short-term sensory stores which operate in parallel. These seem to be comparable in concept to Neisser's iconic and echoic stores. In the second stage a filter mechanism serves to attenuate the processing of all but one input at any given time. The inputs in store then are processed sequentially. Peterson assumes that the filtering is accomplished on the basis of different sense organs. In the third stage Peterson suggests that once again parallel processing can occur. The long-term store provides the capability for maintaining well established activities such as reading and adding, while short-term stores maintain the continuity of diverse types of processing. Since well established skills may be conducted at this stage with relatively little demand placed on the attention mechanism, other activities can be conducted in parallel with that activity.

Peterson follows the suggestion of Moray (1967) that the concept of a fixed capacity central processor is preferable to that of a single fixed channel of limited capacity. Under this concept, parallel operation may occur at any stage in which the central processor is not operating at full capacity. This is in contrast to the concept of a single fixed channel in which concurrent activities are carried out by rapid switching between the activities. Neisser (1967) also suggests that certain types of activities can be conducted independently at the level of the preattentive mechanisms while attention is focused elsewhere.

The fourth stage in Peterson's model is an output stage. In this stage too, Peterson suggests that activities are performed in parallel, e.g., simultaneous speaking and writing.

4.1.3 Some Implications of Attention Studies

Several implications may be drawn from the attention literature reviewed. The various information processing models that have been developed have considerable relevance to the problem of driver alertness. Unfortunately, the converging operations that are necessary to determine which model best describes human information processing have yet to be performed. At present there are two major divergent views regarding information processing. One view, held by such researchers as Broadbent and Treisman, is that information processing is a passive process in which inputs to the system undergo extensive analysis by various analyzers in the system. The opposing viewpoint, held by such researchers as Neisser and Norman, is that an active component which performs some sort of analysis-by-synthesis activity is necessary. The arguments for an active process are quite convincing but are by no means universally accepted as yet.

Based on these information processing models, several tentative conclusions concerning driver alertness can be forwarded. First, we know that drivers can perform the basic driving tasks without actually focusing attention on the driving activity itself. Also, when attention is focused on some activity, the extent to which a second activity can be performed concurrently appears to depend upon the attentional demands of each activity. The driver who is traveling on a crowded highway which is unfamiliar to him and thus requires considerable focusing of his attention on such features as signs and lane markings is much more likely to neglect a developing dangerous situation than is the driver tho is familiar with that road. However, the driver who is familiar with that road may also fail to notice the development of a dangerous situation if his attention is focused elsewhere, e.g., on a daydream. Skill also is important, for as driving skill is attained, the task of driving itself requires less involvement of the attention mechanism which can then be focused on other activities. It is important to note that the driver can focus his attention on only one input at a time, although he can independently conduct gross analyses and perform simple overlearned activities at the preattentive level. In cases where two critical inputs must be handled, one input must remain in store until the first is processed. If, because of poor highway design or other causes, the driver is faced with a situation in which two critical inputs appear simultaneously, the alert driver may have the advantage over the non-alert driver to the extent that he may start processing the inputs sooner. Both the alert and the non-alert driver must still process the two items sequentially, but in certain driving situations, even a modest advantage in the initiation of processing could be critical. According to Neisser (1967), processing time for each input is at least 100 milliseconds.

While the above conclusions are not particularly unexpected and the models differ in some respects as to precisely how information is processed, the models, and the theories underlying the models, provide a general framework within which to assess driving observation and research and upon which to predict performance in various driving situations.

One important lack in the information processing models is an adequate accounting of motivational factors. Until recently, most models of the human cognitive process had shown little concern for the possible effects of motivational factors on performance. Simon (1967) is one of the few theorists who has attempted to incorporate explicit motivational mechanisms into an information processing theory of cognition. Simon makes the point that the single-minded, single-purpose behavior of most existing simulations of human information processing is not representative of actual human behavior, which is responsive to a multiplicity of goals. Simon is not alone in this observation. In discussing experimental design Neisser (1967) states, "The simplifications introduced by confining the subject to a single motive . . . can be justified only if motivation and cognition are genuinely distinct. If, as I suppose, they are inseparable where remembering and thinking are concerned, the common experimental paradigms may pay too high a price for simplicity." (p. 305)

Some basic work is being done in this area. Wiener (1966) presents a thorough review of the research up to that time. Peterson (1969) acknowledges the importance of motivation in information processing and assumes that, in verbal tasks, motivation operates primarily to increase or decrease rehearsal. Wickens and Simpson (1968) present experimental evidence that supports this view. The relevance of the laboratory work to driving behavior is still quite limited, although it is apparent that motivational factors certainly are critical in the driving situation. A consideration of what it is the driver is attempting to do and the value he attaches to accomplishing that activity is necessary to a complete understanding of driver behavior on the highway. The driver whose primary motivation is to arrive at his destination safely will probably drive differently than does the driver whose primary motivation is to arrive at his destination as quickly as possible. In terms of attention, we might speculate that the driver who is concerned with safety might focus his attention on warning indications and conjecture about the movements of other vehicles on the road, whereas the driver concerned with speed may be most attentive to speed limit signs and detection of police vehicles.

While self-preservation undoubtedly is a strong motivational factor in driving performance, it would be extremely difficult to manipulate such motivation in an experimental setting. On the other hand, law enforcement practices readily can be changed to influence the values drivers associate with certain types of driving behavior. The effects of such changes on attention remains a problem for future research.

4.2 Decision Making

The driver is required to make numerous decisions while driving. Various theories have been advanced that attempt to predict decision making behavior in situations such as those encountered in driving. Edwards (1961) reviews many of these. One of the most promising of these theories, though still largely untested in such situations as discussed here, is the theory of signal detection (Swets, 1964). The theory of signal detection regards the observer as relating sensory data inputs to his goals and to information about probabilities and values he has previously acquired. It is a mathematical theory and permits a mathematical description of the decision process. An important assumption is that the human is a noisy receiver of signals, the noise being generated in his nervous system. The task of the human when confronted with a possible signal situation is to determine whether the information he is receiving is due to this internal noise and any external noise present in the situation or whether a signal is actually present. To accomplish this, the theory assumes that the observer establishes a criterion of acceptance that considers not only the likelihood that a signal actually did occur, but also considers the value of a correct decision and the cost of an incorrect decision. The probabilities of "no signal" and "signal" arrived at by the observer are not necessarily the true probabilities. They represent only his suppositions regarding the true probabilities and obviously will be influenced by his own personal biases as gained from past experience and training. It is not until he acts on his decision that he can obtain further information as to the rightness or wrongness of his assumptions regarding the probability that a signal had occurred and can make any adjustments in his assessment of the situation to develop a more optimal criterion level when confronted with this situation in the future.

