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EVALUATIONS OF AUTOMOBILE REAR LIGHTING AND SIGNALING SYSTEMS IN DRIVING SIMULATOR AND ROAD TESTS

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16. Abstract

Simulator studies were made to evaluate a number of conventional and experimental vehicle rear lighting systems. In normal car-following conditions a number of experimental rear lighting systems, using functionally separated signal lamps or color coding provided better performance in signal identification. Some of the results were confirmed in a road test. There were no stable differences in car-following performance measures between systems in the simulator.

Analyses of rear-end collision reports were used to structure groups of scenes which were implemented in the simulator. In this test, which included these unusual (pre-crash) car-following maneuvers, there were no stable differences in performance of drivers attributable to various rear lighting systems, including a High Deceleration Signal (HDS) and an Accelerator Position Signal (APS). There were significant differences in performance due to the test conditions of relative velocity and acceleration, and inoperative stop signal lamps. Unobtrusive measurements of drivers on the road showed that they released the accelerator when the car with the APS coasted on their first exposure, but not in a second exposure. A subjective evaluation test of APS found favorable ratings of it, but an increase of accelerator pedal release frequency by the driver of the following car.

It was concluded that simulated car-following performance was unaffected by the rear lighting systems. The APS provided no benefits in car-following in normal or unusual conditions, while following driver behavior showed a potentially undesirable characteristic in increased accelerator releases. No benefits were found for the HDS in these tests, but no undesirable aspects of the signal were evident.

The findings are discussed in the context of previous studies.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF TABLES (Cont.)

LIST OF TABLES (Concl.)

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Mr. Jack D. Campbell was responsible for modifications and maintenance of the simulator and test vehicles.

INTRODUCTION

The requirements for vehicle rear lighting systems are stipulated in Motor Vehicle Safety Standard No. 108. This Standard has been developed into its present format to provide reliable and effective vehicle rear marking and signaling, and is based upon a continuous process of upgrading the material and performance specifications of vehicle lighting systems as new information becomes available.

However, there has been relatively little change in the configuration of vehicle rear lighting systems in terms of the means of coding presence and signal indications. Modifications to the configuration of rear lighting systems have been suggested by a number of studies (e.g., Finch, 1968; Projector et al., 1969; Mortimer, 1970) but have seen little application up to this time. Fundamentally, it has generally been recommended that some degree of functional separation of lamps be used, as well as color coding, since these concepts are believed to improve the ability of drivers to detect and identify signals given by vehicle rear lighting systems. These are certainly criteria that are relevant for the evaluation of rear lighting system performance.

While most foregoing studies have been made with the systems in normally functioning conditions, a recent study (Mortimer, Domas and Moore, 1974) was also concerned with the ability of alternative rear lighting configurations to retain their effectiveness when a number of common system malfunctions are introduced. The results showed that, while systems with redundant signal and presence lamp compartments offered some advantages, the weight of the data supported the use of functional separation and color coding.

The relevance of changes in the operating characteristics of vehicle rear lighting systems for the reduction of accidents is difficult to ascertain. However, a computer simulation approach, such as that of Carlson and Mortimer (1974), offers one way of attacking this problem. Some of their analyses have suggested that alternative rear lighting systems may be able to reduce rear-end crashes that occur in certain classes of conditions.

Driving tests, in which car-following performance has been measured (e.g., Rockwell and Banasik, 1968) are another useful approach for the evaluation of rear lighting systems. Clearly, such evaluations cannot be made in situations which have a high predisposition for rear-end collisions. They can provide information of the improvements in traffic flow behavior that might be expected by changes in the rear lighting and signaling configuration of vehicles, and differ in that respect from other static or driving studies which have evaluated the detectability and identification of signals.

Because of this limitation of driver tests to situations which do not pose unusual hazards, a driving simulator was constructed (Campbell and Mortimer, 1972) which was intended to be used for the evaluation of rear lighting systems in terms of signal detectability as well as car-following performance. The advantage of a simulation approach of this type, is that it can be used for normative car-following evaluations as well as the study of the behavior of drivers in unusual car-following situations, analogous to those in which the rear-end collisions may occur.

The need to consider the alerting qualities and identifiability of signals given by vehicle rear lighting systems, as well as their effect upon car-following performance has been noted previously (Mortimer, 1967; Rockwell and Banasik, 1968; Mortimer, 1970; etc.).

The objectives of this program are to evaluate vehicle rear lighting systems by taking account of both of these aspects of the performance of drivers. Since the relevance of changes in the configuration of vehicle rear lighting systems should, if possible, be demonstrated to lead to a reduction in crashes the research was made in both "normal" car-following conditions as well as "unusual" situations which were shown by an examination of accident data, to be some of those in which rear-end crashes occurred. Also, while considering changes in vehicle rear lighting systems, such as functional separation and color coding of presence and signal lamps, this study was also concerned with the evaluation of two types of signal systems which ostensibly provide additional information of the behavior of a car being followed.

One of these rear lighting systems incorporated an accelerator position signal, by lighting a green lamp if the accelerator was depressed, a yellow lamp if the accelerator and the brake were released, and a red lamp if the brake was applied, in addition to the normal functioning of the vehicle's marking and signaling system. Aspects of such a display, namely the coasting signal, have been considered in prior research studies (Nickerson et al., 1968; Mortimer, 1970, 1971). The study by Nickerson et al. (1968) suggested that a coasting signal would lose much of its effectiveness in providing information of impending braking unless braking followed onset of the yellow coasting signal with a high probability, of about 80% of the time. Mortimer (1970) made measurements of the coasting time durations associated with various vehicle speeds at the initiation of coasting in normal driving conditions for a number of drivers who were unaware that the vehicle was instrumented for this type of measurement. He found that about half of the coasting durations were of 1-second duration or less, with about 10% of them exceeding 5 seconds. The probability that braking would follow coasting was about 0.5, but in many of these instances the coasting durations were fairly long indicating that these were not emergency braking situations.

These results can be considered on the basis of the findings of a subjective evaluation study, in which drivers followed a stream of cars equipped with a yellow coasting signal lamp which was lighted whenever the accelerator was released (Valasek, 1961). It was found, that the frequent onset of the coasting signal was eventually disregarded by the drivers of the following vehicles who reported that it provided them with little information of value and acted as a source of distraction.

The accelerator position signal system evaluated in this study differed in that a green signal lamp was added to indicate that the accelerator was depressed, as well as an additional red signal lamp in the center of the vehicle which was lighted whenever the brakes were applied.

Another rear lighting system concept was studied, whose intent is to present additional information to drivers of following vehicles. It consisted of a signal which was initiated whenever the deceleration exceeded a preset value of about 0.3 g. The signal consisted of the brake lamps of the rear lighting system flashing at 4 Hz, or a separate lamp mounted in the center of the vehicle, either red or yellow and at various intensities, flashing at 4 Hz in such instances. There has been no previous evaluation of the effectiveness of such a signal upon the performance of drivers.

In addition to these systems providing potentially additional information to drivers, some conventional and experimental rear lighting systems, which differed in the manner in which signals were coded, but which provided the same information as is now available from conventional rear lighting systems, were also evaluated.

ANALYSIS AND DESCRIPTION OF REAR-END COLLISION DATA

Some previous examinations of rear-end collision data have shown that these can be broadly classified into instances where: both vehicles are traveling at high or moderate speeds but a speed differential exists; one vehicle is slowing or stopping; one vehicle is stopped in the traffic lane; or one vehicle is parked. These findings have been obtained using data reported by the National Safety Council (e.g., Mortimer, 1970). More recently, a further breakdown of rear-end collisions was made (Mortimer & Post, 1973) using the HSRI Hit-Lab data banks for Washtenaw County in Michigan. For example, Mortimer and Post (1973) evaluated the actions of the vehicles involved in rear-end collisions by broad classifications such as listed above, and by the ambient lighting condition and the class of road on which the collisions occurred. While, overall, vehicles that were classified as stopping were most frequently involved in rear-end, injury-producing collisions on urban and rural roads, vehicles that were moving straight were generally most involved on limited access highways. There were also considerable effects attributable to the ambient lighting conditions, with one major finding of the analysis being that parked vehicles appear to be relatively much more likely to be struck at night than in daytime.

While such analyses are helpful in providing information of the conditions under which crashes occur, and their relative frequencies, they lack the detail needed to restructure the events leading up to the crash. Since it was of interest for the present research program, that some of the general types of rear-end crash situations be implemented in the HSRI rear lighting and car-following simulator, so that alternative rear lighting systems could be evaluated in conditions in which crashes were found to occur, greater detail of the pre-crash phase was required.

For this reason, a different level of accident reporting was needed than can be derived from mass accident data banks. The vehicle accident data file that was used consists of cases collected by accident investigation teams under sponsorship of the Motor Vehicle Manufacturers Association, the National Highway Traffic Safety Administration, and the Canadian Department of Transportation. There are over 3500 cases in this computer accident file.

The cases selected for use in this study involved injury to at least one occupant of a vehicle, the drivers were not suspected of having used alcohol or drugs, the crashes occurred on dry roads, and involved a rear-end collision.

These crashes were further subdivided by type of road into limited-access, urban, and rural roads, as well as occurring in the daytime or at night. Table 1 shows the frequencies of accident cases obtained for the three types of roads and the two ambient lighting conditions.

TABLE 1. - NUMBER OF ACCIDENT CASES OBTAINED, CLASSIFIED BY TYPE OF ROAD AND AMBIENT LIGHTING

Ambient Lighting	Type of Road			Total
	Limited Access	Rural	Urban	
Day	33	36	91	160
Night	34	23	45	102
Total	67	59	136	262

The case numbers for each of these 262 accidents were also obtained, and were used to search for the hard copy containing the full description of the crash which was used to code the computer file. It was found that a number of accidents had been reported twice in the computer output because some cases involved more than two vehicles, which results in two or more vehicle cases being shown in the computer file. In addition, some of the accident cases were not available for analysis because the hard copy could not be found, some had been improperly coded, and other cases did not meet the requirements of the filter that was used for their selection. While the hard copies of 86 cases were obtained which met the basic requirements that were described for the selection of cases, it was found that a total of 68 cases provided sufficient information of the speed of the vehicles involved so that at least a minimal reconstruction of the accident could be made.

Table 2 shows the classification of these 68 cases by type of road and ambient lighting condition. The accident team which made the report and the case number of the 68 cases which were used in this analysis, are shown in Appendix 1.

TABLE 2. NUMBER OF CASES USED, CLASSIFIED BY TYPE OF ROAD AND AMBIENT LIGHTING

Ambient Lighting	Type of Road			Total
	Limited Access	Rural	Urban	
Day	8	13	28	49
Night	6	4	9	19
Total	14	17	37	68

Table 3 shows the percent distribution of speeds at which the striking and struck vehicles were reportedly traveling before the driver s took action, if any, prior to the crash. It will be noted that the struck vehicle was generally moving at less than 20 mph, whereas the speed of the striking vehicles was 20 mph to over 70 mph.

TABLE 3. PERCENT DISTRIBUTION OF REPORTED SPEEDS OF STRUCK AND STRIKING VEHICLES PRIOR TO IMPACT IN CRASH SAMPLE

Speed of Struck Vehicle - mph	Speed of Striking Vehicle - mph								Total
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+	
0- 9			6	18	24	15	8		71
10-19			8	3	6			3	20
20-29			3					3	6
30-39									0
40-49									0
50-59						3			3
60-69									0
70+									0
Total			17	21	30	18	8	6	100

A further breakdown of these crashes was made by grouping them into general types of situations which prevailed just prior to the crash. Five such conditions could be discerned from the data:

1. Struck vehicle had stopped or slowed for traffic, signals, etc.
2. Struck vehicle was waiting to make a left turn.

3. Struck vehicle stopped due to failure, being out of gas, etc.
4. Struck vehicle was making a right turn.
5. Struck vehicle stopped quickly.

Table 4 shows the distribution of these types of accidents by the type of road and the ambient lighting condition in which they occurred. It will be noted that the bulk of accidents, in this sample, involved vehicles which had stopped or slowed, or were waiting to make a left turn.

TABLE 4. NUMBER OF CRASHES OF EACH TYPE, CLASSIFIED BY ROAD TYPE AND AMBIENT LIGHTING

Type of Road	Ambient Lighting	Type of Crash					Total
		1	2	3	4	5	
Lim-Acc	Day	5	-	3	-	-	8
Rural	Day	7	4	-	1	1	13
Urban	Day	23	3	-	1	1	28
Lim-Acc	Night	3	-	3	-	-	6
Rural	Night	-	3	-	1	-	4
Total		40	16	6	3	3	68

Based on a detailed review of these cases, and certain considerations of the specific types of rear lighting and signaling systems that were to be evaluated, a total of 16 scenes were developed for implementation in the rear lighting simulator, some of which were taken to mirror, as well as possible, the type of situations which it was discerned that may have preceded these rear-end crashes, as well as some others which were added for other reasons. The scenes that were selected, are described in a subsequent section of this report concerned with that simulator test.

EVALUATION OF A SIDE-TASK IN THE REAR LIGHTING SIMULATOR

Objectives

Previous dynamic evaluations (e.g., Mortimer, 1970) of vehicle rear lighting systems have shown the need for a side-task which prevents subjects from unnaturally fixating on the rear of the car they are following. The HSRI rear lighting simulator has been shown to provide similar results as obtained in road tests, but with a generally inflated level of subject sensitivity (Campbell & Mortimer, 1972), particularly in a measure relevant to car-following behavior. In order to attempt to equalize subjects' sensitivity between driving a car and the simulator, a side-task, similar to that used in earlier HSRI road studies, was incorporated. The purpose of this study was to evaluate the effectiveness of the side-task in loading the perceptual/information processing capabilities of drivers tested in the simulator.

Method

Subjects

Four male employees of the Highway Safety Research Institute served as subjects. Their ages were 26, 32, 43 and 45 years. Although two of them had participated in earlier simulator experiments, none were experienced with the side-task.

The Simulator

The rear lighting and car-following simulator used in this study has been described elsewhere (Campbell & Mortimer, 1972). Basically, it presents a dynamic car-following task to the driver who is viewing a lead vehicle ahead of him in the same lane, on a two-lane road. The lead vehicle has the capability of presenting turn, stop, coasting, and other signals in various rear lighting and signaling configurations. The simulation is in 1/12 scale. The subject views the lead vehicle and the roadway through a slit, simulating the windshield of his vehicle, by positioning the dominant eye at the correctly simulated position of a following-car driver (Figure 1). He controls the speed of his vehicle with an accelerator and brake pedal, and makes responses to rear lighting systems by depressing the hand- and foot-operated switches to enable response time to signals, errors and omissions to be obtained. A speedometer, located 45° to the right of the forward field-of-view, displays his vehicle's speed.

The operating characteristics of each of the signal lamps on the rear of the lead vehicle are set in accordance with the requirements for the particular rear lighting system being evaluated in that run. The color of the lamps can be changed by changing filter holders in front of each lamp, and their intensity is set by appropriate controls on the simulator control panel (Figure 2).

In daytime simulations, the overhead lights in the simulator are turned on, providing about 40 ft-c of vertical illumination on the roadway, thereby simulating low ambient daytime lighting conditions. In nighttime simulations, the overhead lights are turned off, while roadway illumination in the vicinity of the subject's vehicle is provided by an overhead lamp, to simulate the headlights of his own vehicle illuminating the roadway and the lead vehicle if it is within appropriate range. In that condition, the speedometer is suitably illuminated to allow the subject to read it with ease.

Control of Lead Car Speed and Signal Presentations - During the testing sequences, the velocity of the lead car and its associated signaling profile were controlled by one of four sections of a magnetic tape. The sections of tape were made by driving a vehicle on a limited-access road and recording its speed and stop and turn lamp actuations, using a magnetic tape recorder. In each case the car started from a standstill, at the side of the road, accelerated up to speed and then made vari-

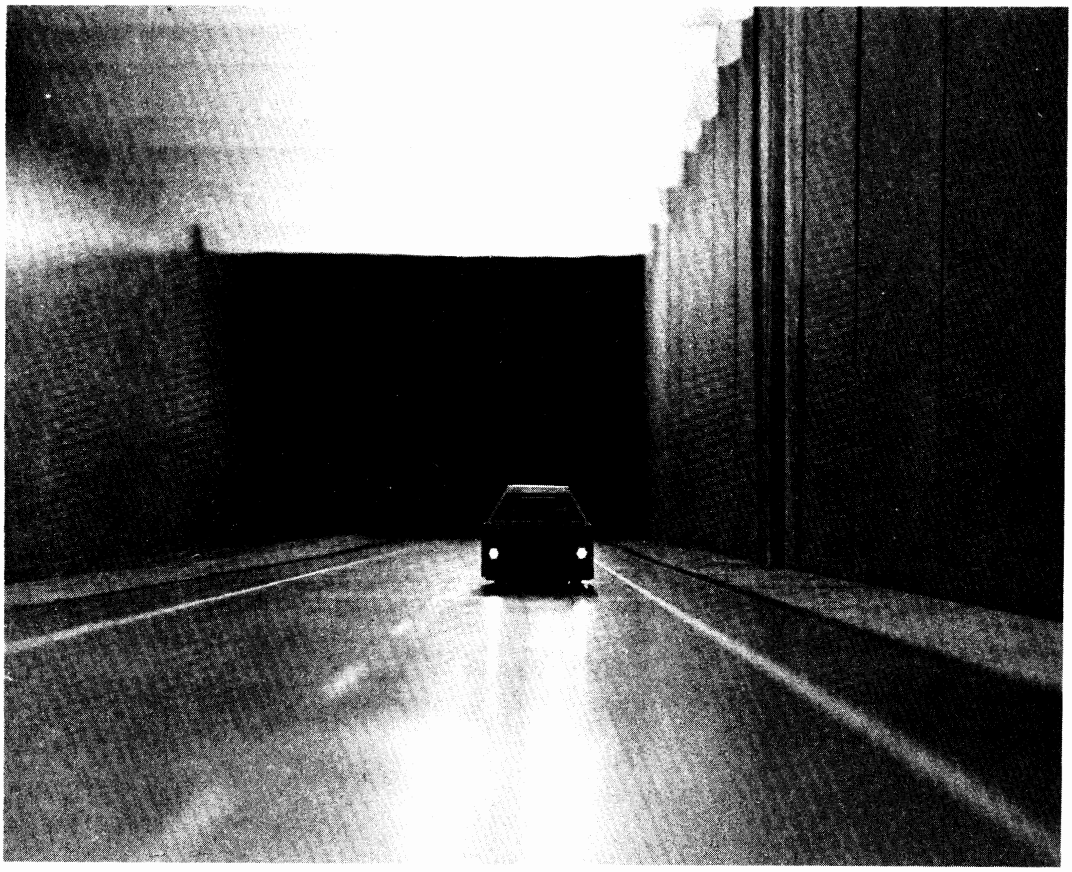


FIGURE 1. SUBJECT'S VIEW OF THE SIMULATOR LEAD CAR AND ROADWAY BELT.

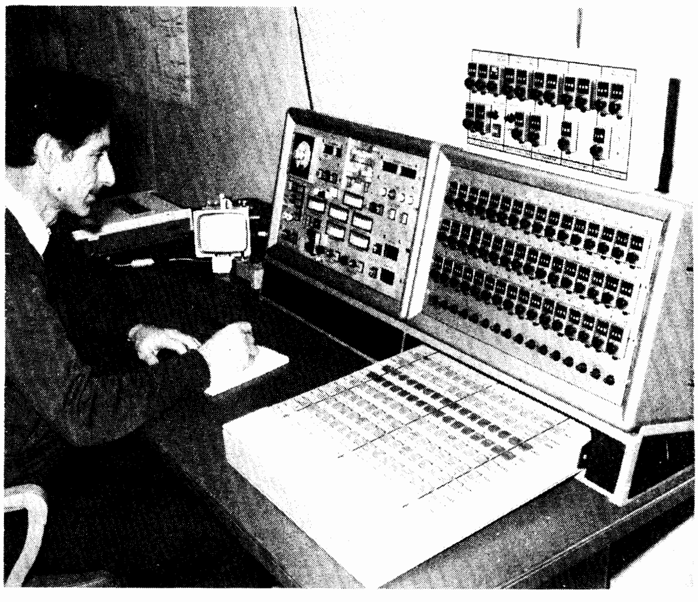


FIGURE 2. SIMULATOR CONTROL PANEL

ous speed changes, as would occur in fairly dense, freeway traffic conditions, and then again came to a stop. Each of the four 8-minute tape sections contained similar velocity profiles (between 0 and 70 mph), but differing orders of presentation of the signals. Twelve signals were presented in each section: two discrete stop and turn signals, two signals in which the stop was followed by turn, and two in which turn signals were followed by stop signals, for a total of six stop and six turn signals per session. An equal number of left and right turn signals were used.

<u>The Side-Task</u> - The side-task required subjects to respond with button presses to the onset of one of two clusters of white lamps (0.25" diameter) mounted at the eye height of the subject seated in the simulator, about 4" above the simulated roadway, 25° off the longitudinal axis of the eye (Figure 3). In this position (57" from the eye), each lamp subtended a visual angle of approximately 15 minutes of arc. A mechanical timing system controlled the onset of the lamps in a pseudo-random sequence, the lamp-interval sequence being repeated every 120 presentations. A lamp was lit for three seconds or until the subject responded correctly to it, by depressing the switch on the same side of the response switch box. Stimuli were presented at the rate of 10/minute. A potentiometer enabled the experimenter to operate the stimulus lamps at two luminance levels: 0.8 fl and 0.08 fl.

Responses to the side-task lamps and to turn signals from the lead car were made with the thumbs, by depressing the appropriate one of four 1.0" diameter pushbutton switches mounted in a metal box 5.0" d x 7.0" w x 2.0" h, which the subject held in the lap (Figure 4). The two lower, inboard switches were used to respond to right and left turn signals presented by the lead car, while the two upper, outboard switches were used to respond to the right and left side-task stimulus lamps. The subject responded

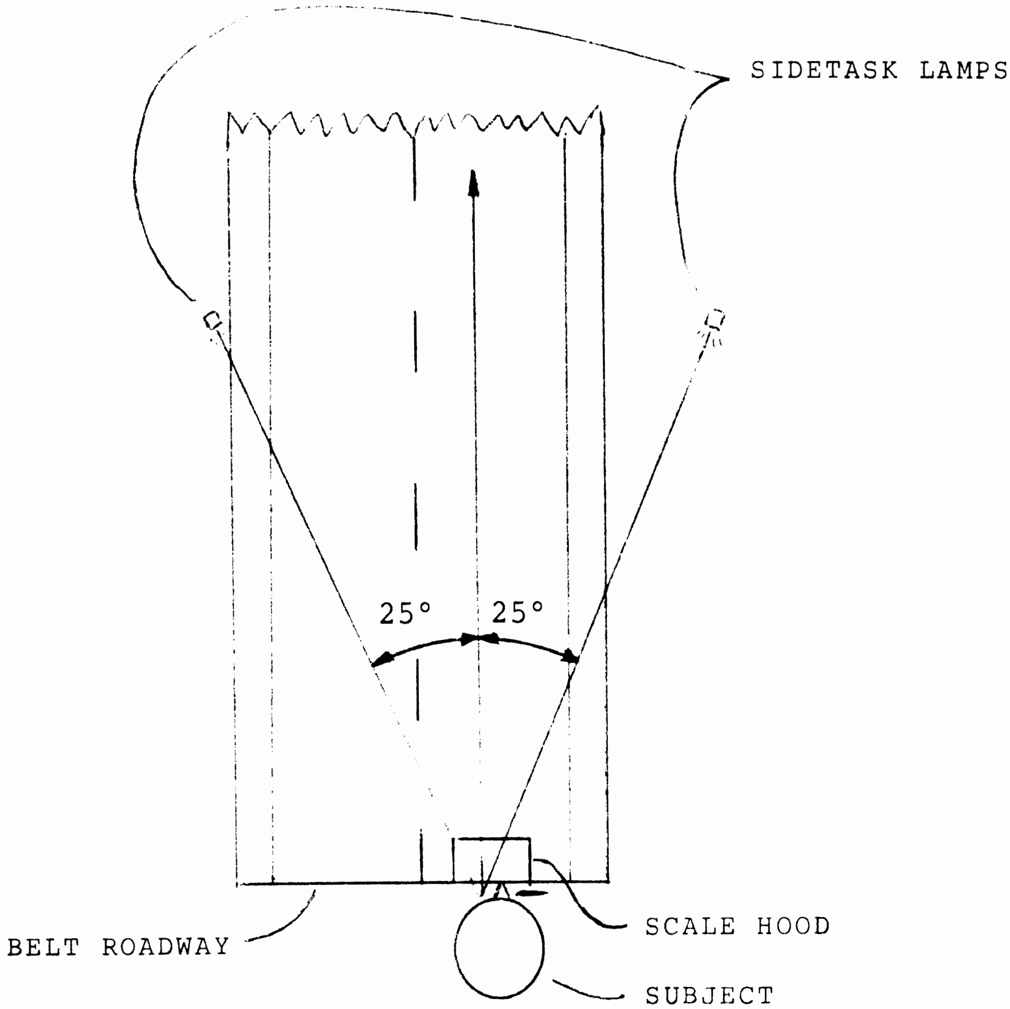


FIGURE 3. OVERHEAD SCHEMATIC VIEW OF SIDE-TASK STIMULUS LAMP BELT ROADWAY LAYOUT.

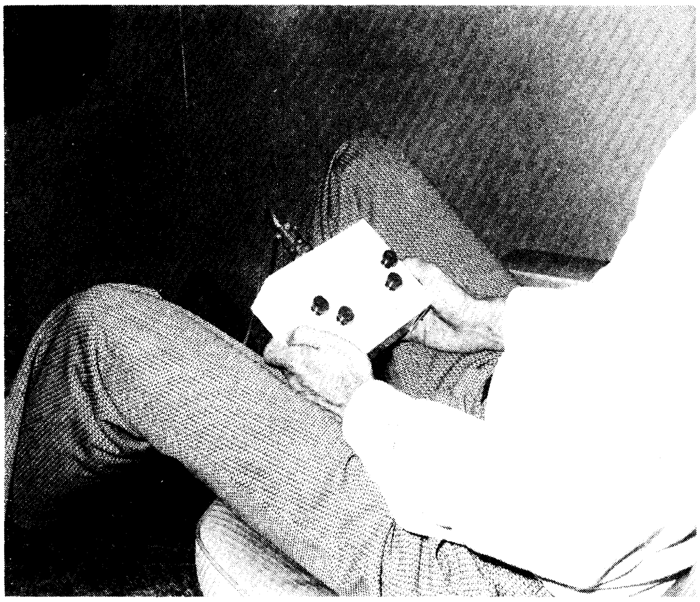


FIGURE 4. THE SUBJECT'S RESPONSE SWITCHES.

to stop signals of the lead car with a footswitch mounted to the left of the brake pedal. Side-task response times and response errors were recorded on magnetic tape through the simulator's computer data acquisition system.

Procedure

At the beginning of each trial, the stationary lead car was placed at a scale headway of 150 feet, and the signaling system demonstrated. One signal of each of the four signal modes was given, and the subject was instructed to respond by depressing the appropriate switch as rapidly as possible following the onset of a signal. When the side-task was used, the mechanical lamp timer was started and the subject was instructed to respond to the stimulus lamps as rapidly as possible and consider the side-task as of primary importance. Before the lead car was put under control of the magnetic tape velocity-signal control system, the subject was informed of the actual headway (150 ft.) and was told to try to maintain that headway throughout the trial by modulating his speed with the brake and accelerator pedals. The velocity signal control tape was then started, although actual data acquisition did not begin until the lead car reached a speed of about 50 mph. The subject was occasionally prompted during the trial as to his actual headway. Data acquisition ended as the lead car slowed at the end of the trial, prior to coming to a stop.

During testing subjects were allowed to view the simulated scene with their dominant eye only, the non-dominant eye being occluded by an opaque glass. Inter-trial intervals were typically 5 minutes, so that the total test period for each subject (including instruction time) on each day required approximately one hour. The overhead lamps in the simulator were not used, in order to simulate night driving.

Independent Variables

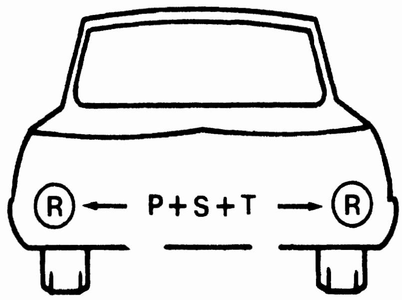
The independent variables were:

1. Side-task: with side-task, without side-task.
2. Side-task luminance: 0.8 fl, 0.08 fl.
3. Lead car signal mode: stop(S), turn(T), stop followed by turn (S→T), turn followed by stop (T→S). (Response times to the second signal only in combination signals were used in the analysis.)
4. Lead car rear lighting system: system 1, system 8 (Figure 5).

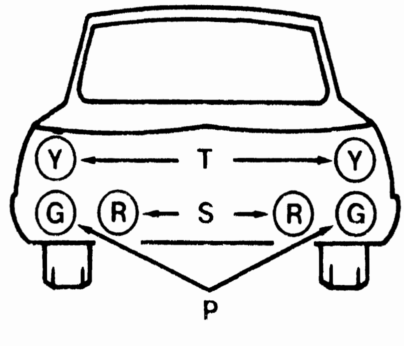
The two lead car rear lighting system configurations employed had been evaluated in earlier road and simulator studies. System 1 represents the conventional automobile rear signaling system with two red lamps which each serve as presence (tail), stop, and turn lamps. System 8 employs functional separation and color coding of each signal with green presence, red stop, and yellow turn lamps. In both lighting systems, presence lamps were operated at 10 cd and signal lamps were operated at 130 cd.

Dependent Variables

The dependent variables examined fell into three categories:



SYSTEM 1



SYSTEM 8

FIGURE 5. THE REAR LIGHTING SYSTEMS USED. P=PRESENCE (TAILLIGHT), S=STOP, T=TURN, R=RED, Y=YELLOW, G=GREEN.

1. Response to side-task signals:
   a. response time
   b. error frequency
2. Response time to signals given by the lead car
3. Headway maintenance:
   a. headway mean and variance (for the entire test interval)
   b. absolute relative velocity mean and variance (for the entire test interval)

Experimental Design

Each subject was tested on two consecutive days at approximately the same time of day. Four trials (two with each lighting system, with and without the side-task present) were made on each day, at one level of side-task stimulus lamp intensity (Table 5). The design was completely counterbalanced given the stipulation that pairs of trials within subjects were made with the same rear lighting systems.

The signal response time data were analyzed in a five-factor analysis of variance, with factors of signal mode (four levels), side-task stimulus lamp intensity (two levels), side-task presence (two levels), signal system (two levels), and subjects (four levels). Headway maintenance data were analyzed similarly, with the signal mode factor omitted. Statistical tests were not performed on the response times to the side-task. Response time and error frequency means were found, however, by side-task stimulus lamp intensity and signal system.

Because of the nature of the design, differences in response times to signals of the lighting systems and in the headway measures attributable to the side-task intensity factor were examined through the side-task lamp intensity and side-task presence interaction, since the intensity factor was irrelevant when the side-task was not present.

TABLE 5. EXPERIMENTAL DESIGN OF THE REAR LIGHTING SIMULATOR SIDE-TASK EXPERIMENT.

Test Day 1				
Subject Number	Trial Number	Signal System	Side-Task Present?	Side-Task Lamp Intensity
1	1 2 3 4	1 1 8 8	Yes No No Yes	High
2	1 2 3 4	8 8 1 1	No Yes Yes No	Low
3	1 2 3 4	1 1 8 8	No Yes Yes No	Low
4	1 2 3 4	8 8 1 1	Yes No No Yes	High
Test Day 2				
Subject Number	Trial Number	Signal System	Side-Task Present?	Side-Task Lamp Intensity
1	5 6 7 8	8 8 1 1	No Yes Yes No	Low
2	5 6 7 8	1 1 8 8	Yes No No Yes	High
3	5 6 7 8	8 8 1 1	Yes No No Yes	High
4	5 6 7 8	1 1 8 8	No Yes Yes No	Low

Results

Side-Task Performance

Statistical tests were not performed on the side-task performance data. The mean reaction times to the side-task signals presented here serve mainly to verify that subjects did respond to the side-task and did so in a comparable manner across signal systems.

Side-Task Reaction Time - Table 6 presents mean response times to the side-task by side-task stimulus lamp intensity and signal system. Mean response times to side-task signals, as a function of rear lighting system, were nearly equivalent (0.80 sec., system 1 and 0.78 sec., system 8) indicating that subjects responded comparably regardless of the signal system used. A larger difference in mean reaction times is evident between levels of stimulus lamp intensity (0.85 sec. at the low intensity, 0.73 sec. at the high intensity). This difference is partly attributed to differences in the rise-time characteristics of the lamps used, as well as their intensities, and is constant across signal systems.

Side-Task Error Rates - Table 6 also lists the mean rates of missed stimuli and commission errors (responding when no side-task signal is present), by stimulus lamp intensity and signal system. Although slightly more stimuli were missed both in system 1 (1.7% missed with system 1, 1.3% system 8) and at the low stimulus intensity level (1.7% missed at low intensity, 1.3% missed at high intensity) the magnitudes of the differences are small, and indicate functionally comparable performance across conditions. The same conclusion may be drawn concerning frequencies of errors of commission (1.2% system 1, 2.0% system 8; 1.9% low stimulus intensity, 1.3% high stimulus intensity).

Reaction Times to Stop and Turn Signals of Rear Lighting Systems

All response times were transformed to Log_e, and these values were used in a five-factor analysis of variance. Signifi-

TABLE 6. MEAN RESPONSE TIMES TO SIGNALS OF THE SIDE-TASK, PERCENT SIGNALS MISSED, AND PERCENT ERRORS OF COMMISSION.

Condition	Mean Response Time (Sec)	Percent Missed[1]	Percent Commission Errors[2]
System 1	0.80	1.7	1.2
System 8	0.78	1.3	2.0
Low Intensity Side-Task	0.85	1.7	1.9
High Intensity Side-Task	0.73	1.3	1.3
Low Intensity Side-Task with System 1	0.88	1.6	1.6
Low Intensity Side-Task with System 8	0.82	1.9	2.2
High Intensity Side-Task with System 1	0.72	1.7	0.8
High Intensity Side-Task with System 8	0.73	0.6	1.8

[1]Percent stimuli missed = (number missed/number presented) x 100.

[2]Percent commission errors = (number commission errors/ number of stimuli presented) x 100.

cant ($p<.01$) main effects of side-task presence and signal system, and a significant ($p<.01$) Signal Mode and Signal System interaction were found. Figure 6 illustrates the side-task main effect, and shows that the presence of the side-task increased geometric mean response times approximately 21.5% (from 0.845 sec. to 1.027 sec.) over those without the side-task. The Signal Mode and Signal System interaction is illustrated in Figure 7. A Tukey (b) test performed on the signal system geometric means within signal modes showed significant differences between systems to exist in the

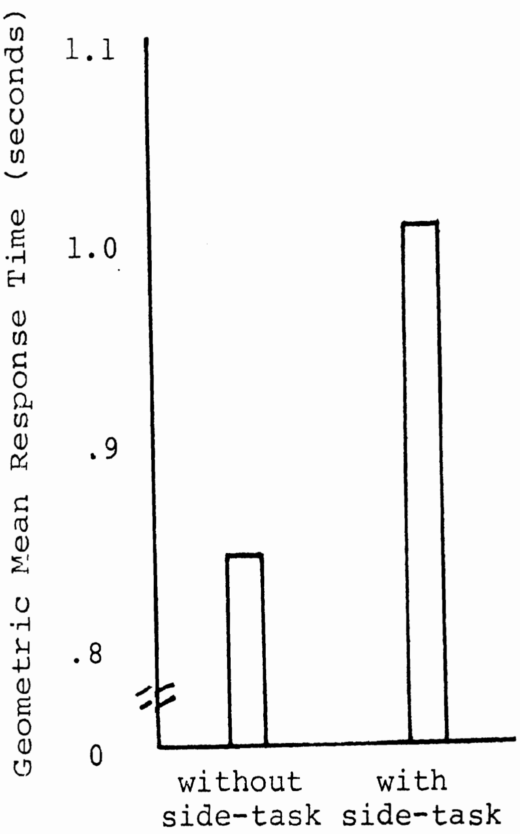


FIGURE 6. GEOMETRIC MEAN RESPONSE TIMES TO SIGNALS OF REAR LIGHTING SYSTEMS, WITH AND WITHOUT THE SIDE-TASK.

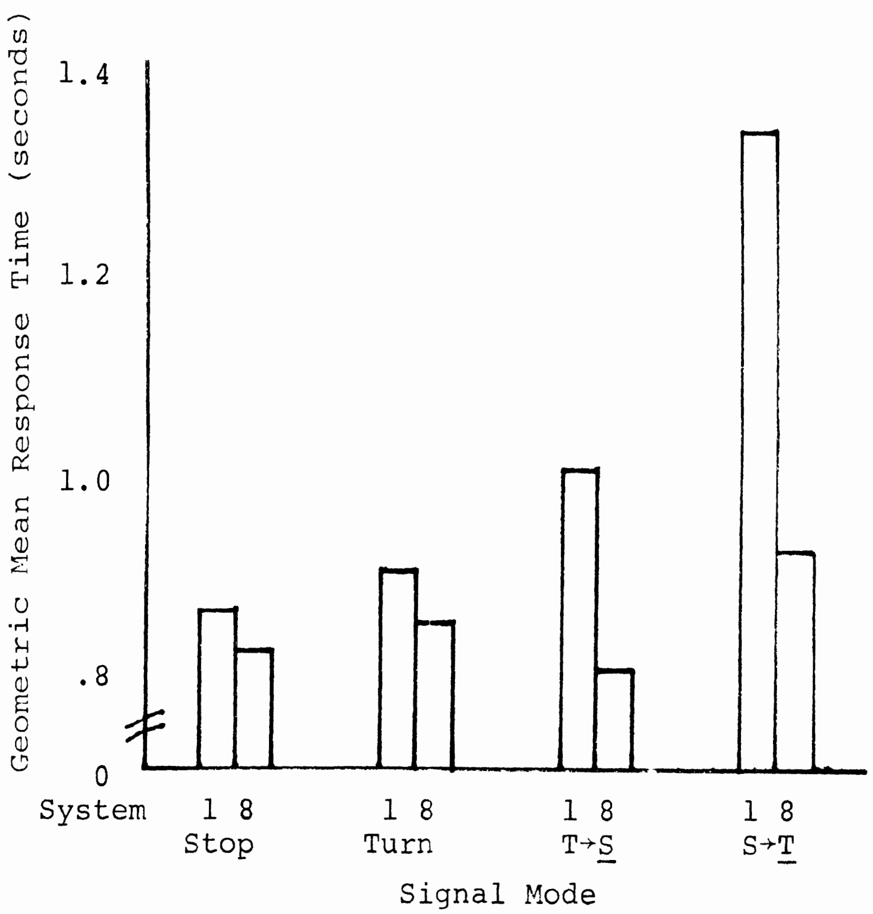


FIGURE 7. GEOMETRIC MEAN RESPONSE TIMES TO SIGNALS OF TWO REAR LIGHTING SYSTEMS.

combination signal modes (turn→stop and stop→turn), with mean response times significantly greater with signals of system 1. Geometric mean response times were equivalent in the stop and turn modes.

The lack of significant Stimulus Intensity and Side-Task, and Side-Task Presence and Signal System interactions indicate that the loading effects of the side-task were equivalent across the stimulus intensities and signal systems used.

Analysis of Measures of Car-Following Performance - Analyses of variance were performed on mean headway, mean absolute relative velocity, headway variance, and absolute relative velocity variance data. No significant effects were found in the mean relative velocity, relative velocity variance, or headway variance analyses. The mean headway analysis showed a significant ($p<.05$) Side-Task Intensity and Side-Task Presence interaction. A Tukey (b) test performed on the side-task presence means within intensities showed mean headway (214.4 ft.) with the side-task at low intensity to be greater than in the corresponding condition without the side-task (176.3 ft.), as shown in Figure 8.

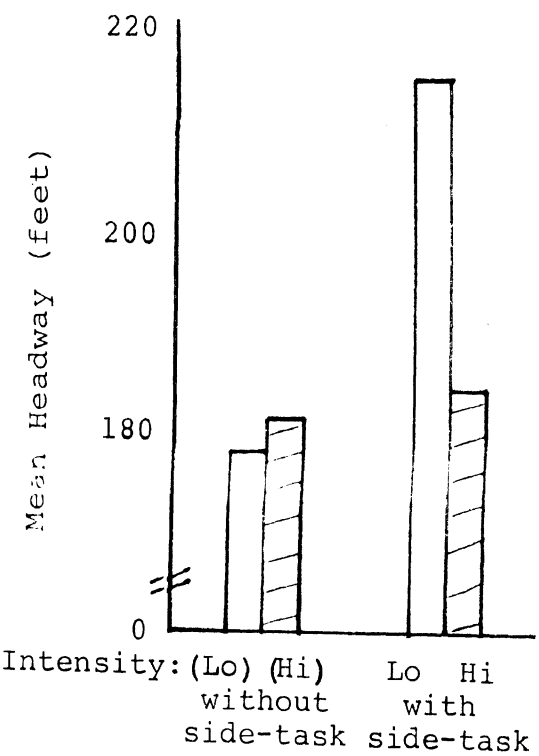


FIGURE 8. MEAN HEADWAY WITHOUT THE SIDE-TASK, AND WITH THE SIDE-TASK AT THE LOW AND HIGH INTENSITIES.

Figures 9-12 illustrate the side-task main effects of mean relative velocity, relative velocity variance, mean headway, and headway variance respectively. All measures are increased when the side-task is present, but the differences were not statistically significant.

Distributions of Response Times to Signals of the Rear Lighting Systems - Figure 13 presents cumulative percentage distributions of response times to all signal modes combined for each signal system, with and without the side-task, showing that the side-task increased reaction times to the signals.

Discussion

The side-task has been shown to effectively load subjects' information processing capabilities by significantly increasing response times to signals of the rear lighting systems and decreasing the accuracy of headway maintenance in terms of mean headway. These decrements in performance did not interact significantly with the signal systems (systems 1 and 8) or signal modes (T, S, S→T, and T→S) employed. Differences in intensity of the side-task stimulus lamps had no effect on stop/turn signal response times, but did affect headway maintenance, as the mean headway was significantly increased by the side-task at the low stimulus lamp intensity only. For this reason, the low side-task intensity will be used in dawn/dusk or night driving simulations. The high intensity will be used with higher ambient levels, as in daylight or early evening simulations.

Although the side-task produced the desired effect of increasing response times to signals, significant changes in car-following behavior (other than mean headway) were not found. Studies employing larger samples of subjects may establish headway variance and relative velocity mean and variance effects, since non-significant but fairly large differences in those measures were found (Figures 9-12) in this study.

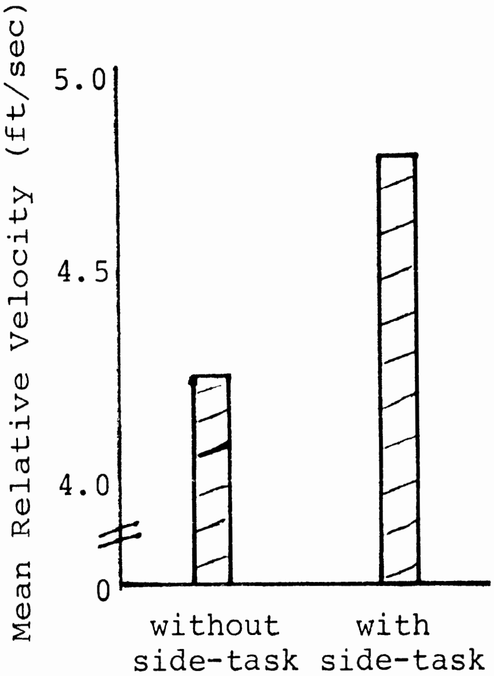


FIGURE 9. MEAN RELATIVE VELOCITY WITH AND WITHOUT THE SIDE-TASK.

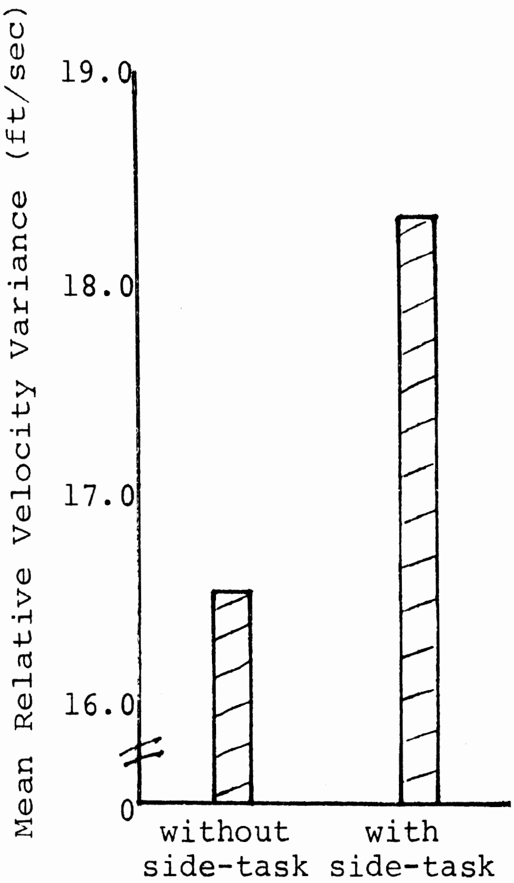


FIGURE 10. MEAN RELATIVE VELOCITY VARIANCE WITH AND WITHOUT THE SIDE-TASK.