In the case of driver decision making, the theory would apply somewhat as follows. First, a detection situation must occur, wherein one of two mutually exclusive states obtain. For example, an obstacle, e.g., a hole in the road present in the path of the vehicle is or is not passable. The driver approaches the situation with some hypothesis regarding the situation. He observes the situation and decides his hypothesis is correct or incorrect. Four alternatives concerning the driver's decision now can obtain:

1. His hypothesis is correct and he decides it is correct (termed - hit).
2. His hypothesis is correct and he decides it is incorrect (termed - miss).

3. His hypothesis is incorrect and he decides it is incorrect (termed - correct rejection).

4. His hypothesis is incorrect and he decides it is correct (termed - false alarm).

Each of these alternatives represents some value, or cost, to the decision maker, and depending on their relative worth to him, will differentially affect the criterion of acceptance that he establishes. The values and costs associated with these alternatives constitute what is termed a payoff matrix, or risk function.

According to the theory, the decision reached by the driver would reflect the influence of the *a priori* probabilities attached to the occurrence of either of the two possible states, the payoff matrix and the sensory data. At the simplest level, given a sample that might represent either state, the decision process constitutes making the best choice between the two alternatives.

Assuming that the observer will attempt to maximize his payoff, he will calculate the likelihood that the sample represents s, the signal plus noise, or $\bar{s}$, noise alone. The ratio of the two values, the likelihood ratio, that he assigns to these two alternatives is the measure that he compares to the criterion when he makes his decision. If this ratio equals or exceeds his criterion level he will respond S, signal present (hypothesis 1). If the ratio does not exceed the criterion value he will respond $\bar{S}$, signal not present (hypothesis 2). Letting d' represent the distance between the means of the probability density functions for noise alone and for signal plus noise, the value of d', which thus represents the effective signal strength, can be estimated from the relative frequencies of the hits and false alarms that occur under controlled experimental conditions. Whatever criterion the observer uses, even if it is not the optimal one, can be described by a single number representing some value of likelihood ratio derived from the experimental data. The data obtained in the experiment can then be utilized to predict the relative probabilities of hits and false alarms for various sets of experimental conditions.

There are certain implications arising from this theory that are of concern in the driving process. Experiments have demonstrated that alterations in the payoff matrix can have significant effects on performance (Swets, 1964). Experimental results indicate that the curve of the function relating the conditional probability of the response S under condition s to the conditional probability of the response S under condition $\overline{s}$ is approximately linear when the values are plotted on probability paper. This would mean that if d' and the a priori probabilities of s and $\overline{s}$ are known, then the payoff matrix could be systematically altered in such a way as to predictably affect perform- Also, information should be gained as to the information required to make an appropriate decision.

Another feature of this theory is that it accounts for the false alarms that often occur in operational situations. If an observer assigns a high probability to an occurrence, he will tend to respond as if his hypothesis were confirmed, even in cases where it was not confirmed. This accounts then for the complacent driver who, even when a warning is seemingly clear, will often ignore the warning and end up in serious trouble. This can happen when he assigns a low probability of occurrence to that event and thus is not alert to such warnings, and even though he sees them, does not process them sufficiently to ascertain their true nature (Williams and Hopkins, 1958). As Neisser (1967) notes in his discussion of information processing, the observer often sees what he expects to see. The driver who "knows" that a particular traffic control sign he is passing establishes a speed limit of 60 m. p. h. may not notice that the sign has been changed to read 40 m. p. h. Since he has assigned a high probability of occurrence to the 60 m. p. h. reading, he may check only the gross features of the sign (e. g., it is white and rectangular) at the preattentive level. On the basis of this preattentive check, he decides that his original hypothesis is confirmed and thus makes a false alarm. The result of this decision could not only get him into trouble with the police but could lead to danger for both himself and others.

The approach to driver decision making offered by this theory is attractive and appears to have applicability to the driving task. However, very little research that is directly relevant to driving has been conducted within this theoretical framework. The theory does fit into the general information processing paradigm and has obvious relevance to the driving situation.

4.3 Vigilance

The driver sometimes finds himself in situations in which the demands placed on him by the basic driving task are minimal and he spends extended periods of time doing very little except watching for traffic control devices and potentially dangerous situations. A large number of studies have been conducted to determine the capability of observers to detect relatively weak and infrequent signals during the course of a long monotonous vigil such as this. Most of these studies were intended for military applications such as radar watches and the like. Typically, the results of these experiments show a degradation in performance during the course of the vigil.

Many of the vigilance studies have been interpreted in terms of signal detection theory (Broadbent, 1963; Colquhuon and Baddely, 1964; Loeb and Binford, 1964; Levine, 1966; Davenport, 1969). Typically, the degradation in performance usually associated with time-on-task is interpreted as changes in the signal criterion β, which is usually taken to represent the conservativeness of the subject in accepting an input as a signal. Jerison (1967) strongly attacks this interpretation and states that the use of signal detection theory as a model for human vigilance has led to a number of unfortunate results. According to Jerison, the large changes in β typically found in vigilance studies can be better explained by an attention model rather than a decision model based on signal detection theory. He feels that investigators have been diverted from the study of attention to the study of variables associated with decisions about information that has already been processed. Jerison states that the observer first must decide how he will observe and then decide what to do about the information that he has received. It is his view that signal detection theory is directly applicable only to the process of deciding what to do with the information that has been received and processed. He considers the basic problem of vigilance to be associated with decisions about how to observe and is primarily concerned with the processes of attention.

The reduction in signal detection rate over time typically found in vigilance studies as time on the task increases is attributed to changes in attention. In this model, the observer is considered to focus less and less attention on the primary detection task as time on the task increases, and instead focus his attention elsewhere. Thus, observing efficiency in the primary detection task worsens with time and the measured β consequently increases.

Jerison concludes that the data from vigilance studies do not indicate an increased conservatism in detection decisions but suggest instead that regardless of what time during the vigil a signal occurs, if the observer is observing alertly he will not miss it. He recommends that the application of vigilance data to field situations implies that a high detection rate can best be achieved through consideration of means for maintaining a high level of alertness.

Jerison, Pickett and Stenson (1965) suggested that observing behavior can be categorized into three main types: alert, blurred, and distracted. They define the alert state as representing optimum observing. Blurred observing is assured to occur as a result of such factors as inappropriate accommodation or fixation and eye tearing. In this state, the observer exhibits an apparent decrease in sensitivity to the signals. Distracted observing occurs where the observer has focused his attention on something other than the primary task, and would include daydreaming. During this state, it is assumed that the subject makes neither detection nor false alarm responses to the primary signal inputs. In this state, the observer exhibits an apparent increase in caution, i.e., β is increased.

A vigilance model based on signal detection theory was developed around the concept of different observing methods. In this model, the effects of attention can be defined by the values of d' and β obtained under each type of observing behavior. Performance in vigilance tasks can be determined on the basis of the relative amounts of each type of observing that occurs. The measure of percentage detections during the vigil is a direct indicant of the percentage of alert observing behavior, assuming strong signals are present. The amount of blurred observing can be determined from the false alarms, and distracted observing from the misses. Thus, this model provides an interpretation for both the results of Mackworth (1968) who reports a decline in sensitivity during a vigil and numerous others (e.g., Broadbent and Gregory, 1963) who report changes in β during a vigil. Assuming that alert observing can be maintained most of the time, Jerison et al (1965) suggest that even small amounts of inappropriate observing (blurring) can effect major changes in sensitivity (d'). Distracted observing would result in an inflated β which Jerison et al strongly assert is not an indication of increased caution, but instead reflects an increase in non-alert or distracted observing. They suggest that measures obtained in laboratory studies of signal detectability can be used as baseline measures against which to evaluate measures obtained under field conditions. If typical observing behavior under field conditions can be determined or controlled, it may be possible with this model to use basic laboratory data on signal detection to accurately predict performance in the field.

The performance degradation typically demonstrated during long periods of vigilance can be overcome to a large extent by the simple expedient of providing periodic rest pauses (McCormack, 1958; Jenkins, 1958). Zuerchner (1965) had his subjects engage in conversation, or stand, stretch and breathe deeply, while still performing the vigilance tasks. He found an improvement in performance under both conditions. The relevance of these findings to the driving situation is apparent.

Motivation is an important factor in vigilance situations and one that often is not considered in studies of vigilance. Pollack and Knaff (1958) found that punishment (a loud horn blast) for missing a signal, resulted in an improvement in detection rate. They also reported an improved detection rate under conditions of monetary reward. Bergum and Lehr (1964), however, found that subsequent cessation of the reward resulted in a greater degradation in performance than that shown by a control group.

Kibler (1965) also has discussed the relevance of laboratory vigilance studies to the real world, particularly in military operations. His primary concern is that typical vigilance tasks do not represent a realistic simulation of present day monitoring activities and he states that it has yet to be established that the results of typical vigilance studies can be validly applied to most present day monitoring functions. He avers that there is a conspicuous paucity of published studies which have actually tested or demonstrated the relevance of laboratory findings to actual monitoring situations. The tasks in these studies typically require the subjects to spend long periods of time watching or listening for weak, infrequently presented signals to which they must make a relatively simple response. Kibler notes that while such tasks may once have had some relevance to certain military operations (radar monitoring, in particular), that relevance has greatly diminished in recent years. He points out that the radar observer of today seldom is faced with the type of task performed in most vigilance studies. Rather, his task now may be better characterized by complex multidimensional signal inputs which require relatively complex processing by the observer and which may represent many different classes of targets. The major problem in this situation does not seem to be so much a degradation in detection performance over time, but rather a general sustained inefficiency in detecting and/or identifying targets and properly processing the information presented in the display (Elliot, 1960, and Self and Rhodes, 1964).

Kibler quotes Fitts as stating that in more complex monitoring tasks, decreased alertness may be evidenced in inadequate responses to critical stimuli. Thus, the adequacy of the response of an automobile driver to a critical information input such as that provided by a tire failure, could be considered an indicant of his level of alertness.

For the driving situation, there are many instances, e.g., driving on limited access divided highways at night, in which the driver may receive only infrequent, weak signals which require a minimal response on his part. Probably one of the most extensive applied research efforts relative to general driving performance has been that related to driving vehicles at night. The Highway Research Board periodically publishes extensive summaries of this and related work. The investigation of nightime driving is an extremely complex undertaking. Even in the most basic studies where attempts have been made to determine the capabilities of observers to detect objects such as a vehicle or a person that might be present on the highway at night, considerable difficulty is encountered in generalizing these results to a wide variety of situations. Basically, the problem seems to be that illumination conditions and target-field relationships can vary so widely that a sufficient body of knowledge is not yet available to permit ready generalization to a wide variety of situations. Blackwell, Schwaff, and Pritchard (1965) states that "a very comprehensive study of illumination and visibility variables in roadway visual tasks is required before general understanding of the problem of seeing while driving can be achieved." Alertness generally has not been an experimental factor in these studies, but the studies on vigilance certainly are relevant in concept to such situations. However, the validity of the laboratory findings must be carefully considered in light of the criticisms previously discussed.

4.4 Driving Considerations

4.4.1 Real World Versus Laboratory Research

As was noted earlier, a problem with basic laboratory research on human performance is that the conditions under which data are obtained in the laboratory often bear little resemblance to the conditions under which the human operates in the real world. Christensen and Mills (1967) state that the use of any method or model for estimating human performance in complex man-machine systems without validation under actual operational conditions is a risky procedure. They emphasize the gross differences that exist between the laboratory and the actual situation and use as an example R. L. Thorndike's findings regarding the differences that exist between aircraft bombardier performance in the training situation and performance in combat. They argue that since we do not really know what humans do in complex man-machine systems, the generalization of basic laboratory data to real world performance in such systems should be done with great care.

This, of course, is not a new argument. After all, the primary aim in most laboratory research on human performance is to better understand the basic workings of the human and not some complex man-machine system.

At the same time, it would be highly desirable if the data from laboratory studies could be applied in a practical sense to actual situations, such as driving an automobile, in which humans are primary participants in a complex man-machine system.

The need to understand the limits of human performance is critical in many situations. The driver of an automobile obviously must process and act on many information inputs as he performs his task. It also is obvious that many drivers do a very poor job in this task and end up dead. About one-third of these deaths occur in single-car accidents. Thus, if they had survived, these drivers probably could not even have blamed the accident on some other driver.

Numerous attempts have been made to determine the causes of single-car accidents. Table 6 is one example of the types of causes to which these accidents are ascribed. While causes stemming from a degradation in alertness and deficiencies in the acquisition and processing of information are not explicitly listed, such factors undoubtedly are important. For example, the purpose of traffic control devices such as signs, markings and signals is to provide information that will enable or require the driver to perform his task in an efficient and safe manner. The vehicle that runs off the road may represent in many cases a failure of traffic control devices to impart vital information to the driver of the vehicle. The inadequacies of these devices are particularly important in instances where the driver may have his primary attention focused elsewhere.

One approach often used in attempts to answer the questions posed above is to obtain observational data for a selected test site and examine the effects of design modifications on driver and pedestrian performance and/or accident frequency over a prolonged period of time. While useful data can be obtained in this way, some disadvantages are apparent in the use of this procedure as a primary means of data gathering. An important consideration is that because of the inefficiency and imprecision typically associated with observational studies, it takes a lot of data to reach any meaningful conclusions.