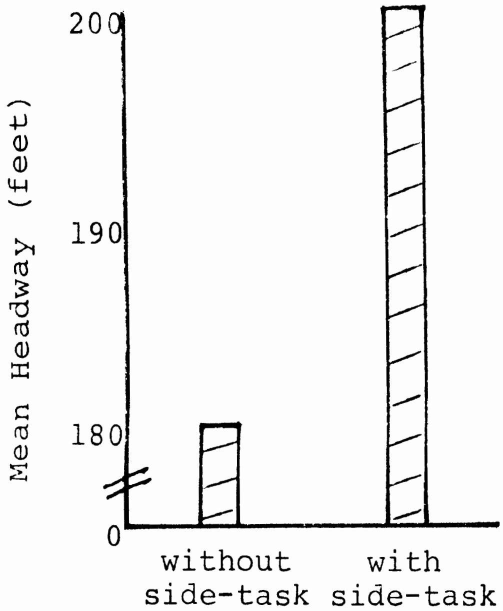


FIGURE 11. MEAN HEADWAY WITH AND WITHOUT THE SIDE-TASK.

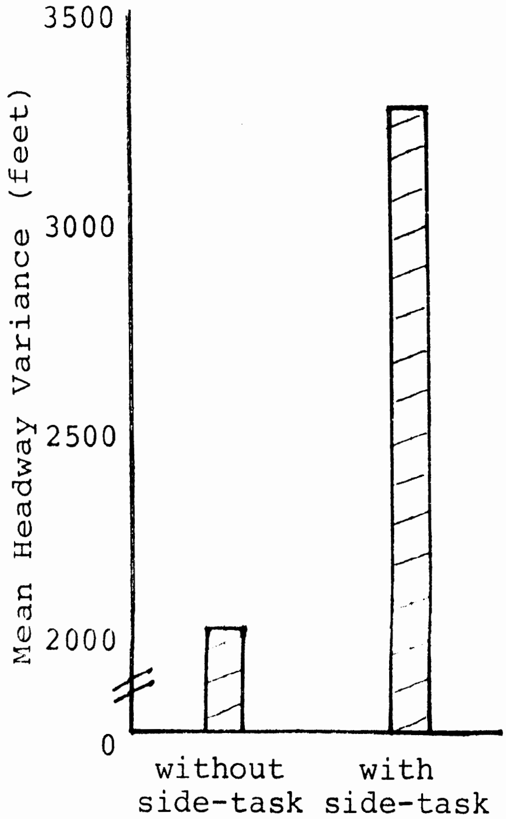


FIGURE 12. MEAN HEADWAY VARIANCE WITH AND WITHOUT THE SIDE-TASK

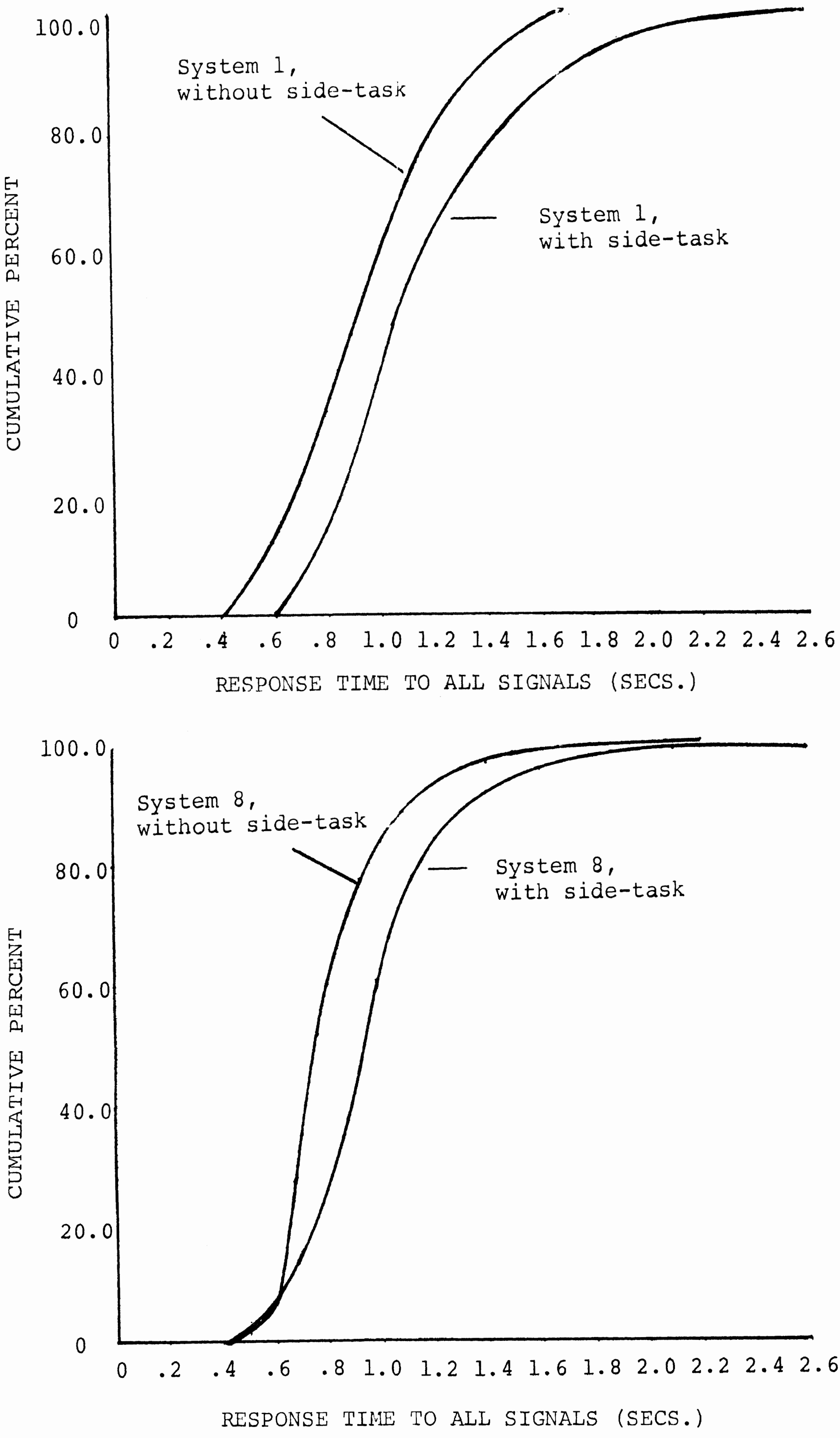


FIGURE 13. CUMULATIVE PERCENT DISTRIBUTIONS OF RESPONSE TIMES TO ALL SIGNALS BY SIGNAL SYSTEMS, WITH AND WITHOUT THE SIDE-TASK.

EVALUATION OF REAR LIGHTING SYSTEMS IN NORMAL SIMULATED CAR-FOLLOWING CONDITIONS

Objectives

Objectives of this study were to evaluate a number of conventional and experimental vehicle rear signaling systems in a simulation of normal car-following using measures of the identification of stop and turn signals and car-following performance.

Method

Subjects

A total of 10 male and female drivers, with normal color vision, were used as subjects. There were 1 female and 9 males, aged between 22 and 44 years.

Procedure

The Simulator - The rear lighting and car-following simulator used in this study has already been described.

In this study, at the start of each trial, the lead vehicle was positioned at a simulated distance of 150 ft. The operating characteristics of each of the signal lamps on the rear of the vehicle were set in accordance with the requirements for the particular rear lighting system being evaluated in that run. The colors of the lamps were changed, as necessary, by changing filter holders in front of each lamp, and the intensity was set by appropriate controls on the simulator's control panel.

In daytime simulations, the overhead lights in the simulator were turned on, providing about 50 ft-c of vertical illumination on the roadway, thereby simulating low ambient daytime lighting conditions. In nighttime simulations, the overhead lights were turned off, while roadway illumination in the vicinity of the subject's vehicle was provided by an overhead lamp, to simulate the headlights of his own vehicle illuminating the roadway and the lead vehicle if it was within appropriate range. In that condition, the speedometer was suitably illuminated to allow the subject to read it with ease. In daytime simulations the luminance of the side-task lamps was 0.8 FL and lowered to 0.08 FL in night simulations.

Control of Lead Car Speed and Signal Presentations - Control of the speed-time history of the lead car during runs, and the type of sequence of rear lighting system signals that were presented by it, was controlled by means of an input tape, made specifically for this test. This was made by driving a vehicle on a limited-access road and recording its speed as well as turn signal, brake and accelerator release events. For each section of tape to be made, the sequence of signal presentations were determined beforehand so that instructions could be given to the driver of the car to ensure that the same sequence would appear on the tape. When brake signals were given, the vehicle brake pedal was applied so that the vehicle began to slow down. Similarly, coasting signals were initiated by having the driver release the accelerator for short or longer time periods, as deemed appropriate according to data obtained previously (Mortimer, 1970). Various orders of these signals were used such that an equal number of stop, turn, stop preceding turn (S→T) and turn preceding stop (T→S) signals were shown. It will be evident, in addition, that whenever braking was involved the accelerator was first released with an appropriate distribution of time intervals between accelerator release and application of the brake. There were also some instances where the accelerator was released, for an appropriate distribution of time, and then reapplied, without braking. Some coasting interval was also involved when the brake pedal was released before the accelerator was reapplied.

Five sections of tape, of this type, were used in this study, lasting 9.2-10.4 minutes. In each case, the lead vehicle would first be stationary, as was the actual vehicle when the tape was made. The lead vehicle then accelerated to a speed of about 50 mph, and then incurred speed variations which were generally of a minor nature such as found in normal driving conditions in moderate traffic density, while signals were also presented, reflecting the behavior of the lead car. In all systems, stop and turn signals were presented both singly or in various combinations, as already described. In those systems in which vehicle coasting (i.e., accelerator released) was also displayed by a signal lamp, this would be shown by the rear lighting system. The maximum speed was of the order of 60 mph, while the speed was mostly between 40-60 mph. The mean speeds of the car recorded on the five tapes were 73.5-79.5 ft./sec., and the standard deviations of each were 7.4-9.9 ft./sec. Each run was concluded by the vehicle coming to a stop, as did the vehicle used for making the tests by pulling onto the shoulder and stopping.

Subjects' Task - The subjects were instructed (Appendix 2.A) to try to maintain a constant headway distance of 150 ft. behind the lead car, and to respond to stop and turn signals and signals of the side-task, as rapidly as possible by depressing the switch on the floor pan with the left foot for stop signals, and the thumb-operated switches for turn signals and side-task signals. At the end of every minute in a test run, the subjects were told the headway, in feet, existing at that time.

Independent Variables - Seven different rear lighting systems were evaluated in four signal modes under night driving simulated conditions, and three of these evaluated under daytime conditions. In addition, each system was evaluated with and without the side-task being used. Thus, the independent variables are described as follows:

1. Rear lighting system: systems 1, 3, 4, 8, 11, 1+APS, 3+APS used in night tests. Systems 1, 3 (4), 8 (11), used in daytime tests.

2. Signal mode: stop (S), turn (T), stop followed by turn (S→T), turn followed by stop (T→S).

3. Side-task: with and without side-task.

The signal system number designations used here are the same as for those systems which have been used in previous studies (Mortimer, 1969; 1970; 1971; 1974). The characteristics of these signal systems are described in Figure 14. It will be noted that systems 3 and 4, and 8 and 11, are identical in daytime test conditions, when the presence lights are not used. The signal lamps simulated lamps of 6 in. diameter, except those used in the vertical array of APS systems. Those lamps were 4.5 in. in simulated diameter. Presence lamps, in all systems, were operated at an equivalent intensity of 10 cd with signal lamps at 130 cd. The green, yellow and red lamps in the vertical stack used in APS systems were operated at 10, 20, and 30 cd, respectively. These intensities of the vertical lamps in the APS systems are the same as used in the road driving studies to be described. The nighttime intensities were selected based on preliminary judgments of discomfort caused by these higher mounted lamps, as viewed on a car used in road tests.

Dependent Variables - The dependent variables used to measure the performance of drivers consisted of response times to the four signal modes, response times to signals of the side-task, measures of car-following behavior, accelerator and brake control use frequency, and rankings of system effectiveness and preference.

Response time to signals of the rear lighting systems - Response times were measured to each of the signal modes. Where

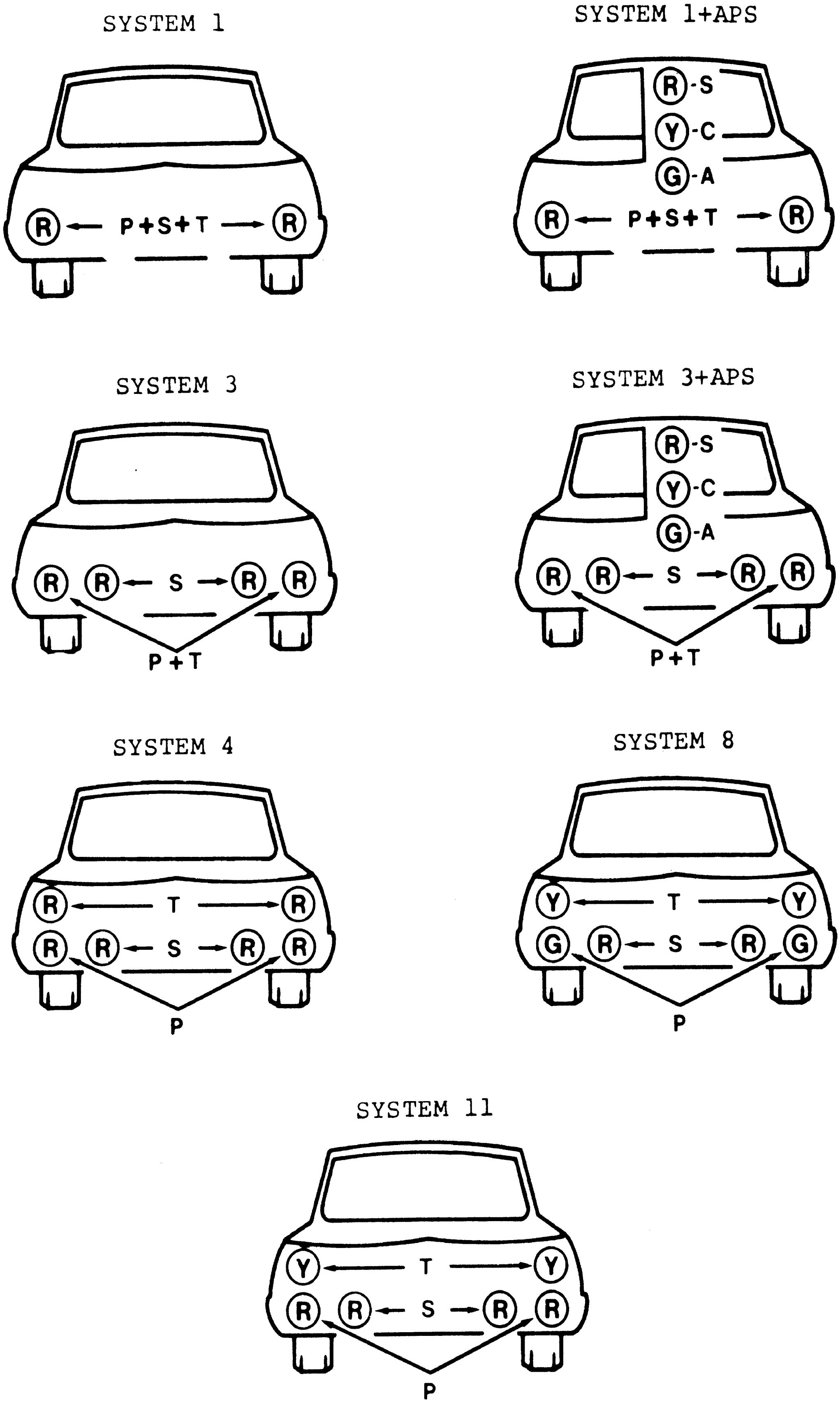


FIGURE 14. REAR LIGHTING SYSTEMS EVALUATED IN THE NORMAL CAR-FOLLOWING EXPERIMENT.

one signal was presented after another, the response time was measured to the second of the two signals.

Response time to signals of the side-task - The time to respond to each signal of the side-task was also measured.

Car-following measures - Mean headway, headway standard deviation, relative velocity standard deviation, following-car velocity standard deviation, and following-car acceleration standard deviation were computed in each run.

Control activity - The frequency of accelerator releases and brake releases were measured in each run.

Preference rankings - Systems were ranked in terms of effectiveness in presenting signals, effectiveness in providing information for constant headway car-following, and overall preference for application to all vehicles on the road.

Experimental Design - Each subject made 20 runs on the simulator, using each of the five lead vehicle input tape sections on four occasions. Each of the five input tapes were used an equal number of times in each condition, in the total experiment. Each subject performed with each of the seven systems at night and three systems in the daytime, with and without the side-task. Each subject was used on five consecutive testing days, receiving two rear lighting systems on each day. The side-task was used with two trials on each day, while it was not used with the other two trials. The ordering of systems was counterbalanced across subjects, in such a way that an equal number of system and ambient lighting conditions were ordered in the same positions across all subjects (Table 7).

The subjects used in these tests either had previous experience in the driving simulator, or they were given some initial familiarization runs, lasting a minimum of one hour, before data were collected.

TABLE 7. EXPERIMENTAL DESIGN OF THE REAR LIGHTING SIMULATOR NORMAL CAR-FOLLOWING EXPERIMENT.

Subjects	Test Day 1	2	3	4	5
1 & 6	1-D 3 5*	3-N 1* 4	1+APS-N 1* 3	3+APS-N 4 2*	3-D 2 4*
	8-N 4* 1	11-N 2 5*	1-N 5 2*	11-D 3* 1	4-N 3* 5
2 & 7	11-N 2* 4	1+APS-N 5 3*	3-N 3 5*	4-N 2 5*	8-N 3 1*
	3-D 1 3*	1-D 4* 2	3+APS-N 4* 1	1-N 1* 4	11-D 2* 5
3 & 8	11-D 4 1*	3+APS-N 3 1*	1-D 3* 1	8-N 5 3*	11-N 4* 1
	1+APS-N 5* 2	3-D 2* 5	4-N 4 2*	3-N 4* 2	1-N 3 5*
4 & 9	1-N 4* 2	11-D 3 5*	8-N 5* 2	11-N 3 1*	1+APS-N 4 2*
	3+APS-N 5 3*	4-N 4* 1	3-D 4 1*	1-D 2* 5	3-N 3* 1
5 & 10	4-N 1* 3	1-N 3* 1	11-D 2 4*	3-D 5* 3	3+APS-N 5* 2
	3-N 5 2*	8-N 4 2*	11-N 3* 5	1+APS-N 1 4*	1-D 4 1*

*Indicates trials in which the side task was used.

Note - Signal systems are represented by a code; i.e., 1-D= system 1, daytime simulation; lead vehicle input tapes are represented by digits 1-5.

Results

<u>Analysis of Response Times to Signals of the Rear Lighting Systems</u> -

Each response time to stop and turn signals was transformed to natural logarithms and submitted to an analysis of variance, with fixed factors of rear lighting system, signal mode and side-task, with subjects as a random factor. Significant ($p<0.01$) main effects were found for system, signal mode and side-task; and significant interactions were found with system and signal mode, side-task and signal mode, and side-task and system. These interactions were evaluated by Tukey (b) tests.

The cumulative percent distributions of the response times to all signals of systems, in the day and night tests, are shown in Figure 15.

The mean response time of each system in each signal mode in the nighttime test is shown in Table 8 and Figure 16. The results of individual comparisons in the nighttime test are also shown in Table 8. In the stop mode system 3+APS produced a significantly lower mean response time than system 3. No other differences between systems in this signal mode were significant. In the turn signal mode there were no significant differences in mean response times. In the T→<u>S</u> mode the mean response time to the stop signal of system 3+APS was significantly lower than systems 1 and 1+APS. In the S→<u>T</u> mode, the mean response times of systems 11, 3+APS, 8, 4 and 3 were significantly lower than systems 1 and 1+APS.

In the daytime test, the analogous results are shown in Table 9 and Figure 17. The only significant differences occurred in the S→<u>T</u> mode, in which mean response times to systems 3 and 11 were significantly lower than to system 1.

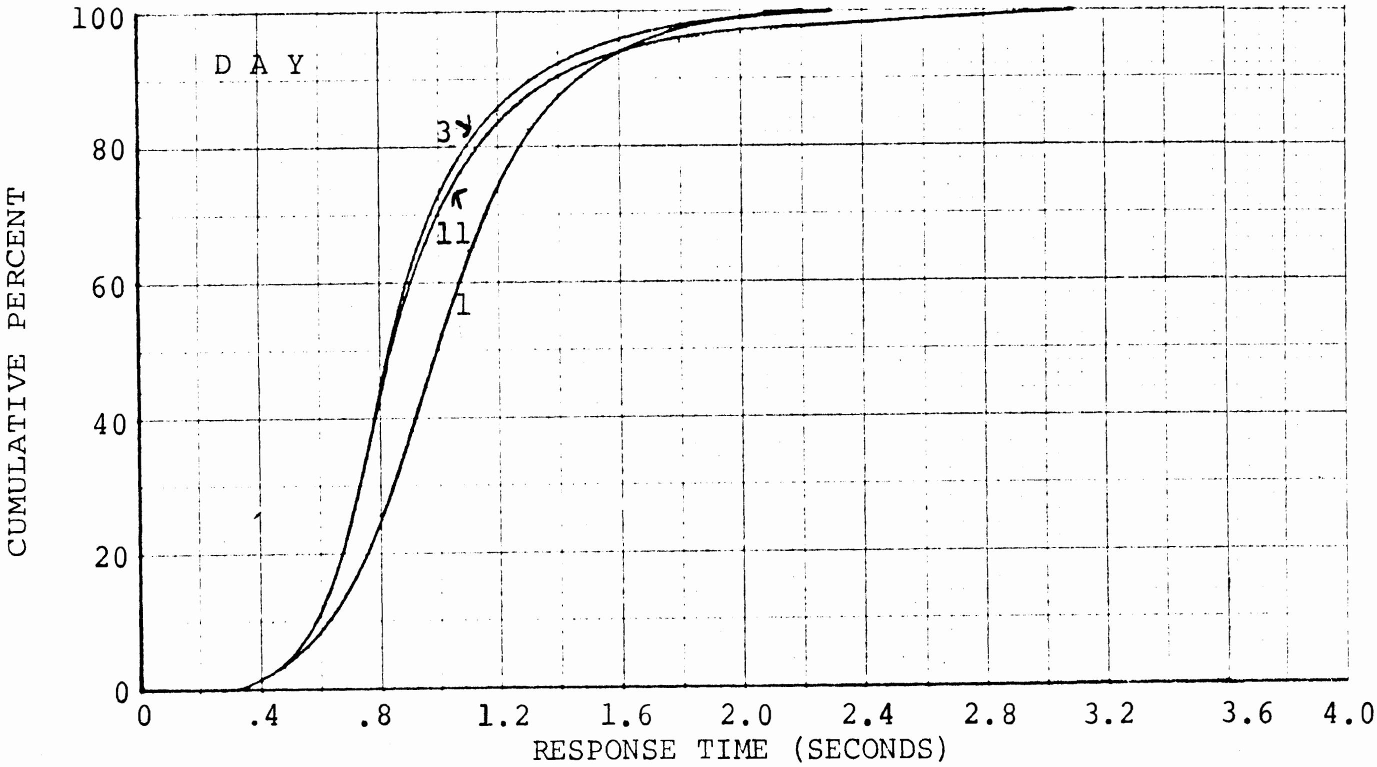
The mean response times of the significant interaction of signal mode and side-task are shown in Figure 18. The mean

TABLE 8. GEOMETRIC MEAN RESPONSE TIMES (SECONDS) TO SIGNALS OF REAR LIGHTING SYSTEMS, IN NIGHT DRIVING SIMULATION.