TABLE 6

NUMBER OF SINGLE CAR ACCIDENTS BY CAUSE

(From Penn, 1963)

Accident Cause	Number of Accidents	Per Cent Of Total
Faulty Driving	1,302	25.0
Speed	1,229	23.6
Drinking or Drugs	768	14.8
Mechanical Failure	520	10.0
Drowsiness	511	9.8
Unknown Vehicle	263	5.1
Miscellaneous	182	3.5
Distraction Inside Vehicle	163	3.1
Adverse Driving Conditions	141	2.7
Distraction Outside Vehicle	83	1.6
Medical Problems	41	0.8
Total	5,203	100.0%

An alternative approach is to simulate the driving situation, or some aspect of it. This approach provides a means of collecting a large amount of data in a relatively short period of time. However, it is well known that people often do not perform the same way in a test situation as they do in the actual situation the test was designed to investigate. Consequently, devices which may be similar in terms of detection and recognition characteristics, as tested in the laboratory, may differ significantly when tested in the actual operating situation. Results from tests which use subjects operating in a known test environment, e.g., a driving simulator, thus run the very real risk of being inappropriate for assessing driver performance in the actual operating situation. In addition, they run the risk of artifactual amounts of fatigue, inattention and motivation being present.

A rather extreme example of how the test situation can influence the test results is found in a report by Bailey and Olsen (1959). In off-road military operations, it is often necessary to use on-foot guides to lead the vehicles when operating at night under blackout conditions and without auxiliary viewing or sensing devices. The speed of the vehicle under these conditions thus is that of a walking man. Bailey and Olsen attempted to quantify the extent of performance degradation resulting under various visibility conditions by having tank crews negotiate a test track at a proving ground. They found that under all the conditions tested the tanks were operated at velocities approaching those of daytime operation. Obviously, the test situation in this case was drastically different from that of the actual off-road situation.

Likely reasons for Bailey and Olsen's discrepant results include: 1) the drivers were well aware that they and the vehicles were in relatively little danger, 2) the drivers knew that no obstacles were present on the test track, and 3) the drivers knew that a path did in fact exist. With this knowledge, their task was primarily just one of determining where the track went. Under the conditions tested, this evidently was not too difficult a task. In the actual field situation, however, the tank driver is faced with a multitude of unknowns concerning his desired path of travel and he must be extremely alert to possible dangers he may encounter. Assuming that the driver has received little or no briefing concerning the proposed route, and realizing that he is fully cognizant of the cost of his vehicle and the disfavor with which his superior would receive news that he had damaged or disabled the vehicle, we can understand why the driver might place a much higher value on a safe arrival at his destination than he would on the time it takes to get there. In the combat situation, a disabled vehicle is extremely vulnerable to enemy attack and the importance of being able to move, however slowly, achieves paramount importance. It is apparent that the expectancies and values set up by the driver in regard to possible events that could occur in the driving situation can have a marked influence on the way in which he operates his vehicle and can be an important factor in determining the level of alertness under which he operates. Such factors undoubtedly also influence driver performance on highways.

Drivers obtain most of their information through direct visual reference to the outside world. As an information processor, the driver observes the road ahead to obtain information and transmits information by manipulations of the steering wheel, brakes and other controls. The effectiveness of traffic control devices in improving driver performance and safety can be related directly to the aid which the devices provide in processing information. Data from laboratory studies are useful here in establishing the capabilities of humans in performing relevant tasks. It must be remembered, however, that these data reflect more or less ideal conditions and thus become less useful, for this purpose, as the operational conditions depart from the ideal and as the alertness of the driver departs from that typical of the high level usually present in most laboratory information processing studies.

4.4.2 Traffic Controls and Signs

Since so much of the information the driver receives is prestnted to him by traffic control devices, a major problem in highway safety is to determine just how, when and to what extent such information can be used by the driver in various operating situations. Valid data concerning the way in which humans process such information should lead to design practices that maximize the effectiveness of traffic control devices. This will not be a simple solution because control devices can appear in a wide variety of driving contexts. Major considerations are the weather, traffic, highway and viewing geometry, and illumination conditions under which the devices are viewed. Other important factors include the amount of visual clutter along the roadway, the presence of other objects in the immediate viewing area of the control device, the familiarity of the driver with that particular roadway, his age, experience, attitudes and level of fatigue, the existence of psychological or physiological stress, effects due to the consumption of alcohol or the taking of drugs and the extent to which he is alert to highway events. We must consider, again, what it is the driver wants to do and what value he puts on achieving that end. Because of all these contributing factors, it is likely that a traffic control device that may be entirely adequate in one context may be entirely inadequate in some other context. The problem is to specify the way in which these various driving contexts affect the way in which the driver is able to use the information provided by traffic control devices.

An important question relates to the way in which the information is to be used. In some cases, the driver must operate solely on the basis of what he can see from his vehicle. In such cases, he must be extremely alert to possible obstacles in his proposed path that might interfere with the expeditious completion of his journey. In other cases, through the use of maps or because of previous experience with the route, he may possess considerable advance information about the proposed route and can concentrate on looking primarily for expected landmarks and obstacles. The visual requirements of the driver and the way in which he obtains and uses visual information may be quite different in these two cases. Selective attention and overall alertness certainly will be critical factors in driving performance under these conditions.

Cumming (1964) took the position that all signposting, linemarking and signalling should be designed with the goal of minimizing uncertainty. Senders, et al (1967) attempted to derive an uncertainty model of the driving situation. A central notion underlying the development of their theoretical work is that drivers tend to drive to a limit:

> "We suggest that the limit is determined by that point when the driver's information processing capacity, either real or imagined, is matched by the information generation rate of the road, either real or estimated. The drivers may be wrong in their estimates, but they will tend to achieve this balance of input information rate and information processing rate. A driver in unfamiliar territory sees a great deal more uncertainty in the situation than a driver familiar with the territory. With familiarity there comes a reduction of uncertainty, a reduction of information flow rate, and a higher permissible velocity, granted the same territory and circumstances. This is reflected in the different ways people behave in automobiles in familiar and in unfamiliar terrains. It might be said that a curvy, familiar road is 'perceptually straight' since uncertainty about the road ahead is low." (Senders, et al 1967)

When viewed in this light, the likelihood of an accident increases as a function of the degree to which information generation by the road, traffic and signal devices exceeds the information processing capability of the operator. Higher driving speeds result in an increase in information generation rate and require a concomitant increase in information processing rate to maintain the balance between generating and processing. This type of balance was implied by Barmack and Payne (1962) in discussing the problem of drinking drivers: "Alcohol apparently induces a passive level of functioning without creating, at least in some drivers, intention to reduce speed. However, higher speeds require more active anticipatory processes. The lack of adjustment to this higher demand level, or the inability to sustain more active processes, defeated most of the drinking drivers." Thus, the drinking driver might be expected to display some of the same response inadequacies as does the driver who is not alert.

The driver of an automobile tends to sample rather than continuously observe the viewing field. Filmed records of drivers' eye movements indicate a maximum rate of sampling of about 1 to 1.4 per second (Cumming, 1964).