System	Signal Mode				System Mean
	Stop	Turn	T→S	S→T	
1	.95	.90	.94	1.20	.99
3	.99	.85	.83	.91	.90
4	.88	.98	.81	.85	.88
8	.91	.89	.80	.82	.85
11	.89	.86	.74	.78	.82
1+APS	.89	.92	.86	1.23	.96
3+APS	.79	.86	.69	.81	.79

Individual Comparisons Between Mean Response Times.

	System		System
1. Stop:	3+APS	Significantly lower mean response time than	3
2. Turn:	None	- - -	-
3. Turn→Stop:	3+APS	Significantly lower mean response time than	1, 1+APS
4. Stop→Turn:	11, 3+APS, 8, 4, 3	Significantly lower mean response time than	1, 1+APS



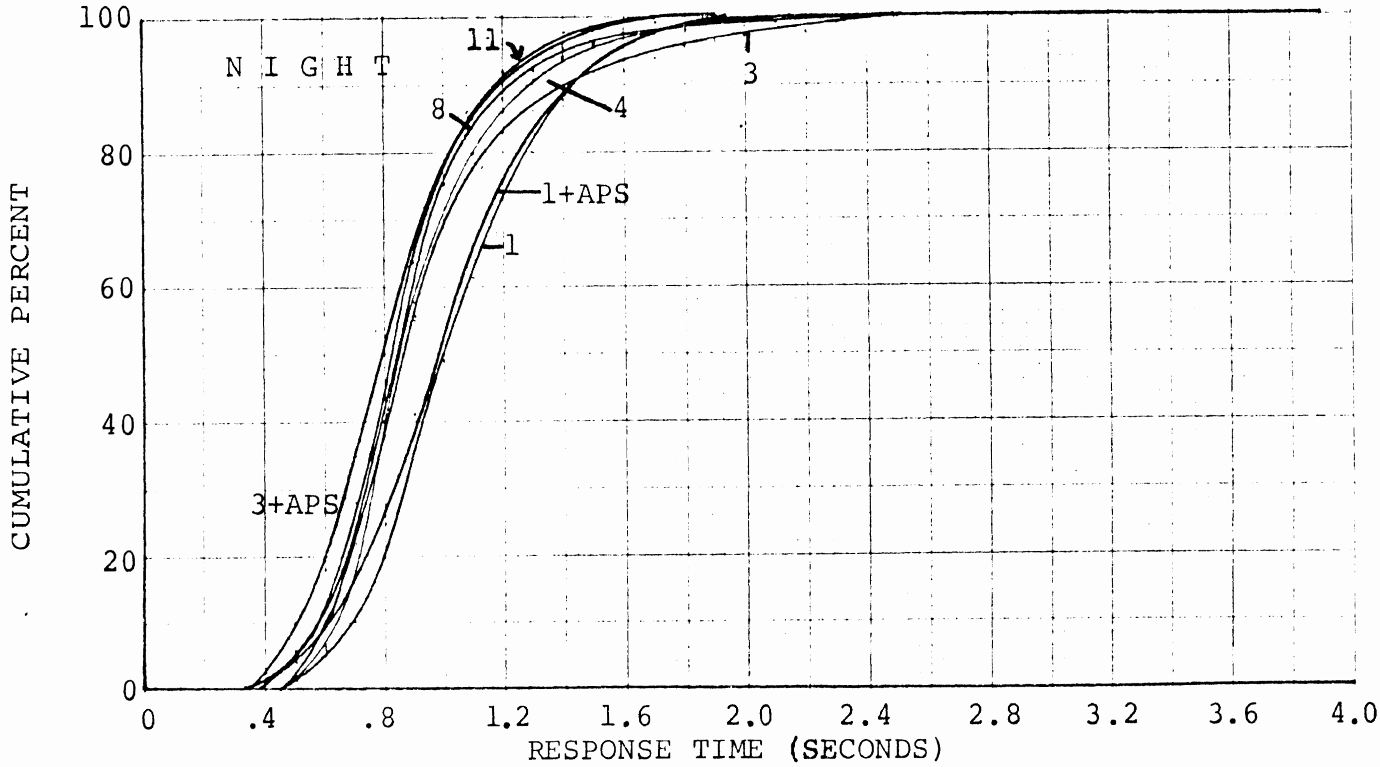


FIGURE 15. CUMULATIVE PERCENTAGE DISTRIBUTIONS OF RESPONSE TIMES TO ALL SIGNALS BY REAR LIGHTING SYSTEMS IN THE DAY AND NIGHT SIMULATIONS.

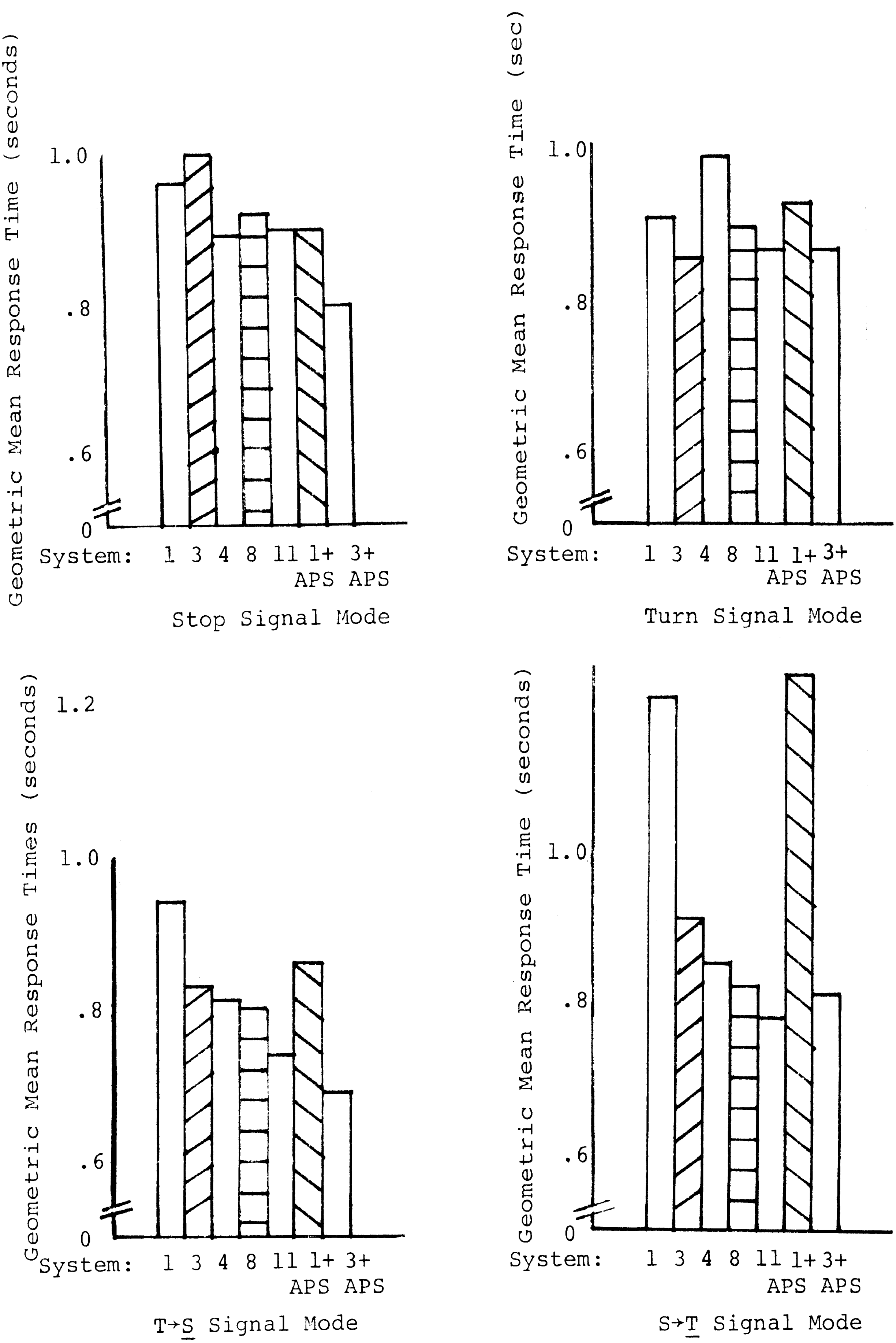


FIGURE 16. GEOMETRIC MEAN RESPONSE TIMES TO EACH SIGNAL MODE FOR EACH REAR LIGHTING SYSTEM IN THE NIGHT SIMULATION.

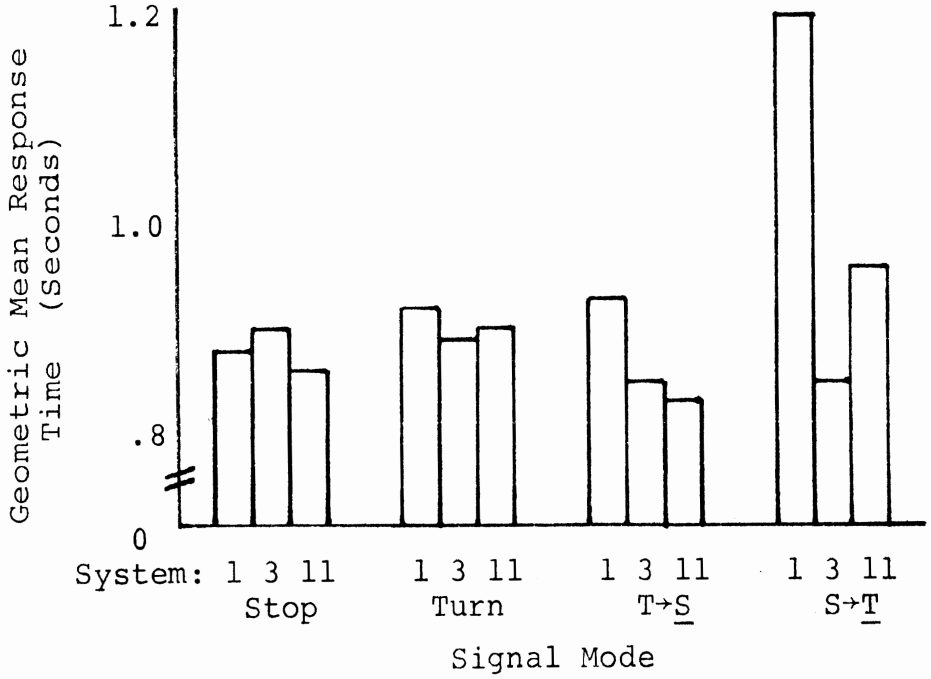


FIGURE 17. GEOMETRIC MEAN RESPONSE TIMES TO EACH SIGNAL MODE FOR EACH REAR LIGHTING SYSTEM IN THE DAY SIMULATION.

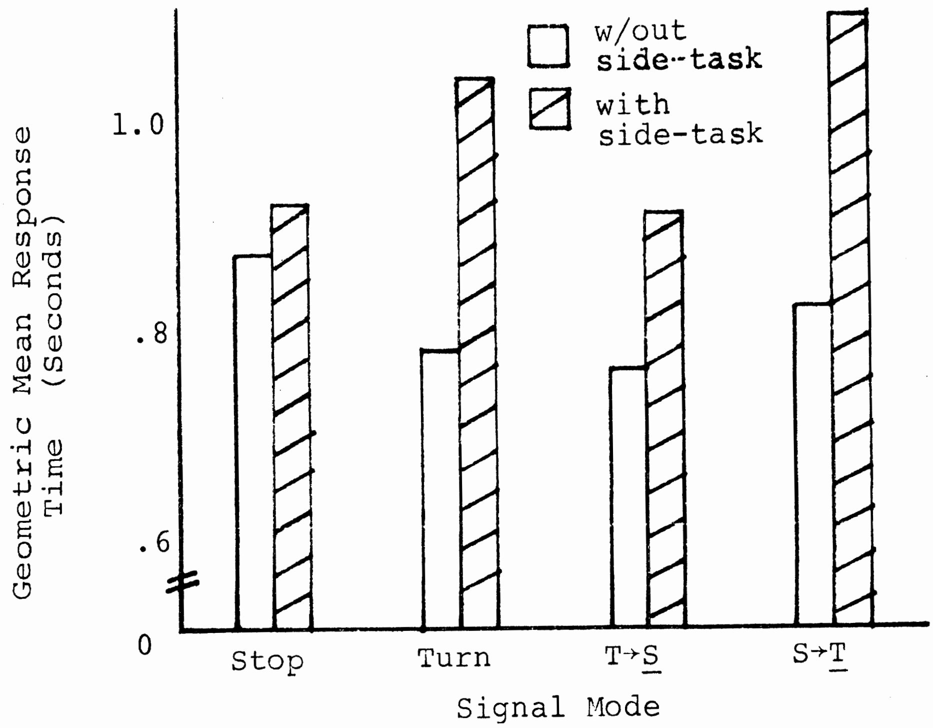


FIGURE 18. GEOMETRIC MEAN RESPONSE TIMES TO EACH SIGNAL MODE WITH AND WITHOUT THE SIDE-TASK, IN DAY AND NIGHT SIMULATIONS.

TABLE 9. GEOMETRIC MEAN RESPONSE TIMES (SECONDS) TO SIGNALS OF REAR LIGHTING SYSTEMS, IN DAY DRIVING SIMULATION.

System	Signal Mode				System Mean
	Stop	Turn	T→S	S→T	
1	.87	.91	.92	1.19	.96
3(&4)	.89	.88	.84	.84	.86
11(&8)	.85	.89	.82	.95	.88

Individual Comparisons Between Mean Response Times

	System		System
1. Stop:	None	Significantly lower mean response time than	--
2. Turn:	None	Significantly lower mean response time than	--
3. Turn→Stop:	None	Significantly lower mean response time than	--
4. Stop→Turn:	3, 11	Significantly lower mean response time than	1

response times with the side-task were significantly greater than without the side-task, in all signal modes. The significant interaction is due to the differences between mean response times among the signal modes, within each side-task condition, which is of little interest to this study. When the side-task was present, mean response times to the stop and T→S modes were less than the other two modes. Without a side-task, mean response times to the turn and T→S modes were less than to the stop mode.

The mean response times in the interaction of system and side-task are shown in Table 10. The results of individual comparisons between these means indicated that the effect of the side-task was to increase mean response times in all systems compared to performance without it, as clearly shown in Table 10.

In addition, in the night test, with the side-task present, the mean response time to signals of system 3+APS was significantly lower than systems 1 and 1+APS, while the mean response time to system 11 was significantly less than system 1. Without the side-task there were more significant differences in the overall mean reponse times to systems. The mean response time, without the side-task, for system 3+APS was significantly lower than 1+APS, 1 and 3. Systems 11 and 8 had significantly lower mean response times than systems 1+APS and 1. System 4 had a significantly lower mean response time than system 1+APS.

In the daytime test, there were no significant differences in overall mean response times between the systems (Systems 1, 3, 11) with or without the side-task.

Missed Signals

Of the 1600 signals presented for which response times were measured, only two signals were not detected. Thus, no analyses were performed on this variable.

Response Time Analysis to Side-Task Signals

The time to respond to signals of the side-task lamps was measured continuously during each daytime and nighttime simulation run. In order to determine if there were differences in the response times to the side-task when following the lead vehicle with different rear lighting systems, an analysis of variance was carried out on the response times to the side-task, in each system, in the day and night tests. The analysis showed that there were no differences between the mean response times on the side-task between the systems in each ambient lighting condition. The only effect was

TABLE 10. GEOMETRIC MEAN RESPONSE TIMES (SECONDS) TO SIGNALS OF REAR LIGHTING SYSTEMS WITH AND WITHOUT THE SIDE-TASK, IN THE DAY AND NIGHT DRIVING SIMULATION.

System, in Day Simulation	With Side-Task	Without Side-Task
1	1.08	.89
3	1.00	.75
11	1.04	.74
System, in Night Simulation		
1	1.08	.91
3	.95	.85
4	.98	.78
8	.96	.76
11	.90	.74
1+APS	1.01	.92
3+APS	.85	.72
Side-Task Mean	.98	.80

Individual Comparisons Between Mean Response Times

	System		System
In day test, with side-task:	None	Significantly lower mean response time than	-
In day test, without side-task:	None	Significantly lower mean response time than	-
In night test, with side-task:	3+APS,11	Significantly lower mean response time than	1
In night test, with side-task:	3+APS	Significantly lower mean response time than	1+APS
In night test, without side-task:	3+APS,11,8,4	Significantly lower mean response time than	1+APS
In night test, without side-task:	3+APS,11,8	Significantly lower mean response time than	1
In night test, without side-task:	3+APS	Significantly lower mean response time than	3

due to the mean response times to the side-task in the daytime test being significantly greater than those in the nighttime test.

Car-Following Measures

On each simulator run the performance of subjects in car-following was measured. The analog values of these variables were digitized at 30 Hz, and these data subsequently used in further analyses.

Mean Headway - The mean headway (Table 11) maintained by subjects in each run was submitted to an analysis of variance. No significant effects were found. The overall mean headway maintained was 146.2 ft., which is close to the headway of 150.0 ft. which the subjects were asked to maintain. The mean headways maintained by subjects were 141.4-159.2 ft.

TABLE 11. MEAN HEADWAY IN FEET.

		Mean H
With side-task		147.2
Without side-task		145.1
System, in day simulation	1	143.5
	3	141.2
	11	145.1
System, in night simulation	1	148.6
	3	148.4
	4	148.7
	8	146.2
	11	147.2
	1+APS	147.6
	3+APS	144.8
Range of means between subjects		141.4-159.2

Headway Standard Deviation - The standard deviation of the headway maintained in each run by a subject was computed, and an analysis of variance carried out on those values. The main effects of side-task and rear lighting system were significant at the 0.05 level. The presence of the side-task led to greater variability in headway than without it. However, a Tukey (b) test failed to reveal any significant differences in mean standard deviation (Table 12) between the systems.

TABLE 12. MEAN STANDARD DEVIATION OF HEADWAY IN FEET.

		Mean SD H
With side-task		25.1
Without side-task		22.9
System, in day simulation	1	20.7
	3	20.3
	11	22.8
System, in night simulation	1	25.6
	3	24.9
	4	26.9
	8	24.1
	11	26.2
	1+APS	25.2
	3+APS	23.8
Range of mean SD between subjects		18.2-34.0

Individual comparisons between mean SD of headway.

Without side-task significantly lower means than with side-task.

Standard Deviation of Relative Velocity - The means of the standard deviations of relative velocity in each level of the side-task and the rear lighting systems in the day and night simulations are shown in Table 13. An analysis of variance showed that the main effects of the side-task and rear lighting system were significant.

TABLE 13. MEAN STANDARD DEVIATION OF RELATIVE VELOCITY IN FT./SEC.

		Mean SD V_R
With side-task		4.6
Without side-task		4.2
System, in day simulation	1	3.9
	3	3.9
	11	4.2
System, in night simulation	1	4.8
	3	4.6
	4	4.9
	8	4.6
	11	4.6
	1+APS	4.2
	3+APS	4.2
Range of mean SD between subjects		3.1-5.4

Individual comparisons between mean SD of relative velocity.

In night test, system 3+APS significantly lower mean than system 4.

Without side-task significantly lower mean than with side-task.

A Tukey (b) test on rear lighting systems showed that there were no differences between systems in the mean standard deviation of the relative velocity in the daytime simulation. In the night simulation system 3+APS resulted in significantly lower mean standard deviation of relative velocity than system 4, at the 0.05 level of significance. The variability of relative velocity was less without the side-task than with the side-task.

Standard Deviation of Following-Car Velocity - The standard deviation of the velocity of the following-car (i.e., the subject's car) obtained in each run was subjected to an analysis of variance, with the finding that no effects were statistically significant. The mean values of the standard deviation of the following-car velocity are shown in Table 14.

TABLE 14. MEAN STANDARD DEVIATION OF FOLLOWING-CAR VELOCITY IN FT./SEC.

		Mean SD V_F
With side-task		9.4
Without side-task		9.4
System, in day simulation	1	9.2
	3	9.1
	11	9.3
System, in night simulation	1	9.6
	3	9.5
	4	9.6
	8	9.5
	11	9.6
	1+APS	9.3
	3+APS	9.3
Range of mean SD between subjects		8.7-9.8

Standard Deviation of Following-Car Acceleration - The mean standard deviations of following-car acceleration in the levels of the side-task and rear lighting system variables are shown in Table 15. An analysis of variance showed that there was a significant main effect of rear lighting systems, at the 0.05 level, but a Tukey (b) test between systems did not find any comparisons significant.

TABLE 15. MEAN STANDARD DEVIATION OF FOLLOWING-CAR ACCELERATION IN FT./SEC.

		Mean SD A_F
With side-task		2.7
Without side-task		2.6
System, in day simulation	1	2.5
	3	2.7
	11	2.6
System, in night simulation	1	2.7
	3	2.8
	4	2.8
	8	2.8
	11	2.6
	1+APS	2.6
	3+APS	2.5
Range of mean SD between subjects		2.0-3.6

Control Activity

Control activity was measured in terms of the frequency of releases of the accelerator pedal and applications of the brake pedal, during each run.

Accelerator Release Frequency Analysis - An analysis of variance of the accelerator pedal release frequency, showed that there was a significant main effect due to the side-task, as well as a task and system interaction.

Table 16 shows the mean frequency of accelerator pedal releases for each system, with and without the side-task. Tukey (b) tests on this interaction showed that the mean frequency of accelerator pedal releases was significantly less with system 4 than systems 8 and 1+APS with the side-task, while there were no differences between systems without the side-task. Also, there were significantly fewer accelerator releases with the side-task present than without it, in systems 1 and 3 in the day simulation and 1 and 4 in the night simulation.

Brake Application Frequency Analysis - An analysis of variance of the frequency of brake applications showed that there were no significant effects attributable to the side-task or the rear lighting systems. The mean frequencies of brake applications with and without the side-task, and for each of the rear lighting systems, are shown in Table 17. There was a large distribution of mean frequencies of brake applications made by the drivers.

Preference Rankings

At the conclusion of participation in the experiment, the subjects rank ordered the systems in terms of their effectiveness in giving signals, for providing information to maintain a constant headway in car-following, and their order of preference of the rear lighting systems for use on all vehicles.

Ranking of Signal Effectiveness - The mean ranks of the judged effectiveness in presenting stop and turn signals of the three systems used in the daytime simulation and the seven sys-

TABLE 16. MEAN FREQUENCY OF ACCELERATOR RELEASES BY SIDE-TASK AND REAR LIGHTING SYSTEM.

		With Side-Task	Without Side-Task
System, in day simulation	1	45.9	52.1
	3	47.2	58.4
	11	46.8	46.4
System, in night simulation	1	43.5	50.4
	3	45.9	45.8
	4	36.4	46.9
	8	52.0	50.2
	11	47.3	48.1
	1+APS	49.2	53.6
	3+APS	45.9	46.5
Range of means between subjects			28.5-71.5

Individual Comparisons Between Mean Frequencies of Accelerator Releases

	System		System
In night test, with side-task:	4	Significantly fewer accelerator releases than	8, 1+APS
In night test, without side-task:	None	- - -	-
In day test, with & without side-task:	None	- - -	-
In day test, with side-task:	1, 3	Significantly fewer accelerator releases than	without side-task
In night test, with side-task:	1, 4	Significantly fewer accelerator releases than	without side-task

TABLE 17. MEAN FREQUENCY OF BRAKE APPLICATIONS.