In such a task, reaction time is approximately 0.3 seconds. This time lag, according to Cumming (1964) ". . . leads to the strategy, in the development of a tracking skill, of taking a preview of the reaction time . . . As the skill develops, it becomes possible to extract the constants, to allow for smoothness and coordination, and so to program further ahead than half a second." Senders, et al (1967) report that the number of observations and the viewing time vary as a function of the difficulty of the driving task and the velocity of the vehicle. During the sampling period, those inputs that are more attention demanding will be those that are attended to and processed further. The limits of the human in processing that information are critical in designing vehicle and roadway systems for maximum safety.

Traffic control devices are a primary source of information for the driver. These devices are categorized as regulatory devices (e.g., signs, traffic lights), warning devices (e.g., railroad crossing flashes, etc.), and are coded along dimensions such as size, shape, color and message content. The devices are coded both individually and by groups. For example, one group of current regulatory signs has rectangular signs all of the same size with black lettering appearing on a white background. They are distinguished from other categories of signs by their message content. The way in which these signs are processed by the driver will depend on whether or not he is close enough to read the message when he first sights the sign. If he is far away, he initially may only be able to assign it to a particular group of signs. Thus, in the case of speed limit signs, at far distances the situation is first one in which the driver merely categorizes the sign as a regulatory device. When he gets closer, he then can determine what the message of that particular sign is and take any action he deems necessary. We can contrast this situation with that of viewing a stop sign. In this case, the sign represents a grouping with only one member. Further, the sign is coded on three dimensions (shape, color and message), any one of which is sufficient to identify the sign as a stop sign. Robinson (1967), in fact, reports that 87% of the drivers who stopped at a red, octagonal sign with the word TOPS on it never even noticed that the sign did not read STOP.

Consider the speed with which stop signs can be identified versus the speed with which speed limit signs can be identified. It is reasonable to assume that, if first sighted at distances where the messages cannot be read, the stop sign generally will be identified sooner than will the speed limit sign since *either* color or shape can be used to identify the stop sign. However, both dimensions are required to identify the speed limit sign. Because of the higher payoff associated with detection and identification of a stop sign, it is more likely that stop signs will be processed beyond the pre-attentive stage and thus be responded to than will speed limit signs. Even after the speed limit sign is categorized as such, the message still must be read to identify the particular type of sign represented.

A study conducted recently in Sweden appears to illustrate some effects on performance of the values drivers associate with various types of signs (Johansson and Rumar, 1966). The measure in this case was whether or not drivers could remember the information presented by a sign they had just passed. Five signs were used. The authors state that the signs were similar as regards size, color, contrast, form, etc., with the exception that one sign (pre-warning for speed limit zone) was circular in shape while the others were triangular. The authors assumed that this difference was not critical in the interpretation of the results. The percentages of drivers remembering correctly the messages on the various signs were as follows:

1.	pre-warning for speed limit zone	78 per cent
2.	police control	63 per cent
3.	road surface damage	55 per cent
4.	warning (unspecified)	18 per cent
5.	pre-warning for pedestrian crossing	17 per cent

If we make the assumption that all the signs were seen, and if we consider retention to be an indicant of the amount of processing received, it would appear that the amount of processing each sign received is indeed related to its subjective payoff value. In a second part of the study, Johansson and Rumar found that the mean percentage of road signs observed by five subjects riding as passengers on a trip of 165 miles was about 90 per cent of the signs passed.

The only task of the subjects was to observe and report signs. Johansson and Rumar interpret these data as evidence for deficiencies in the effectiveness of the road sign system in imparting information to the driver. They do not indicate, however, if all the subjects tended to miss the same types of signs.

Traffic control devices alone may not necessarily produce an information overload. However, when these controls are added to the perceptual demands of driving tasks such as awareness of speed, direction and turning intent of other vehicles, such controls may become critical.

While information overload may produce dangers for the driver, information underload does not necessarily improve performance. Information deprivation may introduce some decrements in driving performance, especially on country highways at night when the view of the countryside is virtually eliminated (Connolly, 1966). Senders (1966) assumes that the processing mechanism operates at full speed if it is operating at all. Serious underloading results in the driver's finding other things to do with the leftover capacity. Thus, he may daydream or doze if not sufficiently busy with the driving task.

Based on field observations, it is obvious that the benefits of design practices derived from the data of laboratory studies are often difficult to demonstrate in actual driving situations. Part of this difficulty, certainly, stems from measurement problems. It is difficult to determine just what constitutes a reasonable and sensitive measure of the performance of a vehicle system under field conditions and even more difficult to develop means for obtaining that measure. With regards to traffic control devices, for example, several basic questions exist. These include: how well does the driver perform in detecting and recognizing a particular device under various viewing conditions? Does he know and understand the meaning of the device? When he sees it and recognizes it, are there other factors present which will influence how he responds to the objectives of the device? The factor of alertness serves to greatly complicate the problem.

4.5 Task Load

Several investigators have used performance on a secondary task as an indicant of the attentional demands of the driving task. Brown and Poulton (1961) measured the "spare mental capacity" of drivers by having them perform a secondary task in which they were to idenfity a digit which was changed in a successive series of auditorily presented digits. They report an increase in errors as a function of increased vehicular and pedestrian traffic. Christner (1962) measured performance on the digit detection task as a function of the input rate (number of vehicles passed, cross traffic, traffic signals, pedestrians) and output rate (slowing, stopping, swerving, changing lanes). She concluded that the digit detection task was not a very sensitive indication of driver information processing load. Brown, Tickner and Simmonds (1966) found that prolonged driving had a negligible effect on a secondary task in which the subject responded to a tone with a name of a month selected by him at random. In light of a study reported by Peterson (1969) regarding performance of concurrent activities, these results are not at all surprising.

Brown, Simmonds and Tickner (1967) discuss a program of research aimed at determining the effects of prolonged driving on performance. They conclude that performance need not be adversely affected by long periods spent in virtually continuous driving. Performance measures included control changes and vehicle movement. In this program, subjects drove almost continuously for periods up to 12 hours. Performance on a subsidiary task varied depending on whether the task was mainly perceptual or motor in nature. Vigilance improved significantly during the prolonged period of driving. Brown et al hypothesize that prolonged driving may result in automatization of control skills thus reducing the load on the driver and allowing him to focus more attention on the perceptual vigilance task. This hypothesis is supported by other data which indicate that the more overlearned, compatible and automatic the relation between the information inputs and response, the less effect increased information load has on performance (Broadbent and Gregory, 1962; Treisman, 1969). Some researchers have hypothesized that the subjects process overlearned and simple information in a parallel rather than sequential manner (Neisser, 1967; Peterson, 1969).

Brown et al (1967) suggest that changes in performance over long periods of time may be due to changes in physiological activation measured by changes in oral temperatures over the driving period. As they note, however, driving time and changes in physiological activations were confounded in their study, hence neither hypothesis is clearly supported by the data. It is also possible that motivational considerations were a factor in their results. In any event Brown et al point out that the changes in performance typically associated with prolonged driving in other studies (Crawford, 1961, reviews many of these) is relatively small compared to the degradation in performance resulting from lack of sleep (Williams, Ardie and Goodnow, 1959). Chiles, Alluisi and Adams (1968) also report circadian periodicities in performance (retention time, response latency) that parallel periodicities found in pulse rate and temperature. They also found that highly motivated subjects did not demonstrate these changes in performance on the tasks used in their studies.

In the case of the work reported by Brown et al, it is apparent that conditions of information processing overload either were not being encountered or were not being measured. Since overload conditions do occur in driving, the effects of prolonged driving on the capability to handle information overload conditions or in inducing distracted or inattentive driving behavior still have not been determined.

4.6 Long-Term Driving

Herbert and Jaynes (1964) have collected some data on the decrement in certain driving skills such as backing, parking or precision steering that occur following varying periods of cross-country driving of off-road vehicles. During nine hours of driving they found progressive deterioration in the test performance of subjects measured at points from zero to seven hours, and a slight improvement ("end spurt") at nine hours.

Greenshields (1966) used the Greenshields-Platt "Driveometer" to measure "fatigue" associated with long term thruway driving. This device records a number of driver activities, including steering wheel reversals, acceleration reversals and brake applications. Speed change, trip time and running time also are recorded. Greenshields reports the results of a pilot study from which it was concluded that the "Driveometer" is sensitive enough to serve as a monitor of changes in driving behavior associated with driving time. Most of the change in driver activity was noted in the number of steering wheel reversals. Drivers tended to reduce the number of steering wheel reversals as driving time increased. Changes in speed also were noted. Accelerator reversals and brake applications showed no systematic changes over time. However, as time on the road increased some drivers showed a decline in the number of responses to highway and traffic events. Changes in performance were greater when the driving task was made more difficult as, for example, when the driver was attempting to maintain a constant speed and tracking position on the road.

Ryan and Warner (1936) measured performance as a function of prolonged driving. After a full day of driving, they found degradations in performance of tests of steadiness, coordination, reaction time and other such functions. Cognitive performance, as measured by a color naming test, was most affected.

Lauer and Suhr (1959) investigated the effects of rest pauses on driving performance. They found that performance on a number of tasks was adversely affected when rest pauses were not given. Measures that showed a performance degradation included reaction time to a red light presented on the instrument panel, side-to-side sway, lateral placement and observer evaluation of overall driving performance. On the other hand, accelerator movements, brake applications, driving time and speed control demonstrated no changes associated with the presence or absence of rest pauses.

4.7 Lack of Sleep

Williams et al (1959) studied the effects on various vigilance tasks of 72 to 98 hours without sleep. On a subject-paced task, they found that loss of sleep resulted in increased errors.

Harris (1960) studied the effects of 60 hours of sleep deprivation on hand and leg control movements. In a task requiring both manipulation of controls and movements from one control to another, he found that the duration of the manipulation movements tended to decrease with sleep loss but that the duration of movements from one switch to another tended to increase. Speed of discrete leg movements showed a decrease during the sleepless period. Critical fusion frequency (CFF) showed a decrease with sleep loss.

4.8 Ambient Temperature

Bursill (1958) found that an increase in ambient temperature resulted in a reduced response rate to visual signals presented peripherally to subjects primarily engaged in a tracking task. Pepler (1958, 1960) also reports performance degradation under conditions of high ambient temperature.

4.9 Noise

Grimaldi (1958) investigated the effects on a pattern tracking task of noise ranging in level from 70 to 100 db and ranging in frequency from 75 to to 9600 Hz. He found that both response time and error frequency were adversely affected by an increase in noise. The greatest decrements occurred in the region of 2400 to 4800 Hz. Jerison (1957) found that an increment in noise level from 80 db to 100 db resulted in degradation in performance on a visual vigilance task and in the estimation of a ten minute interval. Pepler (1960) found that a background of quiet speech resulted in an increase in errors on a pursuit tracking task.

Baker (1963) theorized that high level intermittent noise would result in a greater decrease in vigilance performance than would continuous noise. He bases this rationale on the hypothesis that, based on immediate past experience, subjects develop an expectancy with regard to the future occurrence of signals. Under this hypothesis, intermittent noise serves to degrade performance by reducing the number of expectancy confirmations.

A contrary view is that intermittent noise can maintain or increase alertness through an 'arousal' function (Kirk and Hecht, 1963; Teichner, Arees and Reilly, 1963). McCann (1969) tested performance on a vigilance task under moderate levels of both noise conditions. The task of the subjects was to detect discrepancies between numbers on a check list and those on an audio presentation. McCann reports a significant increase in omission errors under the intermittent noise condition. He attributes this degradation in performance to disruption of the expectancy formation process by the intermittent noise. However, those subjects in the group which received the intermittent noise condition in the last of three 20-minute segments (quiet, continuous noise, intermittent noise) made many more errors in that condition than did subjects who received the intermittent noise condition in the second segment (quiet, intermittent noise, continuous noise). In fact, the latter group made fewer errors in the intermittent noise condition than the first group made in the continuous noise condition. They also made more errors in the intermittent condition as compared to the continuous and to the quiet conditions in which their performance was quite similar.

Teichner et al (1963) suggest that noise has both arousal and distraction properties, the operation of which depends on the adaptation level of the subject and the on-off ratio of the sound. Under this hypothesis, both continuous and intermittent noise can serve to degrade or facilitate performance. Teichner et al found that noise presented at an on-off ratio of 70% at a level of 100 db had no effect on signal detection. They conclude that, under these conditions, the arousal and distraction effects cancel each other. Warner (1969) found no changes in detection time at noise levels of 80, 90 and 100 db, but the total number of detection errors decreased as the noise level increased. He interprets these results as demonstrating a facilitative effect in that the degree of flexibility of attention is increased.

Brown (1965) found that when dance music was playing on the radio subjects reduced the frequency with which they used the accelerator and brake pedals in light traffic. In heavy, traffic, they tended to drive slower.

Konz and McDougal (1968) measured driving performance using the Greenshields-Platt Driveometer under conditions of no music, slow music and Tijuana Brass music. In light traffic conditions, subjects tended to drive faster in the music conditions than in the no-music condition. During the Tijuana Brass music condition, drivers used more accelerator movement than during the other two conditions. However, the changes in performance were slight and the authors conclude the practical significance of the results is not clear. They conclude that the changes observed cannot be defined as either beneficial or harmful without more research.

4.10 Electrophysiologic Measures

Some attempts have been made to correlate alertness with electrophysiological measures. Suenaga, Goto and Suenaga (1967) reported that as a group, bus drivers involved in accidents tended to have EEG's which displayed a dominant alpha wave. Bergey et al (1967) also reports preliminary work on use of EEG as an indicant of alertness. These studies are interesting but much more work is required in this area.