		Mean Frequency
With side-task		14.0
Without side-task		14.7
System, in day simulation	1	14.3
	3	14.2
	11	13.3
System, in night simulation	1	14.1
	3	15.3
	4	15.7
	8	16.0
	11	14.6
	1+APS	14.2
	3+APS	12.0
Range of means between subjects		6.8-25.2

tems used in the nighttime simulation, are shown in Table 18.

An analysis of variance on the daytime rankings showed a significant effect due to systems. Individual comparisons of the mean rank achieved by the three systems in the daytime test, showed that systems 11 and 3 were judged as more effective in presenting stop and turn signals than system 1.

Analysis of variance of the ranks assigned to systems in the nighttime test also showed a significant main effect of systems. Individual comparisons between mean system rankings showed that systems 8, 11, 4 and 3+APS were ranked significantly more effective than systems 1 and 1+APS; and systems 8, 11 and 4 were ranked significantly more effective than system 3.

TABLE 18. MEAN RANKS* OF SYSTEMS BY PERCEIVED EFFECTIVENESS OF SIGNALS IN DAY AND NIGHT TESTS.

		Mean Rank
System, in day simulation	1	2.8
	3	1.6
	11	1.6
System, in night simulation	1	6.3
	3	5.0
	4	2.8
	8	2.2
	11	2.7
	1+APS	5.6
	3+APS	3.4

*Possible range of mean ranks:
1(best) - 3(poorest) in day test
1(best) - 7(poorest) in night test

Individual Comparisons Between Mean Ranks

	System		System
In day test	11,3	Significantly more effective than	1
In night test	8,11,4, 3+APS	Significantly more effective than	1,1+APS
	8,11,4	Significantly more effective than	3

Ranking of System Effectiveness in Providing Headway Information - The mean ranks assigned to systems on their perceived effectiveness in providing information of headway with the lead car, in the day and night tests, are shown in Table 19.

TABLE 19. MEAN RANKS* OF SYSTEMS BY PERCEIVED EFFECTIVENESS IN PROVIDING HEADWAY INFORMATION IN CAR-FOLLOWING.

		Mean Rank
Systems, in day simulation	1	2.7
	3	1.6
	11	1.7
Systems, in night simulation	1	6.3
	3	4.8
	4	3.6
	8	3.0
	11	2.8
	1+APS	4.3
	3+APS	3.2

*Possible range of mean ranks: 1(best) - 3(poorest) in day test
1(best) - 3(poorest) in night test

Individual Comparisons Between Mean Ranks

	System		System
In day test	3, 11	Significantly more effective than	1
In night test	11,8, 3+APS,4	Significantly more effective than	1

Analyses of variance on the rankings showed that there were significant effects between systems in both day and night tests. The results of individual comparisons between the mean ranks, by

Tukey (b) tests, on the daytime simulation showed that systems 3 and 11 were perceived as more effective than system 1. In the night test, systems 11, 8, 3+APS and 4 were judged more effective than system 1.

Ranking of Systems by Preference for Use on All Vehicles - The mean rankings of systems by perceived preference for use on all vehicles, in the day and night simulation studies, are shown in Table 20. An analysis of variance on the rankings of systems in the daytime test showed a significant effect due to systems. Individual comparisons between the mean rankings of systems in the daytime test, showed that systems 11 and 3 were significantly preferred to system 1.

An analysis of variance on the rankings of systems in the night test also showed a significant effect between systems. Individual comparisons between the mean ranks of systems in the nighttime test showed that systems 11, 8, 4, 3+APS and 3 were significantly preferred to system 1; systems 11, 8 and 4 were significantly preferred to system 1+APS; and system 11 was significantly more preferred than system 3.

TABLE 20. MEAN RANKS* OF SYSTEMS BY PREFERENCE FOR USE ON ALL VEHICLES.

		Mean Rank
Systems, in day simulation	1	2.9
	3	1.6
	11	1.5
Systems, in night simulation	1	6.2
	3	4.2
	4	3.0
	8	2.6
	11	2.1
	1+APS	5.8
	3+APS	4.1

*Possible range of mean ranks:
1(best) - 3(poorest) in day test
1(best) - 7(Poorest) in night test

Individual Comparisons Between Mean Ranks

	System		System
In day test	11, 3	Significantly more preferred than	1
In night test	11,8,4, 3+APS,3	Significantly more preferred than	1
	11,8,4,	Significantly more preferred than	1+APS
	11	Significantly more preferred than	3

ROAD TEST EVALUATION OF TWO REAR LIGHTING SYSTEMS

Objectives

The purpose of this study was to validate the reaction time findings of the normal nighttime car-following rear lighting simulator experiment with actual on-the-road measurements made with rear lighting systems 1 and 11.

Method

Apparatus

The lead, rear lighting vehicle is shown in Figure 19. Seventeen lamps and housings are mounted on the rear of the car. Each lamp has an effective diameter of 3.5 ins. and is individually controllable for intensity and function. Intensities of 10 cd for presence and 130 cd for signals were used for both systems 1 and 11, controlled by the panel shown in Figure 20.

The following car, in which the subjects rode, contained signal response switches for the subject, reaction time clocks, and accelerator and brake application counters. The subject-driver had stop and turn response pushbuttons mounted on the steering wheel yoke and a foot pedal mounted on the floor to the left of the brake pedal with which to respond to side-task lights mounted on the hood. The passenger-subject responded to the side-task lights and stop and turn signals with pushbuttons mounted in a small box which he held in his lap.
The reaction time clocks were started by telemetered signals from the lead car at the onset of the stop or turn signal. The clocks were stopped when the subjects responded with the appropriate button presses. Logic circuitry operated by the experimenter enabled detection of incorrect responses.

FIGURE 19. REAR LIGHTING SYSTEMS TEST CAR USED AS THE LEAD VEHICLE.

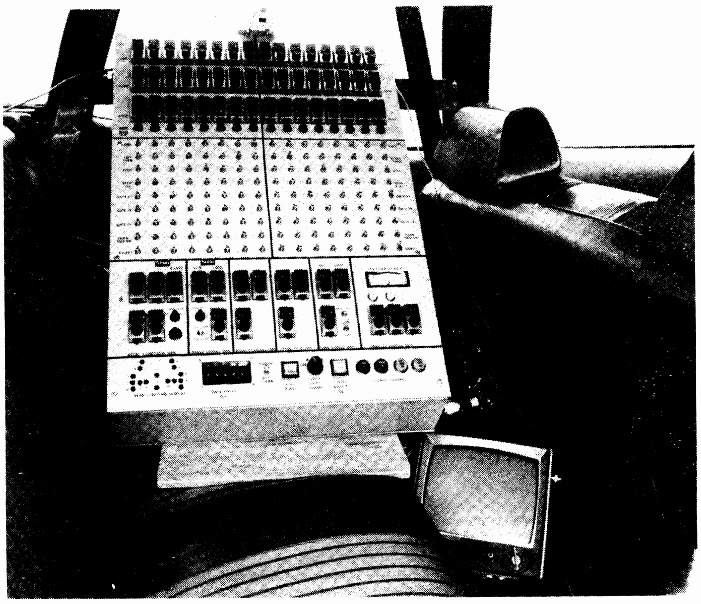


FIGURE 20. THE LAMP CONTROL AND MONITORING PANEL.

The green side-task lights mounted on the hood of the following car were lighted in a random order at the rate of ten per minute and stayed on for four seconds or until both subjects responded to them. Side-task response data were not recorded, although the experimenter did verify that the task was being performed properly and that the lights were being extinguished within about one second of their onset. The side-task lights had a luminance of 3.3 FL.

Procedure

Both subjects rode in the front seat of the following car with one of the subjects arbitrarily selected to drive. The subjects were read the instructions shown in Appendix 2B which outlined their tasks and explained the operation of the response switches. The experimenter rode in the back seat and recorded response times, errors, and accelerator releases and brake applications. The driver was instructed to try to follow at a distance of 150 ft. behind the lead vehicle. The experimenter had a simple rangefinder system which enabled him to monitor the actual headway. Throughout the study this distance was checked and corrected if the variation became too great by instructing the driver to lengthen or close the gap. The study was conducted at night on a four-lane, divided expressway. Subjects were given practice in responding to the side-task and signals as they drove to the expressway. Once on the freeway, the correct separation distance was achieved and the study begun. The lead car traveled at a constant 50 mph. Signals were presented at intervals of 30-90 secs. and remained on for approximately 6 secs. When one signal followed another in a paired presentation, approximately 5 secs. elapsed between onsets.

A total of 64 reaction times were measured per subject for each system; half with the side-task and half without. Within each system-side-task condition, eight presentations of each of the four signal modes were made in a random order. The order of system-side-task conditions was counterbalanced across subjects.

Subjects were instructed that the priority of tasks was: (1) driving the vehicle safely; (2) responding to the side-task when used; (3) responding to signals from the lead car; and (4) maintaining a headway of 150 ft.

At the end of the testing, subjects used a seven-point scale to rate the effectiveness of each system "in enabling the driver to maintain a constant headway or inter-car distance during the trial" and "in communicating stop and turn signals." A rating of 1 was considered "extremely effective"; a rating of 7 was considered "not at all effective."

Results

Analysis of Response Times to Signals of the Rear Lighting Systems

All signal response times were transformed to natural logarithms and were analyzed in a five-factor analysis of variance with factors of signal mode (at four levels: stop, turn, turn followed by stop, and stop followed by turn), side-task presence (at two levels; with and without side-task), lighting system (at two levels; systems 1 and 11), subjects (at four levels; four subjects nested under each of the two levels of the subject position factor) and subject position (at two levels; drivers and passengers). This analysis showed significant ($p<0.01$) main effect of side-task presence and signal mode, and a significant (<0.01) signal mode and lighting system interaction. Table 21 shows the geometric mean response times for all of the fixed factors investigated. From this table it is evident that the side-task presence main effect is due to considerably lower mean response times when the side-task is not used. The difference in side-task presence means is 0.18 secs., and is identical in magnitude to the difference found in the simulated driving study.

TABLE 21. GEOMETRIC MEAN RESPONSE TIMES TO SIGNALS OF TWO REAR LIGHTING SYSTEMS, FOR 8 SUBJECTS IN NIGHT DRIVING ON AN EXPRESSWAY.

		Geometric Mean Response Time (Seconds)
Signal mode	Stop	.90
	Turn	1.03
	Turn→Stop	.84
	Stop→Turn	1.06
Side-task	With	1.05
	Without	.87
Subject position	Driver	.92
	Passenger	.99
System	1	1.00
	11	.90

Table 22 shows the geometric mean response times to each of the four signal modes, for systems 1 and 11. Analysis of this significant interaction, by a Tukey (b) test showed that the mean response time to the turn signal in the S→T mode of system 11 was significantly less than for system 1. No other differences in these means were statistically significant.

The cumulative distribution of the response times to all signals of each system are shown in Figure 21, and indicates the somewhat better overall performance of system 11.

Analysis of Errors and Missed Signals

When a subject responded incorrectly to a signal, but subsequently corrected the error by depressing the correct switch, the response was counted as an error and the total response time

TABLE 22. GEOMETRIC MEAN RESPONSE TIMES (SECONDS) TO SIGNAL MODES OF TWO REAR LIGHTING SYSTEMS, IN THE NIGHT ROAD TESTS.

	Signal Mode			
System	Stop	Turn	T→S	S→T
1	.89	.99	.87	1.33
11	.90	1.07	.84	.81

Individual Comparisons Between Mean Response Times

	System		System
1. Stop	None	Significantly lower mean response time than	-
2. Turn	None	Significantly lower mean response time than	-
3. Turn→Stop	None	Significantly lower mean response time than	-
4. Stop→Turn	11	Significantly lower mean response time than	1

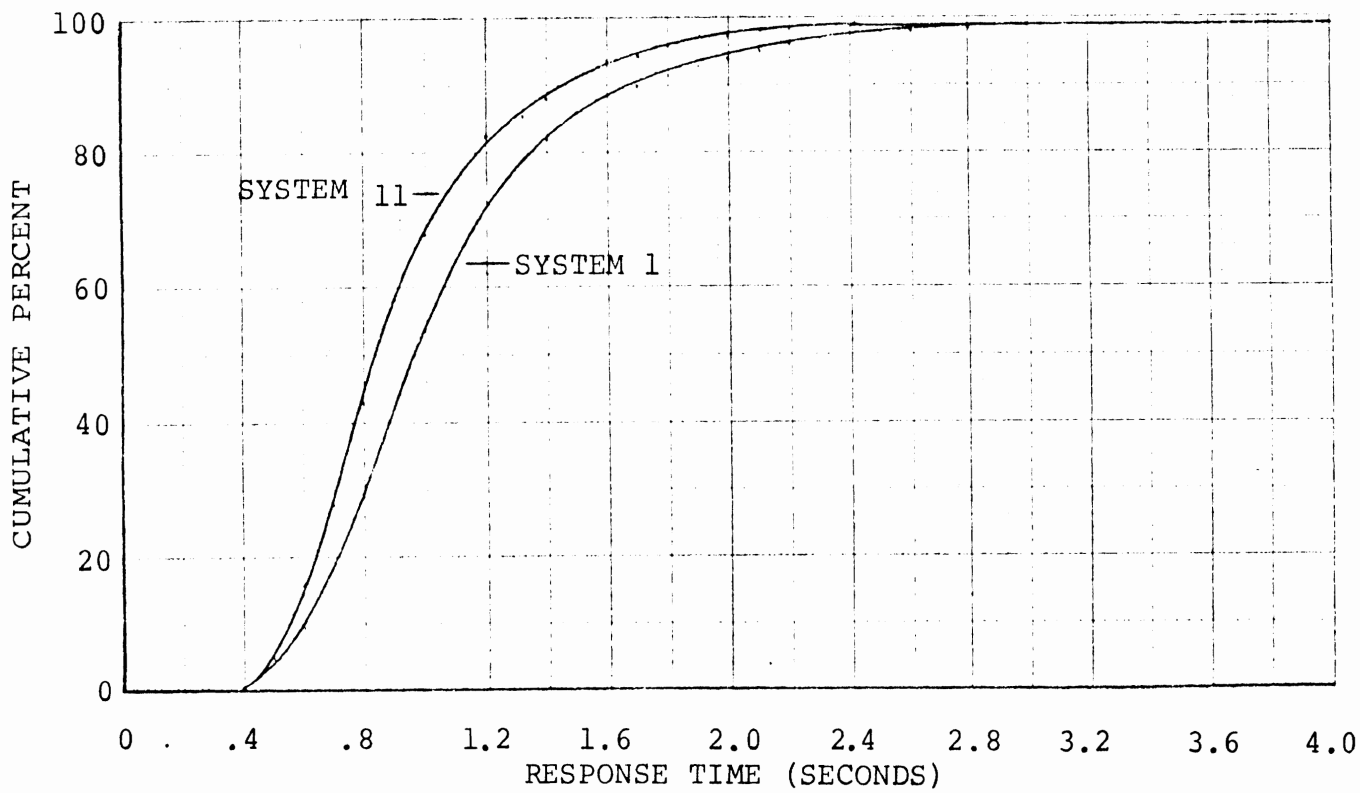


FIGURE 21. CUMULATIVE PERCENTAGE DISTRIBUTIONS OF RESPONSE TIMES TO REAR LIGHTING SYSTEMS 1 AND 11.

was taken from the initiation of the signal on the lead car to the time the correct response was made. The frequency of errors to each of the four signal modes and the two rear lighting systems, is shown in Table 23. A total of 20 errors were made to signals of system 1 and 22 errors to those of system 11. There are clearly no significant differences in the frequencies of errors attributable to either the signal modes or the rear lighting systems. A total of 42 errors made in the test represents 4.1% of the 1024 signals presented.

TABLE 23. FREQUENCY OF ERRORS AND MISSED SIGNALS TO SIGNAL MODES OF TWO REAR LIGHTING SYSTEMS, IN THE NIGHT ROAD TEST.

	Frequency of Errors				
	Signal Mode				
System	Stop	Turn	T→S	S→T	Total
1	4	7	4	5	20
11	4	6	7	5	22
Total	8	13	11	10	42
	Frequency of Missed Signals				
	Signal Mode				
System	Stop	Turn	T→S	S→T	Total
1	0	3	3	0	6
11	3	0	2	0	5
Total	3	3	5	0	11

The frequency of missed signals in each signal mode for the two rear lighting systems, is also shown in Table 23. A signal was considered to be missed if an erroneous response was made and not subsequently corrected, or if no response was made to a signal within a period of ten seconds from the initiation of the signal. There were a total of 11 signals missed, which represent 1.07% of the signals that were presented. There are no differences attributable to the variables of interest, in affecting the frequency of missed signals.

EVALUATION OF REAR LIGHTING SYSTEMS IN UNUSUAL SIMULATED CAR-FOLLOWING CONDITIONS

Objectives

The objectives of this study were to evaluate the longitudinal control performance of drivers when sometimes exposed to unusual car-following conditions, for various rear lighting systems used on the lead vehicle, so as to allow inferences to be made as to their effectiveness in certain classes of these situations, some of which predispose drivers to an increased likelihood of rear-end collisions.

Method

Subjects

Two female and eight male drivers were used in this test, between 20-44 years of age. Each of the subjects had some previous experience in driving the simulator.

The subjects participated for about one hour in the experiment on each of three successive days, during which they were given an average of 30 trials. A short questionnaire was administered to each subject when testing was completed, to obtain opinions of the usefulness of the lighting systems to which they had been exposed. All subjects had previous experience with the Accelerator Position Signal (APS) either as participants in earlier studies or during familiarization runs in preparation for this test. None were given any instructions or suggestions on how to interpret the various modes of the High Deceleration Signal (HDS). Subjects were instructed not to discuss the experiment or the questionnaire with each other until after completion of both.

The Driving Simulator

The simulator used in this study is the same as that already described, with some modifications made for this experiment. The major change was that a viewing shield was designed and constructed, so that when it was closed it would block the subject's view of the lead car, while not obstructing the speedometer displaying the velocity of his own vehicle. The shield could be rapidly opened by electronic remote control, exposing the lead vehicle.

An audio tape loop was made of the lead vehicle's operating noise while traveling at high speed. This noise was then presented to the subject through earphones worn throughout the experiment. This recorded noise was intended to mask sounds which could have given cues of the lead vehicle's relative velocity or position while the viewing shield was closed. Thus, the recorded noise was used to mask cues to subjects, so that they could not anticipate the nature of the scene that was about to be presented when the shield was opened.

The Rear Lighting Systems - The following rear lighting systems were used in the experiment, most of which have already been described (Figure 14):

System 1
System 1+Accelerator Position Signal (APS)
System 1+High Deceleration Signal (HDS), in four variations
System 3
System 3+APS
System 3+HDS, in four variations
System 8
System 11

For all systems the presence lamp intensity was 10 cd, and the stop and turn signal lamp intensity was 130 cd. The turn signal flash rate was 1.5 Hz, with 50% "on" time. The turn signal started in the "on" mode. For the Accelerator Position Signal the intensities were 30 cd for red, 20 cd for yellow and 10 cd for green, as used before in the nighttime simulation study.

One form of the High Deceleration Signal (HDS) consisted of an auxilliary stop signal lamp which operated in a flashing mode whenever the deceleration of the lead vehicle exceeded 0.35 g, the flash rate was 4 Hz, with 50% "on" time. This auxilliary lamp was mounted high up and in the center of the rear of the vehicle in the same lamp compartments that were used for the red and yellow lamps of the accelerator position signal. In one other operating mode of the HDS, the conventional stop lamps of the rear lighting system were used, but flashed at 4.0 Hz when the deceleration exceeded the cut-off value.

The high deceleration signal was used in conjunction with systems 1 and 3, as follows:

1. The high deceleration signal lamps were the same as the stop signal lamps, operated at 130 cd (1 or 3+HDS).

2. The high deceleration signal lamp was yellow, in the center of the rear of the vehicle, at 130 cd (1 or 3+HDS-Y-130).

3. The high deceleration signal lamp was yellow, in the center of the rear of the vehicle, at 1000 cd (1 or 3+HDS-Y-1000).

4. The high deceleration signal lamp was red, in the center of the rear of the vehicle, at 1000 cd (1 or 3+HDS-R-1000).

The Test Scenes

Sixteen lead car velocity-acceleration-signal conditions were used, as shown in Table 24. These sixteen lead car conditions were used with all applicable lighting systems and constituted 86 discretely different scenes after duplications among lighting systems were eliminated. One scene, consisting of system 1 with the HDS at 130 cd applied to the conventional stop lamps, was presented four times in order that the effects of familiarization or learning could be evaluated. Altogether, therefore, 89 scenes were used.

TABLE 24. CHARACTERISTICS OF THE SIXTEEN BASIC CAR-FOLLOWING CONDITIONS TO WHICH SUBJECTS WERE EXPOSED.

Condition	Initial Relative Velocity	Initial Acceleration	Subsequent Acceleration	Final Lead Car Velocity	Signal
1	0	+.1 g	0	70 mph	-
2	+10 mph	+.1 g	0	70 mph	-
3	-10 mph	+.1 g	0	70 mph	-
4	0	0	0	remains constant	-
5	+5 mph	0	0	remains constant	-
6	-5 mph	0	0	remains constant	T
7	-20 mph	0	0	remains constant	-
8	-35 mph	0	0	remains constant	-
9	0	-.1 g	0	20 mph	C
10	0	0	-.2 g	0 mph	T(S)
11	+10 mph	-.2 g	0	0 mph	S
12	-10 mph	-.2 g	0	0 mph	S
13	0	0	-.4 g	0 mph	(S),(HDS)
14	+10 mph	-.4 g	0	0 mph	S, (HDS)
15	-10 mph	-.4 g	0	0 mph	S, (HDS)
16	0	-.4 g	0	0 mph	-

The following signals were displayed:

T = turn signal (left or right, chosen randomly).
C = coast (the yellow lamp of the APS; otherwise no signal).
S = stop signal. (S) indicates that the stop signal was not on initially, but came on when the brakes were subsequently applied.

(HDS)= high deceleration signal (in applicable systems).
The APS displayed green in conditions 1-8 and yellow in conditions 9 and 16.

In conditions 10 and 13 the APS showed green initially (for approximately 2 seconds), then yellow (for approximately 0.5 second), then red when the deceleration was commanded. Note that condition 16 was a representation of a system in which the stop lamp switch had failed.

The sixteen lead car conditions were categorized into eight primary actions of the lead car, as shown below:

Group	Conditions	Lead Car Actions
1	1,2,3	Acceleration at 0.1 g
2	4,5	Zero or positive relative velocities
3	6,7,8	Negative relative velocities
4	9	Coasting at 0.1 g
5	10,11,12	Deceleration at 0.2 g
6	13,14,15	Deceleration at 0.4 g
7	16	Deceleration at 0.4 g (stop lamp switch inoperative)
8	13 (trials 1-4)	0.4 g deceleration (learning effects with system 1+HDS).

Dependent Variables

Analyses were performed on data from each group of scenes for the following dependent variables:

1. Headway standard deviation (between the times at which the viewing shield opened and the trial was terminated).

2. Minimum headway (between the times at which the subject responded and the trial was terminated).

3. Time to crash (a running computation of: headway÷relative velocity) at the time at which subject responded.

4. Minimum time to crash (between the time at which the subject responded and the trial was terminated).

5. Actual headway at the time at which the viewing shield opened and at each second thereafter for 15 seconds.

Subject response was defined as the point at which the subject released the accelerator pedal after the viewing shield had been opened.

Headway standard deviation was analyzed for all groups of conditions. Minimum headway, time to crash at response, and minimum time to crash were analyzed only for those groups of conditions in which a response was required from the subject to avoid a crash (groups 3-8). Actual headways measured during the trials were analyzed only for those groups of conditions in which the lead car did not come to a stop (groups 1-4).

Procedure

The subjects were instructed to maintain a constant velocity of 50 mph whenever the viewing shield was closed (see Appendix 2C for instructions to subjects). They were also instructed that, when the viewing shield opened, they should make the velocity changes necessary to maintain the headway the same as when the shield opened throughout the trial.

A pay-off matrix involving monitary rewards was utilized to discourage subjects from erroneously releasing the accelerator, and subsequently applying the brake, if such control action was not necessitated by the condition presented by the lead car when the shield opened. This pay-off scheme was successful, since errors were made on only 1% of the trials overall, six subjects made no errors, and the subject making the most errors was correct more than 94% of the time.

Scenes were presented with an inter-trial interval of approximately two minutes. Exposure time to the scenes varied, and was determined by the amount of time it took the subject to stabilize headway between his vehicle and the lead vehicle (for trials where the lead vehicle did not come to a stop), or until the subject brought his own vehicle to a halt, in those trials where the lead vehicle came to a stop. Scenes lasted at least 15 seconds under the former conditions, in which the lead vehicle continued to move throughout the trial period.

The headway between the subject's vehicle and the simulated lead vehicle was a simulated 200 feet when the viewing shield opened at the beginning of each scene. Subjects had been told this distance would always be the same, but emphasis in the instructions was placed on maintaining the same headway as when the viewing shield was opened, rather than on maintaining a constant 200 feet. Between scenes, appropriate computer commands were entered, changes made as necessary to the lead vehicle's lighting system, and the next relative velocity and acceleration commands entered into the control system of the simulator. Each subject viewed each of the 89 scenes once. The scenes were presented in a randomized order for each subject.

Results

The results will be presented by considering the findings within each of the eight groupings of the scenes, described by the initial conditions at the time, or after some seconds, of the shield opening.

Group 1 Conditions:

Lead car accelerating at 0.1 g from relative velocities of 0, +10, and -10 mph.

Headway standard deviations were analyzed in a 3-factor analysis of variance with factors of rear lighting system (at 3 levels: systems 1, 1+APS and 8), initial relative velocity (at 3 levels: relative velocities of 0, +10 and -10 mph), and subjects (at 10 levels). No significant differences were found. Mean headway standard deviations are shown by lighting system and initial relative velocity in Table 25.

TABLE 25. MEAN HEADWAY STANDARD DEVIATION: LEAD CAR ACCELERATING AT 0.1 g FROM RELATIVE VELOCITIES OF 0, +10 and -10 MPH.

System	Initial Relative Velocity			Mean
	0	+10	-10	
1	59.1	56.1	47.2	54.1
1+APS	47.5	46.0	47.2	46.9
8	52.2	60.3	50.5	54.3
Mean	52.9	54.2	48.3	51.8

Actual headways were analyzed in a 4-factor analysis of variance with factors of time from viewing shield opening (at 15 levels: 0-14 seconds), rear lighting systems (at 3 levels, as above), initial relative velocity (at 3 levels, as above), and subjects (at 10 levels). Significant ($p<.01$) main effects of time and initial relative velocity, and a significant time and initial relative velocity interaction were found. There were no differences attributable to the rear lighting systems.

Group 2 Conditions:

Lead car moving at constant relative velocities of 0 and +5 mph.

A 3-factor analysis of variance with factors of lighting system (at 3 levels: systems 1, 1+APS and 8), relative velocity (at 2 levels: 0 and +5 mph) and subjects (at 10 levels) was performed on the headway standard deviation data. The main effect of lighting system ($p<.05$) and relative velocity ($p<.01$) were significant (Table 3). As expected, mean headway standard deviation (Table 26) was greater in the +5 mph initial relative velocity trials than in the 0 mph relative velocity trials.

TABLE 26. MEAN HEADWAY STANDARD DEVIATION: LEAD CAR MOVING AT CONSTANT RELATIVE VELOCITIES OF 0 AND +5 MPH.

System	Relative Velocity		Mean
	0	+5	
1	7.2	29.4	18.3
1+APS	8.6	17.2	12.9
8	14.7	27.1	20.9
Mean	10.2	24.6	17.4

Individual comparisons between lighting system means

System 8 significantly greater than system 1+APS

Lighting system 1+APS was found to have a significantly ($p<.05$) smaller mean headway standard deviation than system 8 in individual comparisons made by Tukey (b) test.

Analysis of the actual headways was done in a 4-factor analysis of variance with factors of time from viewing shield opening (at 15 levels: 0-14 seconds), rear lighting systems (at 3 levels, as above), relative velocities (at 2 levels, as above), and subjects (at 10 levels). Main effects of time and relative velocity were found significant ($p<.01$) as were the time and lighting system, time and relative velocity, relative velocity and lighting system, relative velocity and lighting system and subjects, and time and relative velocity and lighting system interactions ($p<.01$ in all cases). The interaction involving subjects is attributed to expected individual differences between subjects. The time and relative velocity and lighting system interaction, however, contains all other significant effects and was examined by performing Tukey (b) tests on differences between lighting systems at each point in time within each of the relative velocity conditions. Differences between lighting systems were found significant only in the +5 mph relative velocity condition and only at points 9-14 seconds after the viewing shield opened (Figure 22). At points 9-14 seconds, the mean headways with lighting systems 1 and 8 were both significantly greater than system 1+APS. In addition, at points 11-14 seconds, mean headways with lighting system 1 were significantly greater than those with system 8.

It would appear from Figure 22 that lighting system 1 presented less information concerning the error in headway, while systems 1+APS and 8 enabled subjects to better recognize the error and correct for it, to different degrees.

Group 3 Conditions:

Lead car at constant relative velocities of -5, -20 and -35 mph.

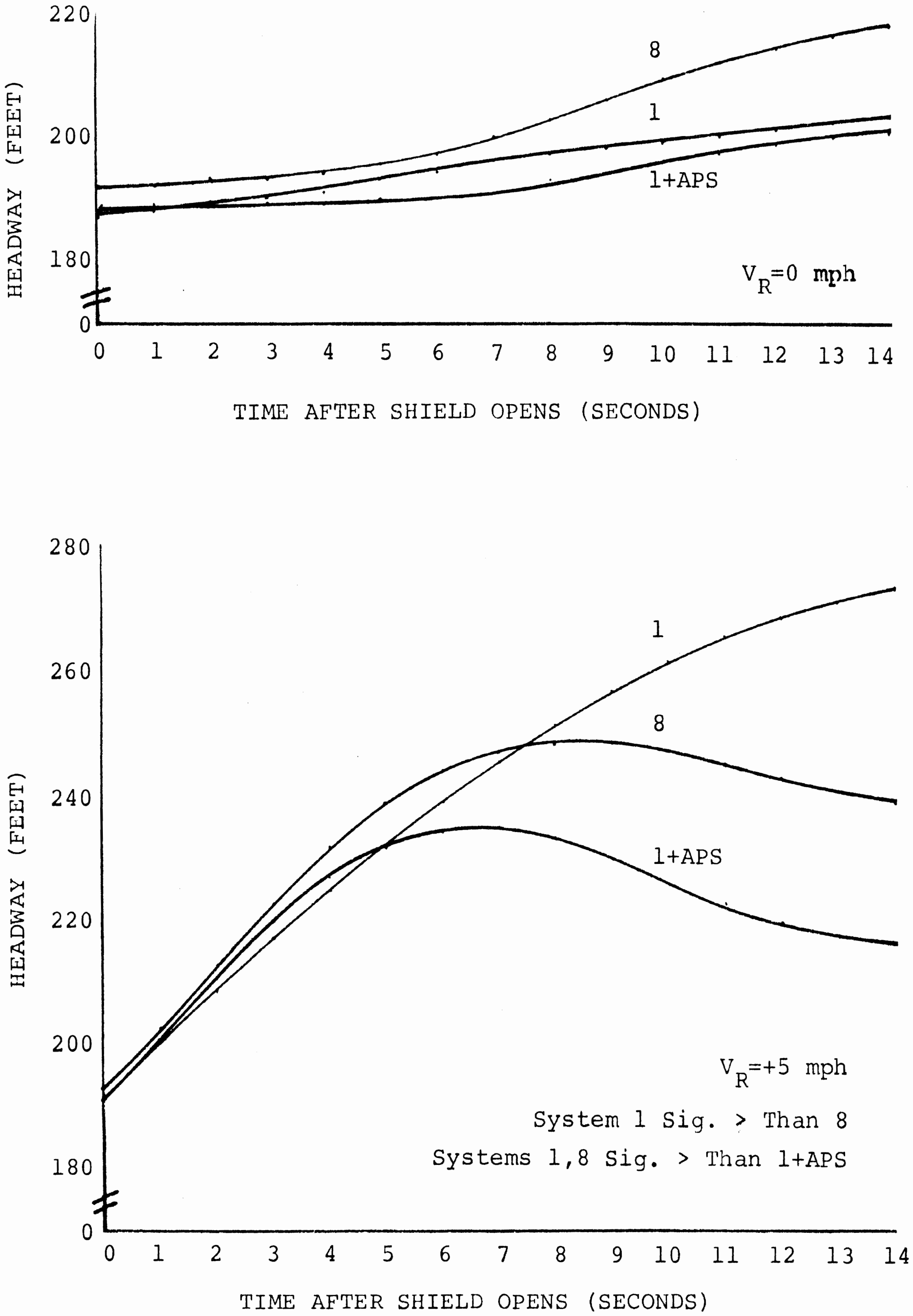


FIGURE 22. MEAN HEADWAY FOLLOWING VIEWING SHIELD OPENING FOR RELATIVE VELOCITIES OF 0 AND +5 MPH.

Headway standard deviation, minimum headway, time to crash at response, and minimum time to crash were each evaluated in 3-factor analyses of variance with factors of lighting system (at 3 levels: system 1, 1+APS and 8), relative velocity (at 3 levels: -5, -20 and -35 mph), and subjects (at 10 levels).

Significant ($p<.01$) relative velocity main effects were found in all four analyses. Mean headway standard deviation was significantly larger in the -35 mph relative velocity condition than in the -5 and -20 mph conditions. Mean minimum headway was significantly greater in the -5 mph relative velocity condition than the -20 and -35 mph conditions, and greater in the -20 mph condition than the -35 mph condition. Mean time to crash at response was greater in the -5 mph condition than in both other conditions. No other significant effects were found in the headway standard deviation, time to crash at response, or minimum headway analyses (Table 27).

In the minimum time to crash analysis, significant lighting system ($p<.05$) and relative velocity ($p<.01$) main effects and a significant lighting system and relative velocity ($p<.05$) interaction were found. Since both main effects were contained in the interaction, individual comparisons between lighting systems by Tukey (b) test were made within levels of the relative velocity factor. It was found that the mean minimum time to crash was significantly ($p<.01$) greater for system 8 than systems 1 and 1+APS, in the -5 mph relative velocity condition only. No other differences between systems were found. Tukey (b) tests were also made on relative velocity condition means within systems, and showed mean minimum time to crash to be significantly ($p<.01$) greater in the -5 mph condition than in the -20 and -35 mph conditions, for all three systems (Table 27).

Analysis of the actual headways following the opening of the viewing shield was made in a 4-factor analysis of variance with factors of time from viewing shield opening (at 15 levels:

TABLE 27. MEAN HEADWAY STANDARD DEVIATION, MINIMUM HEADWAY, TIME TO CRASH AT RESPONSE, AND MINIMUM TIME TO CRASH: LEAD CAR MOVING AT CONSTANT RELATIVE VELOCITIES OF -5, -20 AND -35 MPH.

Mean Headway S.D.

System	Relative Velocity -5	-20	-35	Mean
1	20.1	30.6	40.2	30.3
1+APS	20.2	31.9	43.0	31.7
8	22.7	29.5	43.3	31.8
Mean	21.0	30.7	42.2	31.2

Individual comparisons between relative velocity means.

Relative velocity of -35 mph significantly greater than -5,-20 mph.

Mean Time to Crash at Response

System	Relative Velocity -5	-20	-35	Mean
1	21.3	5.4	2.5	9.7
1+APS	24.9	5.2	2.5	10.9
8	29.2	5.4	2.5	12.4
Mean	25.1	5.3	2.5	11.0

Individual comparisons between relative velocity means.

Relative velocity of -5 mph significantly greater than -5,-20 mph.

Mean Minimum Headway

System	Relative Velocity -5	-20	-35	Mean
1	151.7	107.9	39.3	99.6
1+APS	149.4	103.0	39.3	97.2
8	151.7	106.4	41.4	99.8
Mean	150.9	105.8	40.0	98.9

Individual comparisons between relative velocity means.

Relative velocity of -5 mph significantly greater than -20,-35 mph.
Relative velocity of -20 mph significantly greater than -35 mph.

Mean Minimum Time to Crash

System	Relative Velocity -5	-20	-35	Mean
1	24.0	5.2	2.2	10.4
1+APS	24.9	5.0	2.1	10.7
8	32.6	5.2	2.2	13.3
Mean	27.2	5.1	2.2	11.5

Individual comparisons between lighting system means.

At relative velocity of -5 mph, system 8 significantly greater than systems 1, 1+APS.

0-14 seconds). Lighting systems (at 3 levels, as above), relative velocities (at 3 levels, as above) and subjects (at 10 levels). Time and relative velocity main effects were significant ($p<.01$) as were the time and relative velocity, and lighting system and relative velocity and subject interactions. Since the lighting system factor was not significant (exclusive of the subject interaction) no further analysis was pursued.

Group 4 Conditions:

Lead car coasting at -0.1 g.

Two-factor analyses of variance with factors of lighting system (at 3 levels: system 1, 1+APS, and 8) and subjects (at 10 levels) were performed on the headway standard deviation, minimum headway, time to crash at response, and minimum time to crash data. No significant effects were found (Table 28). A 3-factor analysis of variance with factors of time from viewing shield opening (at 15 levels: 0-14 seconds), lighting systems (at 3 levels, as above) and subjects (at 10 levels) was performed on the actual headway data. Significant ($p<.01$) differences were found for the time main effect and the time and subject, and the lighting system and subject, interactions. No differences in time periods attributable to lighting systems were found.

TABLE 28. MEAN HEADWAY STANDARD DEVIATION, MINIMUM HEADWAY, TIME TO CRASH AT RESPONSE, AND MINIMUM TIME TO CRASH: LEAD CAR COASTING AT -0.1 g.

System	Mean Headway S.D.	Mean T.C. at Response	Mean Minimum Headway	Mean Minimum T.C.
1	23.6	20.9	125.7	12.3
1+APS	25.7	20.2	114.6	12.2
8	22.3	16.3	121.7	11.8
Mean	23.9	19.1	120.7	12.1

Group 5 Conditions:

Lead Car deceleration at 0.2 g from initial relative velocities of 0, +10 and -10 mph.

Each dependent variable was analyzed in a 3-factor analysis of variance with factors of rear lighting systems (at 5 levels: system 1, 1+APS, 3, 3+APS and 8), initial relative velocity (at 3 levels: 0, +10 and -10 mph) and subjects (at 10 levels). Significant ($p<.01$) initial relative velocity main effects were found in each analysis. Tukey (b) tests were performed on the initial relative velocity means for each dependent variable, and showed the mean headway standard deviation to be significantly ($p<.01$) greater in the +10 mph condition than in the 0 and -10 mph conditions, and mean minimum headway, time to crash at response, and minimum time to crash, to be greater in the 0 and +10 mph conditions than in the respective -10 mph conditions (Table 29). No significant differences were attributable to lighting systems.

Group 6 Conditions:

Lead car decelerates at -0.4 g from initial relative velocities of 0, +10 and -10 mph.

It was found that several subjects responded in the +10 mph relative velocity trials while the lead car was still moving away (i.e., when the relative velocity was positive). Since time to crash is meaningless under such conditions, actual response times, rather than time to crash at response, were calculated and analyzed in this group of conditions only.

All dependent variables were analyzed in 3-factor analyses of variance with factors of lighting systems (at 13 levels: systems 1, 1+APS, 1+HDS, 1+HDS-R-1000, 1+HDS-Y-130, 1+HDS-Y-130, 1+HDS-Y-1000, 3, 3+APS, 3+HDS, 3+HDS-R-1000, 3+HDS-Y-130, 3+HDS-Y-1000 and 8), initial relative velocities (at 3 levels: 0, +10 and -10 mph), and subjects (at 10 levels).

TABLE 29. MEAN HEADWAY STANDARD DEVIATION, MINIMUM HEADWAY, TIME TO CRASH AT RESPONSE, AND MINIMUM TIME TO CRASH: LEAD CAR DECELERATING AT -0.2 g FROM INITIAL RELATIVE VELOCITIES OF 0, +10 and -10 MPH.

Mean Headway S.D.

System	Initial Relative Velocity 0	+10	-10	Mean
1	24.9	32.3	26.6	27.9
1+APS	21.7	31.0	23.5	25.4
3	22.8	33.9	21.6	26.1
3+APS	20.2	28.3	21.7	23.4
8	22.9	30.6	19.0	24.2
Mean	22.5	31.2	22.5	25.4

Individual comparisons between initial relative velocity means.

Initial relative velocity of +10 mph significantly greater than 0, -10 mph.

Mean Time to Crash at Response

System	Initial Relative Velocity 0	+10	-10	Mean
1	22.3	17.0	10.3	16.5
1+APS	22.3	14.5	8.2	15.0
3	26.6	17.7	7.4	17.2
3+APS	25.3	25.2	8.0	19.5
8	22.4	21.6	8.8	17.6
Mean	23.8	19.2	8.6	17.2

Individual comparisons between initial relative velocity means.

Initial relative velocity of 0, +10 mph significantly greater than -10 mph.

Mean Minimum Headway

System	Initial Relative Velocity 0	+10	-10	Mean
1	141.2	134.8	99.9	125.3
1+APS	143.3	133.1	116.1	130.8
3	137.9	139.6	121.4	133.0
3+APS	151.3	159.6	117.7	142.9
8	127.5	149.0	122.8	133.1
Mean	140.2	143.2	115.6	133.0

Individual comparisons between initial relative velocity means.

Initial relative velocity of 0, +10 mph significantly greater than -10 mph.

Mean Minimum Time to Crash

System	Initial Relative Velocity 0	+10	-10	Mean
1	13.1	8.9	7.6	9.9
1+APS	12.2	9.1	6.8	9.4
3	11.7	11.6	6.9	10.1
3+APS	11.6	11.1	7.1	9.9
8	10.9	10.5	7.3	9.5
Mean	11.9	10.2	7.1	9.8

Individual comparisons between initial relative velocity means.

Initial relative velocity of 0, +10 mph significantly greater than -10 mph.

A significant ($p<.01$) initial relative velocity main effect, and a significant interaction of initial relative velocity and subjects, were found in each analysis. Tukey (b) tests were made on differences between initial relative velocity means for each dependent variable and showed: mean headway standard deviation to be significantly greater in the +10 and -10 mph initial relative velocity conditions than in the 0 mph conditions (Table 30),

TABLE 30. MEAN HEADWAY STANDARD DEVIATION: LEAD CAR DECELERATING AT -0.4 g FROM INITIAL RELATIVE VELOCITIES OF 0, +10 AND -10 MPH.

Mean Headway Standard Deviation

	Initial Relative Velocity			
System	0	+10	-10	Mean
1	29.8	43.8	38.2	37.3
1+APS	32.3	44.3	41.3	39.3
1+HDS	33.6	36.2	40.1	36.6
1+HDS-R-1000	27.3	39.1	37.9	34.8
1+HDS-Y-130	34.8	43.1	41.7	39.9
1+HDS-Y-1000	31.2	37.4	36.5	35.0
3	32.1	31.0	37.8	33.6
3+APS	29.8	41.3	39.3	36.8
3+HDS	37.1	36.9	41.3	38.4
3+HDS-R-1000	27.8	43.8	39.2	36.9
3+HDS-Y-130	29.6	33.6	38.4	33.9
3+HDS-Y-1000	29.6	36.2	37.5	34.5
8	29.4	39.2	39.4	36.0
Mean	31.1	39.9	39.1	36.0

Individual comparisons between initial relative velocity means

Initial relative velocity of +10, -10 mph significantly greater than 0 mph.

and mean minimum headway and mean response time to be greater in the 0 and +10 mph conditions than in the -10 mph conditions (Tables 31 and 32). No differences between initial relative velocity means were found for mean minimum time to crash (Table 33).

TABLE 31. MEAN MINIMUM HEADWAY: LEAD CAR DECELERATING AT -0.4 g FROM INITIAL RELATIVE VELOCITIES OF 0, +10 and -10 MPH.

Mean Minimum Headway

System	Initial Relative Velocity 0	+10	-10	Mean
1	114.4	88.8	78.9	94.0
1+APS	103.0	87.9	66.8	85.9
1+HDS	106.8	115.5	74.0	98.8
1+HDS-R-1000	118.4	108.9	79.0	102.1
1+HDS-Y-130	102.0	100.8	64.7	89.2
1+HDS-Y-1000	118.9	109.1	81.6	103.2
3	115.9	125.6	76.6	106.0
3+APS	112.5	100.4	71.3	94.8
3+HDS	93.5	107.8	67.6	89.6
3+HDS-R-1000	111.5	101.8	73.4	95.6
3+HDS-Y-130	118.3	116.6	76.5	103.8
3+HDS-Y-1000	110.4	112.5	82.7	101.9
8	110.1	103.8	74.6	96.1
Mean	110.4	106.1	74.5	97.0

Individual comparisons between initial relative velocity means.

Initial relative velocity of 0, +10 mph significantly greater than -10 mph.

TABLE 32. GEOMETRIC MEAN RESPONSE TIME: LEAD CAR DECELERATING AT -0.4 g FROM INITIAL RELATIVE VELOCITIES OF 0, +10 AND -10 MPH.

Geometric Mean Response Time (Seconds)

System	Initial Relative Velocity 0	+10	-10	Mean
1	1.24	3.15	1.07	1.61
1+APS	1.18	3.20	1.13	1.62
1+HDS	1.28	2.48	1.09	1.51
1+HDS-R-1000	1.17	2.08	1.01	1.35
1+HDS-Y-130	1.63	2.97	1.08	1.73
1+HDS-Y-1000	1.23	2.56	.92	1.43
3	1.23	2.94	1.11	1.59
3+APS	1.27	2.82	1.08	1.57
3+HDS	1.44	2.66	1.08	1.60
3+HDS-R-1000	1.31	2.35	.94	1.42
3+HDS-Y-130	1.16	2.66	1.01	1.45
3+HDS-Y-1000	1.31	2.28	.92	1.40
8	1.17	2.92	1.08	1.55
Mean	1.27	2.68	1.04	1.53

Individual comparisons between initial relative velocity means.