Lecrett (personal communication 1969) performed an on-road study in which changes in occipital EEG, GSR, heart rate and cervical EMG were recorded during long-duration driving. The findings in this study reveal changes in all of the above with driving time. Unfortunately no measures of driving performance were taken, so it is not possible to correlate these results with degradation in driving performance due to decreased alertness. With regard to the use of physiological measures as indices of constructs such as alertness or stress, Miller (1969) aptly points out that many of these indices represent measures of classically conditioned autonomic responses. As such these measures may be stable within subjects but show little between-subject communality. Therefore, while any measure or set of measures of physiologic function could be reliably correlated with alertness in a single individual, measures which are accurate accross individuals are much less likely.

4.11 Recapitulation of Literature Review

4.11.1 Attention and Information Processing

The various models of attention and information processing have certain features in common. Most of the models assume that certain items can be processed in parallel but that focal attention is serial and restricted to one item at a time. Concurrent activities are handled through rapid switching from one activity to another or through processing the items at different levels. For example, in Neisser's model, certain items can be processed at the pre-attentive level when focal attention is being directed elsewhere. The major difference in the various models is whether attention and subsequent analysis are a totally passive operation, or whether an active component exists in which some form of analysis by synthesis is an important mechanism of the processing. The arguments for an active or constructive form of processing are more attractive, but the issue certainly is not yet settled.

The model depicted in Figure 11 represents a general model of attention which can be applied to the problem of driver alertness. The model is patterned primarily after Neisser's model (Neisser 1967). The concept of pertinence forwarded by Norman (1969) is included in the model. Neisser also included such factors in his model and he discusses the importance of context and expectations to analysis by synthesis, particularly in verbal material where grammatical rules are critical. Neisser emphasizes the importance of background processes in providing frames of reference or cognitive structures which are used in the constructive activity of attention and recall. Organizational factors, such as those provided by the rules of grammar and by rhythm, are primary factors in the processing of information.

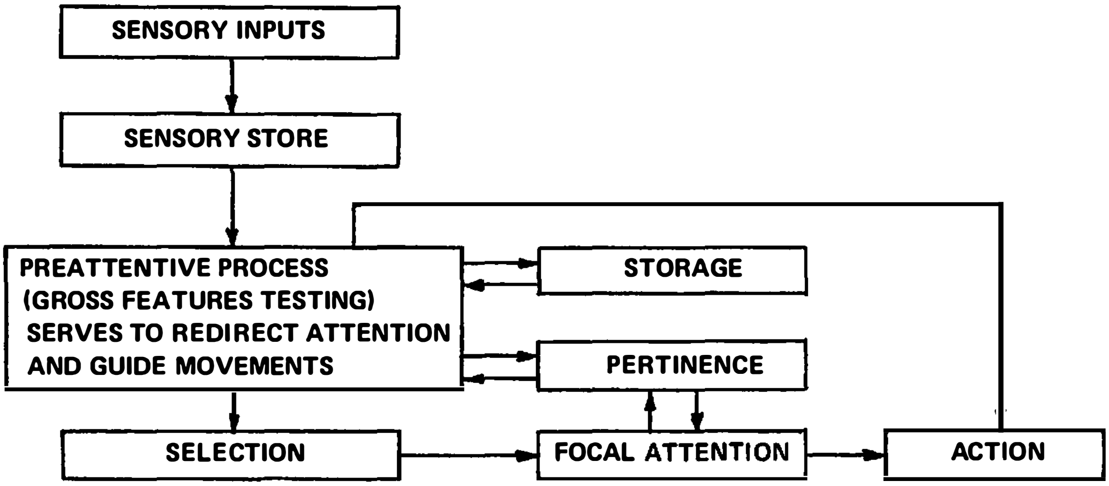


FIGURE 11 A MODEL OF ATTENTION

In applying this model to driver alertness, it is apparent that many of the activities common to driving can be conducted at the pre-attentive level. As the driver becomes more experienced and skillful, he can allocate more and more of these routine, mechanical activities to the pre-attentive mechanisms. This is efficient on his part, for he can then perform these activities in parallel, i.e., independently of each other, and thus free his attention mechanisms for other more critical or more interesting activities. When the driver focuses his attention on something, he excludes consideration of any other inputs until that input is processed and transferred out of the very short-term sensory store into a more permanent store. The guided movements of driving and occasional redirection of his attention continue to be handled at the pre-attentive level.

It must be emphasized that the pre-attentive mechanisms can perform only crude, holistic analyses of information inputs, and the probability of misidentifying an input is relatively high. The pre-attentive mechanisms operate in a global way and subtle differences or changes in the inputs may go unrecognized. The driver who has driven the same route every day for years and has become so familiar with the road signs along the way that he only monitors them at the pre-attentive level is not very likely to notice a critical change in a sign unless that change is quite marked. On the other hand, the driver who is driving that route for the first time probably will be focusing much of his attention on the road signs and will correctly identify the sign in question. In this case, there is a danger that he may miss other important inputs, such as a stop light, because he has directed his attention toward the signs.

4.11.2 Decision Making

The concepts of signal detection theory are important to decision making in that they provide a means for considering the effects of rewards and costs on performance. Motivation clearly is a critical factor in the performance of drivers. While practically no research directly applicable to driver alertness has been conducted under this paradigm, it is apparent that the basic concepts of this approach would hold considerable promise for driver research. The driver who contemplates breaking the speed limit certainly considers the costs associated with possible apprehension by the police and the rewards associated with arriving at his destination sooner. Precisely how such factors in a pay-off matrix affect the decision criteria and performance of drivers is not yet known, but the basic concept provides a model under which experimentation could be conducted.

4.11.3 Vigilance

The results of the experiments on vigilance typically indicate a decrement in performance over extended periods of time. Rest pauses, loud noises and other such events can effect a temporary return to a higher level of performance. Motivation is critical in these situations and can greatly affect performance. Some situations (e. g., driving at night on a straight road with very little traffic) approximate the laboratory conditions in many respects, but most driving situations bear only a limited resemblance to the laboratory vigilance studies. Generalization to driving situations thus is limited. In situations which are not so intrinsically boring and devoid of information inputs as are the vigilance studies, the progressive decrement in vigilance performance over time is less likely to occur.

4.11.4 Applications

The lack of an underlying theory or model has weakened much of the existent applied research on driver alertness. Too often, what theory is generated is strictly ad hoc and is seldom tested in a more complete experiment. Thus, much of the applied data in this area is fragmentary and preliminary in nature, and has yet to be expanded upon. Some of the reasons for this inadequacy lie in the nature of the problem. As was noted in the discussion on vigilance, it is often very difficult to conduct studies in the laboratory which can be appropriately generalized to field operations. Conversely, it is often very difficult to conduct a field study which adequately tests the theories generated in the laboratory. In studies of alertness, for example, it is necessary for the subjects to be in a driving situation for relatively long periods of time. To be a valid test, the driving situation should be as realistic as possible. The difficulties in establishing such conditions without undue danger to the subjects and without confounding of the data because of the uncontrolled factors in that situation are considerable.