Initial relative velocity of 0, +10 mph significantly greater than -10 mph.

Initial relative velocity of +10 mph significantly greater than 0 mph.

TABLE 33. MEAN MINIMUM TIME TO CRASH: LEAD CAR DECELERATING AT -0.4 g FROM INITIAL RELATIVE VELOCITIES OF 0, +10, AND -10 MPH.

Mean Minimum Time To Crash

System	Initial Relative Velocity 0	+10	-10	Mean
1	7.5	5.4	4.8	5.9
1+APS	6.8	5.3	4.1	5.4
1+HDS	6.9	10.8	4.5	7.4
1+HDS-R-1000	7.9	10.5	4.9	7.7
1+HDS-Y-130	7.2	9.6	4.1	7.0
1+HDS-Y-1000	8.9	9.4	4.8	7.7
3	7.5	7.7	4.8	6.7
3+APS	7.4	6.0	4.4	5.9
3+HDS	6.5	7.0	4.2	5.9
3+HDS-R-1000	7.6	9.9	4.5	7.3
3+HDS-Y-130	7.6	8.7	4.6	6.9
3+HDS-Y-1000	7.3	9.9	4.8	7.4
8	7.8	5.9	4.4	6.0
Mean	7.5	8.2	4.5	6.7

No significant differences.

No significant differences attributable to rear lighting systems were found in any analysis.

Group 7 Conditions:

Lead car decelerates at -0.4 g from 0 mph relative velocity, stop lamp switch inoperative.

Two factor analyses of variance with factors of rear lighting system (at 3 levels: systems 1, 1+APS and 8) and subjects (at 10 levels) were used to analyze the four dependent variables. The lighting system main effect was significant in all analyses. It was shown by Tukey (b) tests that system 8 had a greater mean headway standard deviation than systems 1 and 1+APS, lower mean minimum headway and mean minimum time to crash than systems 1 and 1+APS, and lower mean time to crash at response than system 1 ($p<.05$) in each case; Table 34).

TABLE 34. MEAN HEADWAY STANDARD DEVIATION, MINIMUM HEADWAY, TIME TO CRASH AT RESPONSE, AND MINIMUM TIME TO CRASH: LEAD CAR DECELERATING AT -0.4 g FROM RELATIVE VELOCITY OF 0 MPH. STOP LAMP SWITCH INOPERATIVE.

System	Mean Headway S.D.	Mean TC at Response	Mean Minimum Headway	Mean Minimum TC
1	36.4	8.3	91.2	5.6
1+APS	37.1	7.6	93.1	5.4
8	46.5	6.9	64.9	4.0
Mean	40.0	7.6	83.1	5.0

Individual comparisons between lighting system means.

System		System
8	Significantly greater mean headway standard deviation than	1, 1+APS
8	Significantly lower mean time to crash at response than	1
8	Significantly lower mean minimum headway than	1, 1+APS
8	Significantly lower mean minimum time to crash than	1, 1+APS

Group 8 Conditions:

Lead car decelerates at -0.4 g from 0 mph relative velocity - repeated exposures to system 1+HDS.

The four dependent variables were analyzed in two-factor analyses of variance with factors of trial (at 4 levels: trials 1-4) and subjects (at 10 levels). None of the analyses showed significant effects (Table 35).

TABLE 35. MEAN HEADWAY STANDARD DEVIATION, MINIMUM HEADWAY, TIME TO CRASH AT RESPONSE, AND MINIMUM TIME TO CRASH: LEAD CAR DECELERATING AT -0.4 g FROM RELATIVE VELOCITY OF 0 MPH, FOR FOUR SUCCESSIVE TRIALS WITH SYSTEM 1+HDS.*

Trial	Mean Headway S.D.	Mean TC at Response	Mean Minimum Headway	Mean Minimum TC
1	32.9	13.1	112.0	7.1
2	30.7	15.5	114.0	7.2
3	29.7	11.2	108.6	7.1
4	34.3	14.5	101.8	7.2
Mean	31.9	13.6	109.1	7.2

*The four trials were distributed among those of other conditions, and were not contiguous.

Questionnaire Responses

The questionnaire administered at the completion of the testing was concerned with the usefulness of the lighting displays enabling the subjects to quickly and correctly interpret the action of the lead car.

All subjects reported that the high deceleration signal enabled them to make the most rapid determinations of high rates of closure. Five subjects reported that the accelerator position signal was helpful in determining constant or diverging headway. The same five subjects, however, reported that combinations of red and green lights were difficult to interpret, and were misleading in conditions in which the headway was closing rapidly.

Three of these subjects also stated that green lights alone, in high closure rate conditions, were misleading. One other subject, however, felt that green taillights enabled the most rapid determination of the lead car's action in both converging and diverging headway conditions.

UNOBTRUSIVE MEASUREMENTS OF THE RESPONSE OF DRIVERS TO AN ACCELERATOR POSITION SIGNAL SYSTEM

Objectives

The objectives of this study were to attempt to determine the effect of signals given by the Accelerator Position Signal on drivers who were exposed to it for the first time and who may not have been aware that some of their responses in driving were being recorded.

Method

The Test Cars

Two station wagons were used. The lead car was equipped with the Accelerator Position Signal (APS). This system consisted of a rear signal lamp display wired so as to signal the driver's use of the accelerator and brake pedals. Three signal lamps were mounted in a vertical configuration on a 12-inch by 25-inch black rectangular board, which was centered on the car's tailgate (Figure 23). The lamps, in descending order, were red, yellow, and green-blue. Each lamp was circular and had a diameter of 4.0 inches. The lamps were connected to a voltage regulator inside the car so that their intensities could be adjusted for day or night driving. In day tests each lamp was operated at 60 candelas. In night tests, the red, yellow and green lamps were operated at 30 cd, 20 cd and 10 cd, respectively.

The red signal lamp was wired to the conventional brake light system, so that it was lighted when the driver applied the brakes. The conventional stop lamps were functional throughout the experiment. The green lamp was wired to the carburetor linkage in such a way that it was lighted when the driver depressed the accelerator pedal. The yellow lamp was wired so that it was lighted whenever the driver was depressing neither the brake nor the accelerator pedal.

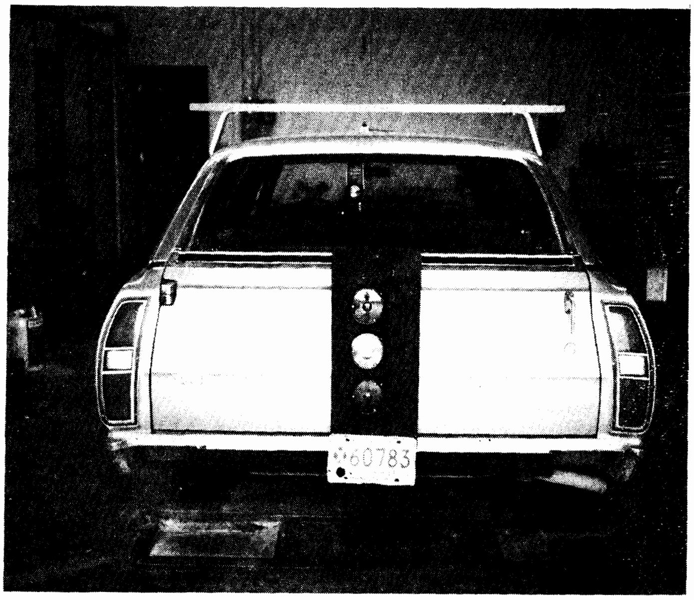


FIGURE 23. TEST CAR WITH ACCELERATOR POSITION SIGNAL LAMPS.

The lead vehicle was also equipped with a video (TV) camera unobtrusively positioned to view out of the rear window (Figure 23); a video tape recorder, operable by the driver; a video monitor, visible to the driver; and a microphone so located that the conversation of the driver of this car and the driver of the second vehicle, as transmitted via radio, would be recorded on the sound channel of the video tape recorder (Figure 24). Both vehicles were equipped with Citizens Band transceivers to accomplish this communication and transmission of data. The transceiver antennas on both vehicles were installed and modified so as to limit their conspicuity.

General Procedure

Only passenger cars were used as subject vehicles, in order to minimize variability in performance which could occur because

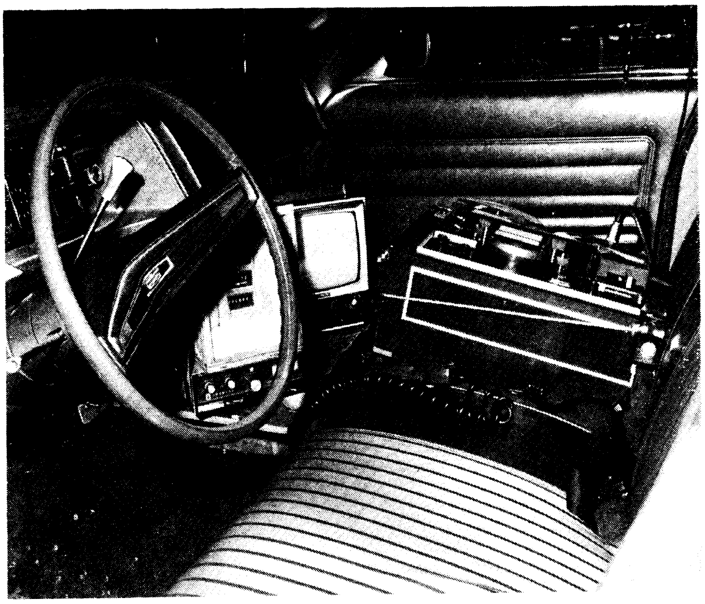


FIGURE 24. VIDEO TAPE RECORDER AND TV MONITOR IN TEST CAR EQUIPPED WITH THE ACCELERATOR POSITION SIGNAL LAMP.

of the generally more limited acceleration potential of other vehicles. In addition, by choosing only those vehicles with relatively low driver-eye-height positions, subjects were made more dependent on the signals presented by the lead car, rather than on the road ahead of the instrumented vehicle.

At night, only those vehicles with both left and right headlamps operating were included, since the headlamp center-to-center spacing was used in the data reduction.

Freeway Procedure

An average of 24 subjects were tested in each of the four freeway conditions (day vs night, APS on vs off). Only four-lane (two in each direction), limited access freeways were used.

Although the freeway was posted at a 70 mph maximum speed limit, most subjects were traveling 60 to 65 mph. After a prospective subject vehicle passed the trailing test vehicle and pulled back into the right lane, the trailing vehicle accelerated to the road speed of the subject and radioed that speed information to the driver of the instrumented vehicle, which was usually about a half mile ahead.

The instrumented vehicle was then accelerated or decelerated as needed to achieve a speed about 5 mph slower than the subject vehicle. The trailing vehicle periodically updated the information on the subject vehicle's speed, and maintained a 200- to 300-foot headway behind it.

The instrumented vehicle initiated a coast, or a coast followed by a brake when the subject vehicle came to within 100 to 300 feet. If the subject vehicle was constrained from passing the instrumented vehicle, the instrumented vehicle accelerated 5 mph so as to match the subject vehicle's speed, and maintained that speed until the constraining vehicle had passed.

Three response types available to the subject vehicle were recorded: braking, passing without braking, or remaining in the right lane without braking.

If the subject vehicle remained in the right lane, the instrumented vehicle accelerated back to the speed maintained at the time of initial signal presentation. After a minimum lapse of 10 seconds, and after the relative velocity between the vehicles again fell to about zero, and after the subject vehicle was again within a 100- to 300-foot headway range, a second signal condition (coast or coast-followed-by-brake) was presented.

This presentation could be made a third time, if passing was not accomplished after the second trial. After the third signal, however, an appropriate maneuver was executed to insure that the subject vehicle would pass the instrumented car.

Where more than one signal was given to a subject on the freeway, coast and coast-followed-by-brake signals were alternated.

Freeway subjects were not counted when their passing option was impeded by an anticipated turn off (to the right), as subsequently observed on the video tape recording.

<u>Rural Road Procedure</u>

An average of 28 subjects were observed in each of the four rural road conditions (day vs night, APS on vs off). The roads were posted for 55 to 65 mph maximum speed limits in the daytime, and 45 to 55 mph maximum speed limits at night.

The trailing and the instrumented test cars parked on the road shoulder or at an intersection, usually a half mile apart from each other. When a potential subject vehicle passed the parked trailing vehicle, headed in the direction of the instrumented vehicle, the trailing vehicle would pull out and unobtrusively pursue that vehicle unless additional traffic precluded this maneuver. If this maneuver was accomplished, the driver of the trailing vehicle would communicate his status via radio to the instrumented vehicle, which would then pull out some distance ahead of the approaching subject vehicle.

The driver of the instrumented vehicle would proceed at a speed 5 mph slower than the approaching subject vehicle, based on information communicated by radio by the trailing vehicle's driver. This speed level then became the reference speed level for the remainder of the trial for that particular subject.

When the subject vehicle had closed to within 30 to 300 feet of the instrumented vehicle, the first of the signal conditions was presented. During the presentation of this and subsequent signal conditions, the speed of the instrumented vehicle would always drop, but would return to the reference speed before the subsequent presentation. The reference speed would be modified, however, if the subject vehicle slowed considerably (so that the headway rose to more than 300 feet), or if the subject vehicle approached to less than 30 feet in an attempt to pass.

An attempt was made to present 4 to 8 signal conditions to each subject over a period of one and a half to four minutes. Signal presentation order was generally randomized while attempting to maintain a ratio of three coast (alone) signal to two coast-then-brake signals. This ratio was chosen based on data previously presented (Mortimer, 1970), concerning measured frequencies of coast and coast-then-brake maneuvers expected at the speed ranges used.

Throughout each trial, the trailing vehicle lagged 100 to 200 feet behind the subject vehicle, observing the latter's brake applications, as indicated by the stop signal lamps. If no brake signal had been observed by the end of the series of presentations, the instrumented vehicle attempted to decelerate sufficiently to necessitate the application of the service brakes in the subject vehicle. If no brake signal was confirmed in that maneuver the stop lamps of the subject's vehicle were considered to have been inoperative, and the data were discarded.

Recording of Data

A video tape recording was made of unsuspecting drivers as they drove behind the instrumented vehicle. By measuring the image width of the vehicle (for daytime runs), or the headlamp center-to-center width (for nighttime runs), and by comparison of those measures with calibrations made of vehicles of similar sizes, the headway distance between the instrumented vehicle and the subject vehicle was calculated. The second experimenter's vehicle followed the subject vehicle at a distance great enough not to have a major effect on the subject's driving performance, but close enough to observe stop signals and to estimate the speed. This information was relayed by radio to the driver of the instrumented vehicle.

Independent Variables - The independent variables were:

1. Rear lighting system (conventional, and conventional supplemented by the Accelerator Position Signal).

2. Road classification (two-lane rural, and rural freeway).

3. Ambient lighting (day, night).

Dependent Variables - The dependent variables were:

1. Frequency of subject's brake applications.

2. Response time between change of operating status on the instrumented vehicle (from cruise to coast and from coast to brake) and application of the service brakes, as noted by lighting of the stop lamps on the subject's vehicle.

3. Headway and relative velocity between subject and the lead car.

Results

Freeway Driving Test

Frequency of Passing, Braking, No Overt Response - The response of the following vehicle driver was recorded in terms of whether or not he passed the test car, applied the brakes, or made no noticeable response. These responses were classified for those events when the test car began coasting or applied the brakes, in the day and night tests, conducted with and without the accelerator position signal being used. The proportions of the responses of the following drivers in these conditions is shown in Table 36. The comparisons of primary interest are those showing the response of the following driver when the test car is giving signals with the accelerator position signal system and without it. It will be noted that the proportion of responses with and without the APS, in each condition, are similar. A Chi-square analysis of the data within the coasting and braking signal conditions showed that differences in the proportions of responses of the following driver were not statistically significant. When the test car applied the brakes, it can be seen that there were a greater proportion of braking responses made by the

TABLE 36. PROPORTION OF RESPONSES OF DRIVERS FOLLOWING THE TEST CAR WITH AND WITHOUT THE ACCELERATOR POSITION SIGNAL (APS), ON THE FREEWAY.

Response of Following Driver	Test Car Coasting				Test Car Braking			
	Day		Night		Dav		Night	
	With APS	Without APS	With APS	Without APS	With APS	Without APS	With APS	Without APS
Pass	.79	.78	.32	.59	.42	.60	.50	.40
Brake	.16	0	.18	.12	.29	.10	.25	.40
No Response	.05	.22	.50	.29	.29	.30	.25	.20
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
No. of Cases	19	9	22	17	7	10	20	15

following-car driver, showing that a change in behavior can be elicited if the signal indication and the behavior of the lead vehicle is sufficiently demanding. Also, it will be noted that in this freeway test, the drivers of the following vehicles most often either made no response (i.e., did not apply their brakes) or passed the test car. For these reasons, the freeway test approach was considered of limited value.

Two-Lane Road Test

Frequency of Passing, Braking, No Overt Response - The responses of drivers on the two-lane roads, in terms of passing, braking, or making no response (i.e., not braking) to coasting or braking of the lead car, are shown in Table 37. In this case, it will be noted that none of the vehicles passed the test car, because they were constrained by the few opportunities for overtaking on these roads. It will again be noted, that the proportion of responses in braking when the test car was coasting or applying the brakes, with and without the accelerator position signal, are quite similar. A Chi-square test on these data also proved to be non-significant. It can be seen that there were

TABLE 37. PROPORTION OF RESPONSES OF DRIVERS FOLLOWING THE TEST CAR WITH AND WITHOUT THE ACCELERATOR POSITION SIGNAL (APS), ON TWO-LANE ROADS.

Response of Following Driver	Test Car Coasting				Test Car Braking			
	Day		Night		Day		Night	
	With APS	Without APS	With APS	Without APS	With APS	Without APS	With APS	Without APS
Pass	0	0	0	0	0	0	0	0
Brake	.09	.10	.14	.11	.62	.60	.51	.51
No Response	.91	.90	.86	.89	.38	.40	.49	.49
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
No. of Cases	87	71	96	84	65	63	81	59

considerably greater proportions of responses of the following-car driver in braking when the test car applied its brakes, than was the case on the freeway.

<u>Effects of Coasting and Braking on Headway</u> - For each vehicle that followed the test car for a sufficiently long period of time that it was considered to be in a car-following mode, on the two-lane roads, measurements were taken of the headway between the test car and the following car at the instant that the test car began coasting or braking, and the headway which resulted at the end of a period of five seconds or when the following vehicle applied the brakes. For each of these cases the fraction was computed which consisted of the change in headway (ΔH) divided by the initial headway (H) when the test car began coasting or braking. These proportions ($\Delta H/H$) were obtained for the day and night tests, with and without the accelerator position signal. The means of these proportions are shown in Table 38 and can be taken as indications of the sensitivity of the driver of the following car in responding to coasting and braking of the test car, with smaller values indicating greater sensitivity of the driver. The values in parentheses beneath the mean proportion

TABLE 38. MEAN PROPORTION ($\frac{\Delta H}{H}$) OF CHANGE IN HEADWAY OF FOLLOWING VEHICLE† FIVE SECONDS AFTER START OF TEST CAR COASTING OR WHEN FOLLOWING VEHICLE BRAKED, WITH AND WITHOUT ACCELERATOR POSITION SIGNAL (APS), ON TWO-LANE ROADS.

Action of Test Car	Action of Following Vehicle	Day			Night		
		With APS	Without APS	No. of Cases*	With APS	Without APS	No. of Cases
Coasting	No Response	.06	.13	143	.05	.05	158
		(151)**	(128)		(159)	(167)	
Coasting	Braking	.19	.24	15	.11	.33	22
		(107)	(115)		(125)	(145)	
Braking	No Response	.05	.10	50	.06	.08	69
		(160)	(140)		(163)	(159)	
Braking	Braking	.13	.17	78	.11	.12	71
		(131)	(114)		(134)	(138)	

†The change in headway is taken as the difference between the initial headway at start of coasting or braking and the headway after 5 seconds, if there is no response, or when the following driver applies the brakes.

*Includes sum of different vehicles and those exposed more than once.

**Values in parentheses are the mean headway at start of coasting or braking of the test car.

values, are the mean headways when the test car began coasting or braking.

It will be noted that in most conditions the differences in the mean proportions are quite small, clearly showing no differences attributable to the rear lighting systems.

However, the case where the lead vehicle began coasting without a response in braking noted by the following driver, in the daytime test, the mean proportional change in headway was .06 with the APS and .13 without APS. While this difference in the response of the following driver did suggest a benefit attributable to the accelerator position signal, it will also be noted that the mean headway at which coasting began was 151 ft. with APS and 128 ft. without APS. If it is assumed that the coasting deceleration of the test car in these two conditions was the same, on average, then it would be expected that, if the driver of the following vehicle had not changed speed, the proportional change in the headway would be less at the longer initial headway than at the shorter initial headway. This partly explains the smaller value obtained with the APS than without it, in this condition. All of the difference, however, cannot be explained in this way. Furthermore, the mean proportional changes in the headway with the APS signal are in no case larger than without the signal, suggesting that there may be some benefit to drivers of the following vehicles. At the same time, it will be noted that some of the cells have very few cases, such as when the test car began coasting and the following vehicle applied the brakes. Where there are such few cases, differences in the proportions are not sufficiently reliable for inferences to be made of the effects of the signal systems.

In order to further evaluate the response of the driver of the following car and to take account of the initial headway when the lead car coasted or braked, an analysis of covariance was made on the headway existing after five seconds of coasting or when the driver of the following car braked.

Table 39 shows the resulting mean headways adjusted for the initial headway at the start of coasting or braking of the lead car, in day and night tests and with and without the APS. The analysis of covariance showed that there was a significant main effect of the APS in the day and night test when the lead car coasted for the first time in these conditions and no overt response (i.e., braking) was made by the following car. The mean headways which resulted were greater with the APS on than off by

TABLE 39. MEAN HEADWAY AT RESPONSE (FEET) ADJUSTED FOR HEADWAY AT SIGNAL PRESENTATION WITH AND WITHOUT THE ACCELERATOR POSITION SIGNAL IN DAY AND NIGHT TESTS ON THE TWO-LANE ROAD.

Action of Test Car	Action of Following Vehicle	Ambient Condition	APS Condition	Mean Headway at Response*	Number of Cases
Coasting	No Response	Day	On	160.4	25
			Off	147.0	25
(First Exposure)		Night	On	165.6	25
			Off	150.8	25
Coasting	No Response	Day	On	131.2	20
			Off	131.4	20
(Second Exposure)		Night	On	138.0	20
			Off	135.0	20
Braking	No Response	Day	On	154.6	17
			Off	149.5	17
		Night	On	163.1	17
			Off	153.0	17
Braking	Braking	Day	On	117.0	21
			Off	109.8	21
		Night	On	126.4	21
			Off	115.6	21

*After 5 seconds or at braking.

17.4 ft. in the day and 14.8 ft. at night. The analysis also showed that on the second exposure to coasting, there were no significant differences in the resulting mean headways with or without the APS. There were no significant differences in mean headways in those cases where the lead car braked.