In general, those applied studies which are pertinent to the attention model discussed above tend to support that model. It is apparent that as drivers become more experienced or familiar with a particular activity they tend to relegate this activity to the pre-attentive level. However, the studies on environmental factors and long-term driving provide evidence that some attenuation of the inputs may also be taking place. For example, the sleepy driver or overheated driver shows less response to signals at the pre-attentive level than does the wide-awake and alert driver. The importance of such factors as rest pauses and extraneous motivating inputs in maintaining alertness are evident.

In terms of future research, two factors seem to be critical. First, the factor of realism is critical in the conduct of both laboratory and field studies. Motivational considerations in particular are vital to an understanding of driver performance and too often are totally ignored or at least not manipulated in most driving studies. On the basis of laboratory studies, it is apparent that such factors cannot safely be ignored. The second factor has to do with the establishment of a theoretical base or bases on which to design and conduct applied studies. A shift from applied studies in which data are collected to test features of some theoretical paradigm seems highly desirable.

5. APPENDIX B - SAMPLE CONSENT FORM

CONSENT FORM

Description of the research study including services of subjects and conditions under which they will be performed:

As a part of a CAL project investigating driver alertness it is necessary to evaluate the effect of the following on driver performance:

1. Duration of drive.
2. Information available to the driver.
3. Vehicle noise level.
4. Use of an automatic speed control.

In order to evaluate these effects, subjects are required to drive the CAL driving simulator for five hours. During this time the following will be measured:

1. Position accuracy.
2. Yaw.
3. Steering wheel movements.
4. Accelerator movements.
5. Electroencephalograms.
6. Electromyograms.
7. Galvanic skin response.
8. Complex reaction time.
9. Vigilance.

The measurement of variables 5, 6, 7 will require the use of surface recording electrodes. This type of electrode is comfortable, suitable for long-term use (up to 48 hours) and provides for good recording.

I certify that I understand the research described above and am aware of the nature of my participation in it. I hereby agree and consent to serve as a subject in that study.

Date

Signature

or

Signature of Parent or Guardian

6. APPENDIX C - Tabled Subject Performance Data

TABLE 7

MEAN INTEGRATED ABSOLUTE ROAD POSITION ERROR x TIME

PERIOD	TASK COMPLEXITY					
(Minute)	LOW			MODERATE		
	Low	Moderate	High	Low	Moderate	High
1-30	3.76	3.33	3.52	4.10	3.58	3.62
31-60	4.28	3.76	4.10	5.48	4.37	4.54
61-90	5.36	4.65	4.27	6.43	4.87	6.02
91-120	5.90	5.25	5.32	6.40	5.03	7.22
121-150	6.55	6.10	5.97	6.47	4.92	9.33
151-180	6.88	6.40	4.18	6.55	4.83	11.74
181-210	7.26	7.59	4.23	7.47	4.98	12.74
211-240	8.84	7.83	6.46	8.04	4.89	11.98

TABLE 8

MEAN 2° STEERING WHEEL REVERSALS x TIME

PERIOD	TASK COMPLEXITY					
(Minute)	LOW			MODERATE		
	Low	Moderate	High	Low	Moderate	High
1-30	20.61	22.70	24.57	18.17	19.43	20.72
31-60	18.31	21.22	21.39	16.84	17.69	18.86
61-90	17.56	20.50	21.61	16.77	16.15	17.57
91-120	18.68	19.30	21.29	16.49	16.48	18.06
121-150	16.43	17.61	21.45	16.41	16.28	16.47
151-180	16.13	18.73	22.76	16.42	17.18	16.36
181-210	15.77	17.55	20.27	15.65	16.54	12.77
210-240	16.17	16.02	19.83	16.67	16.39	15.15

TABLE 9

MEAN INTEGRATED ABSOLUTE VELOCITY ERROR x TIME

PERIOD	NOISE LEVEL		
(Minute)	Low	Moderate	High
1-30	3.02	4.18	4.50
31-60	3.73	5.09	4.15
61-90	3.95	3.53	4.67
91-120	4.36	3.52	5.17
121-150	5.09	3.81	3.85
151-180	2.98	3.16	5.30
181-210	3.30	4.44	5.29
211-240	2.91	5.40	6.38

TABLE 10

MEAN RESPONSE LATENCY TO RAMP STIMULUS

Measurement	LOW TASK COMPLEXITY			MODERATE TASK COMPLEXITY		
PERIOD	NOISE LEVEL			NOISE LEVEL		
(Minute)	Low	Moderate	High	Low	Moderate	High
2	5.86	8.53	13.03	6.75	7.66	3.93
28	6.57	7.74	9.56	7.09	7.60	8.92
40	6.33	9.07	9.40	7.06	7.29	7.95
59	6.55	8.40	9.25	8.90	7.97	10.77
89	6.75	8.46	7.37	7.90	7.78	7.92
100	7.31	2.10	7.04	8.07	7.58	7.92
108	6.45	7.01	6.94	7.20	7.18	8.50
119	7.70	8.15	8.64	7.62	6.87	7.79
139	7.72	7.69	8.52	7.27	7.25	7.36
150	7.55	7.66	6.84	7.05	6.96	7.28
170	5.74	6.45	6.90	6.68	7.25	9.74
178	7.86	7.49	7.07	8.03	7.18	7.94
188	5.52	8.73	6.70	6.69	6.83	9.64
199	5.70	6.92	6.93	7.98	7.61	10.88
208	6.16	7.21	7.98	6.64	8.10	7.80
220	7.35	8.64	8.55	5.83	6.95	9.86
240	6.68	7.65	7.31	7.70	8.34	8.62

TABLE 11

MEAN INTEGRATED ABSOLUTE POSITION ERROR DURING BLOWOUT

Time of Occurrence (Minutes)	LOW TASK COMPLEXITY			HIGH TASK COMPLEXITY		
	NOISE LEVEL			NOISE LEVEL		
	Low	Moderate	High	Low	Moderate	High
18	2.5	3.5	3.0	4.0	6.0	2.0
79	4.0	3.0	5.0	5.0	5.0	6.5
159	3.5	5.5	5.5	3.0	5.0	2.5
228	14.5	3.5	6.5	5.5	4.5	26.5

TABLE 12

MEDIAN FREQUENCY OF ALPHA BURST OCCURENCE

	LOW TASK COMPLEXITY			MODERATE TASK COMPLEXITY		
PERIOD	NOISE LEVEL			NOISE LEVEL		
(Hours)	Low	Moderate	High	Low	Moderate	High
1	.00	1.75	1.75	3.25	.50	3.25
2	1.00	2.00	1.25	3.00	2.25	4.75
3	1.75	2.75	4.75	3.00	1.50	3.25
4	1.50	2.75	3.00	6.00	1.50	8.50

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