A linear regression analysis was also made between the initial and resulting headways, following coasting or braking of the lead car. Table 40 shows that, within a set of conditions of actions

TABLE 40. SUMMARY OF LEAST SQUARE REGRESSIONS (PREDICTION OF HEADWAY AT RESPONSE FROM HEADWAY AT SIGNAL PRESENTATION) WITH AND WITHOUT THE ACCELERATOR POSITION SIGNAL IN DAY AND NIGHT TESTS ON THE TWO-LANE ROAD.

Action of Test Car	Action of Following Vehicle	Ambient Condition	APS Condition	Slope	Y-Intercept	r^2	S.E.	No. of Cases
Coasting	No Response	Day	On	.99	-7.7	.90	16.8	25
			Off	.96	-15.7	.88	21.8	25
(First Exposure)		Night	On	.95	4.6	.88	20.0	25
			Off	.93	-7.0	.95	16.5	25
Coasting	No Response	Day	On	.88	2.9	.95	11.0	20
			Off	.98	-11.5	.94	10.0	20
(Second Exposure)		Night	On	1.02	-13.4	.92	16.4	20
			Off	1.00	-12.3	.91	14.2	20
Braking	No Response	Day	On	1.04	-18.4	.96	12.4	17
			Off	.99	-14.2	.87	22.6	17
		Night	On	.83	25.5	.78	18.9	17
			Off	.92	0.8	.97	11.5	17
Braking	Braking	Day	On	.76	13.6	.70	25.3	21
			Off	.75	9.1	.75	22.7	21
		Night	On	.65	38.9	.75	26.2	21
			Off	.68	22.9	.87	16.8	21

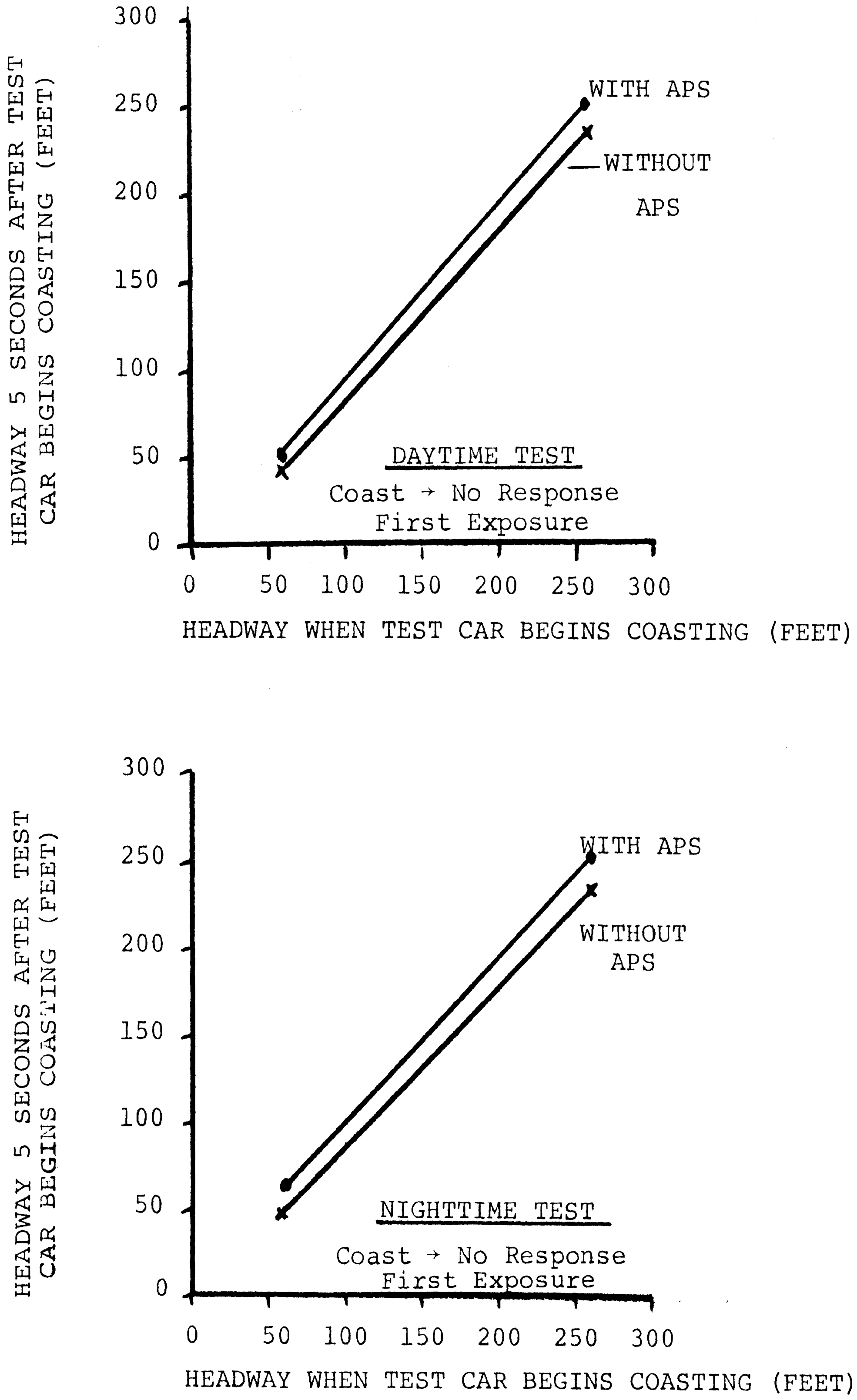
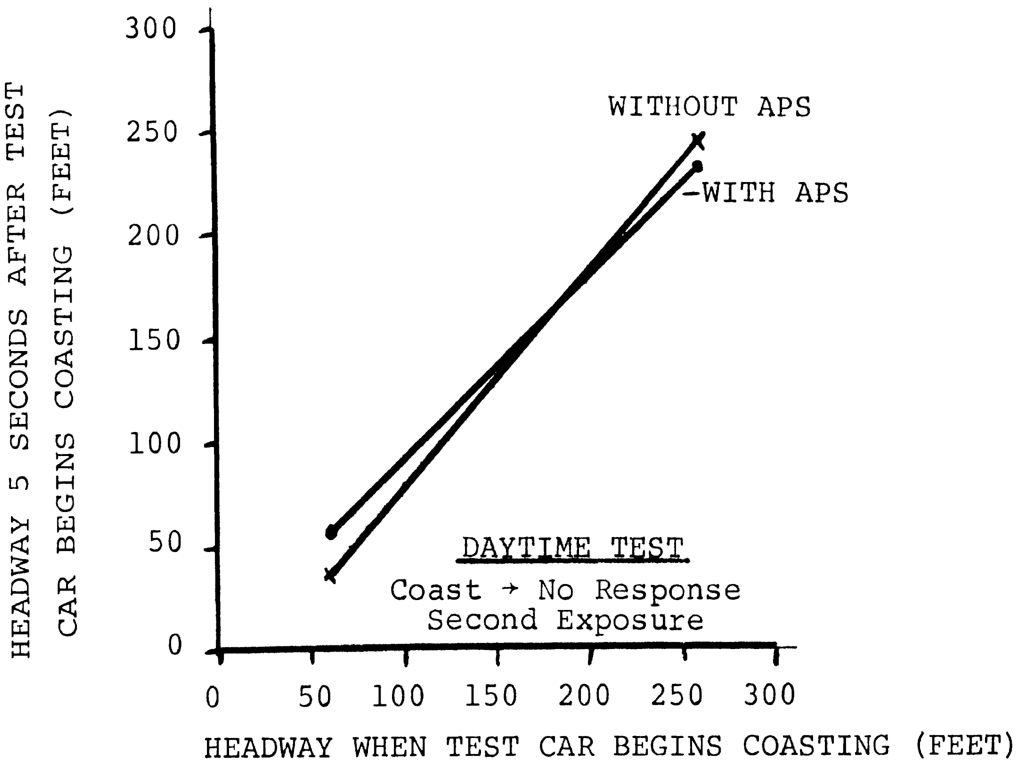


FIGURE 25. REGRESSION LINES FOR PREDICTION OF HEADWAY FIVE SECONDS AFTER THE TEST CAR BEGINS COASTING FROM HEADWAY WHEN THE TEST CAR BEGINS COASTING (WHEN THE FOLLOWING CAR DID NOT BRAKE). DATA FROM THE FIRST TRIAL OF THE DAY AND NIGHT TESTS, WITH AND WITHOUT THE APS.



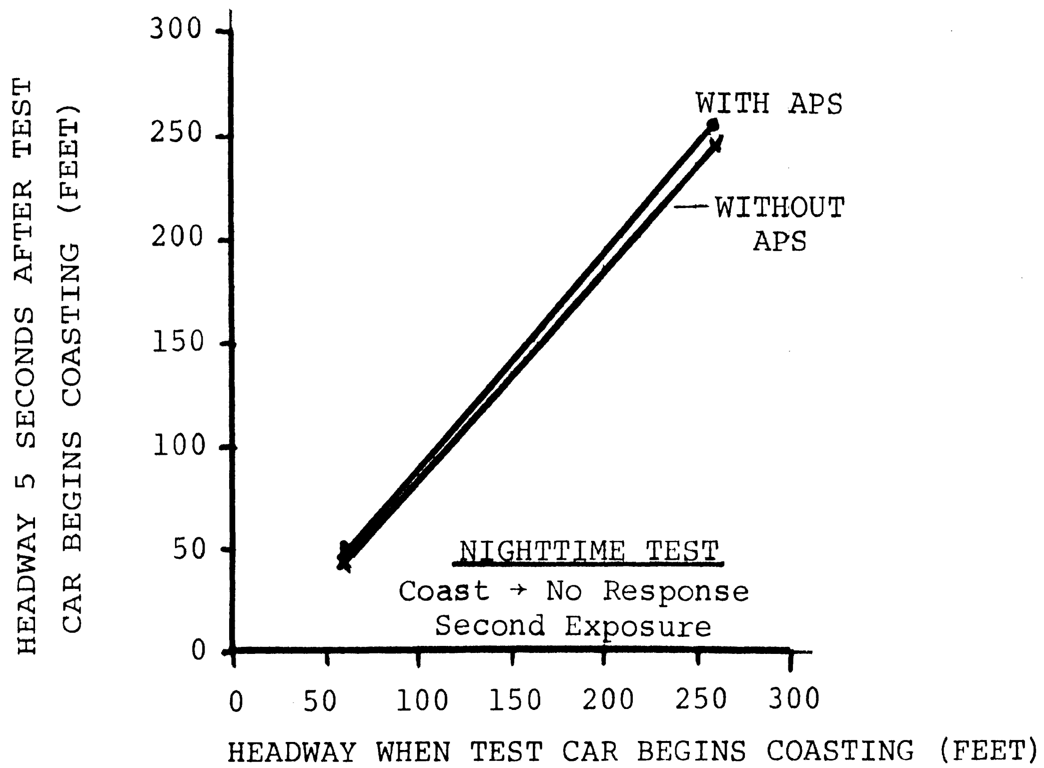
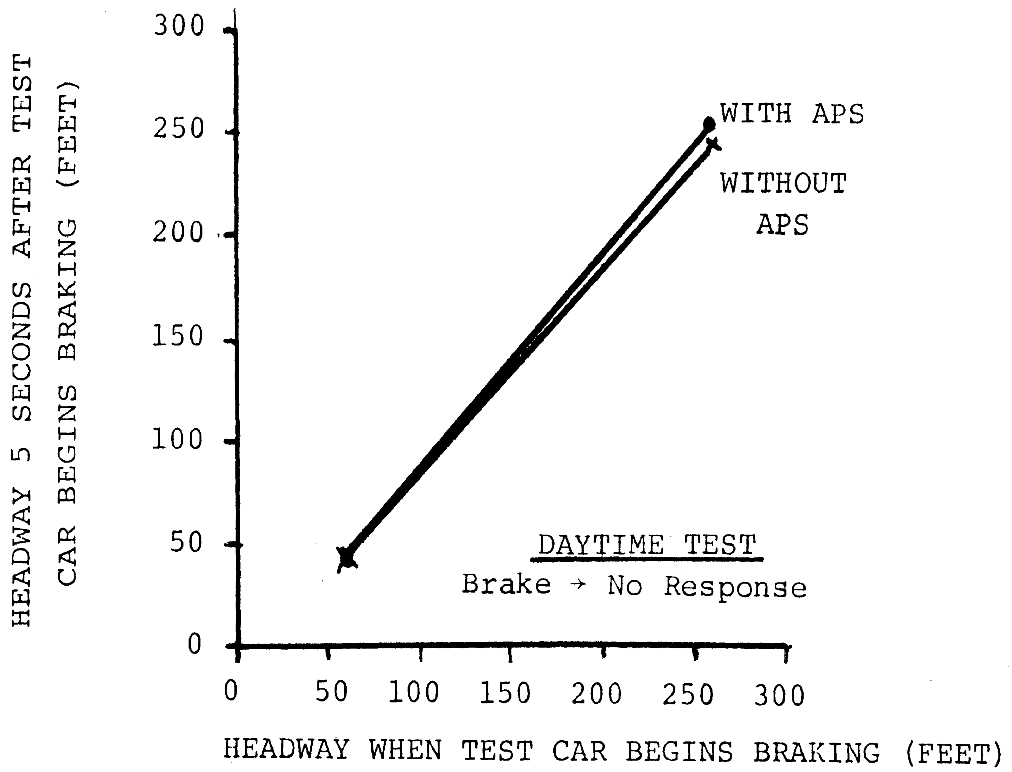


FIGURE 26. REGRESSION LINES FOR PREDICTION OF HEADWAY FIVE SECONDS AFTER THE TEST CAR BEGINS COASTING FROM HEADWAY WHEN THE TEST CAR BEGINS COASTING (WHEN THE FOLLOWING CAR DID NOT BRAKE). DATA FROM THE SECOND TRIAL OF THE DAY AND NIGHT TESTS, WITH AND WITHOUT THE APS.



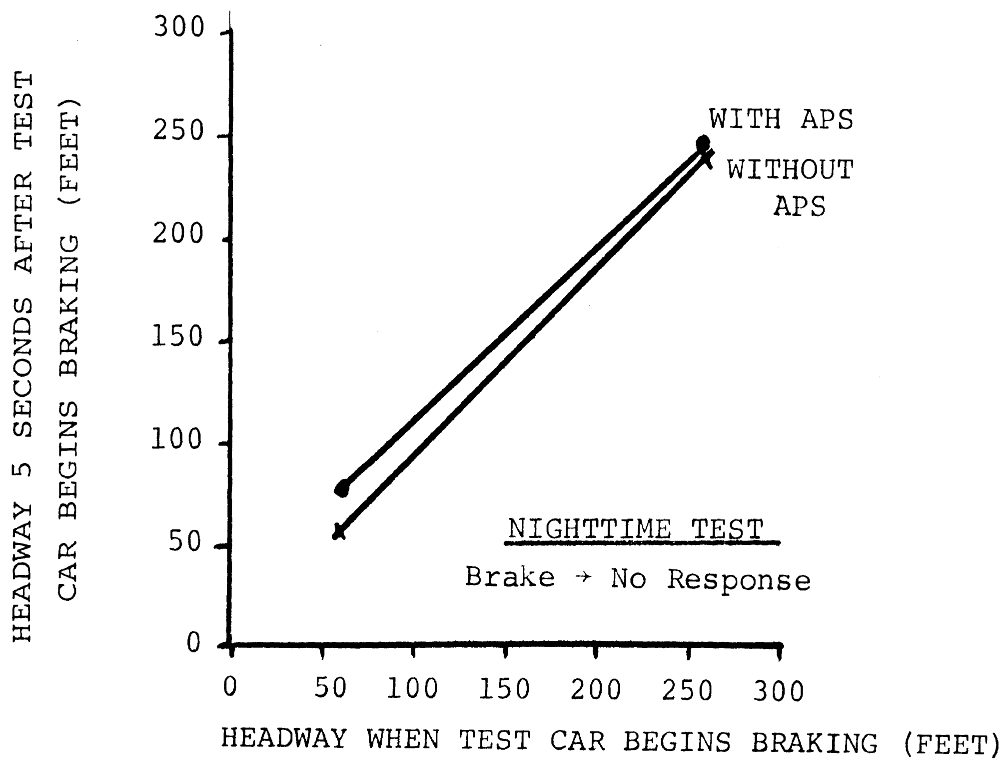
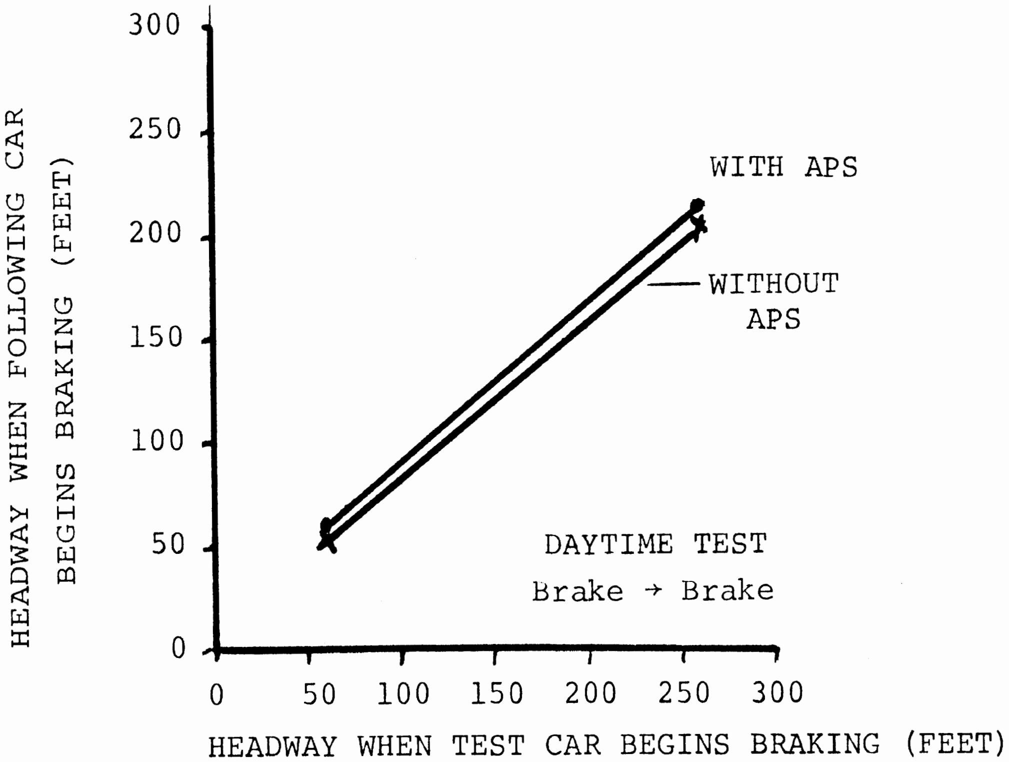


FIGURE 27. REGRESSION LINES FOR PREDICTION OF HEADWAY FIVE SECONDS AFTER THE TEST CAR BEGINS BRAKING FROM HEADWAY WHEN THE TEST CAR BEGINS BRAKING (WHEN THE FOLLOWING CAR DID NOT BRAKE). DATA FROM THE DAY AND NIGHT TESTS, WITH AND WITHOUT APS.



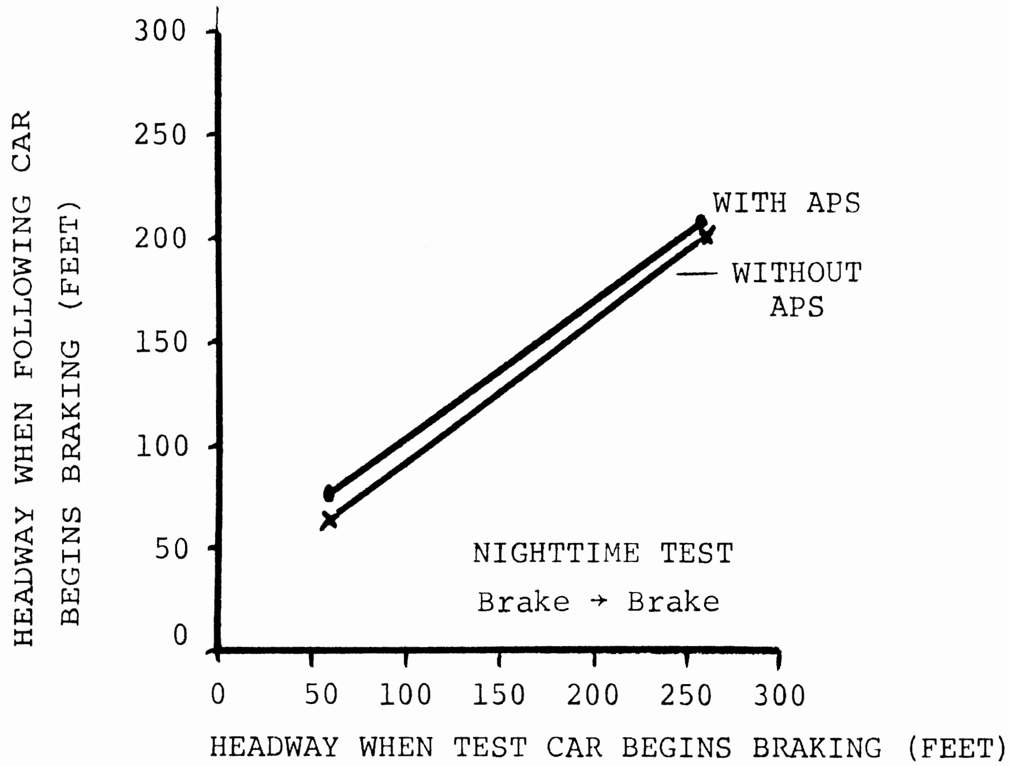


FIGURE 28. REGRESSION LINES FOR PREDICTION OF HEADWAY WHEN THE FOLLOWING CAR BEGINS BRAKING FROM HEADWAY WHEN THE TEST CAR BEGINS BRAKING. DATA FROM THE DAY AND NIGHT TESTS, WITH AND WITHOUT APS.

were the same whether the APS was on or not. The generally high values of the coefficient of determination (r^2) shows that the resulting headway was greatly influenced by the initial headway. Where the lead car braked and there was no overt (brake) response by the following car (Figure 27) the slopes of the lines are similar to those where the lead car coasted, suggesting that the deceleration of the lead car in braking produced little effect on the relative velocity so that the headway did not change much, and thus did not impose a requirement for braking on the driver of the following car. When the following car driver did brake after braking of the lead car, the slope of the lines (Figure 28) is less, showing that the gap had decreased to a greater extent, requiring braking by the driver of the following car. In this case, the resulting headways were greater with the APS on than off, but the differences between the means were not significant according to the analysis of covariance.

The cases where the lead car coasted without the following car braking (coasting → no response) are shown in Figures 25 and 26, for the first and second exposures to this condition, respectively. Clearly, on the second exposure, there are no differences in the resulting headways attributable to the APS indicating that drivers responded the same whether the APS coasting signal appeared on or not. On the first exposure (Figure 25) the resulting headways were greater when the APS was on than off.

The data suggest that the drivers of the following car had infrequently removed their foot from the accelerator at the end of five seconds of coasting of the lead car when the APS was off, and the difference between the initial headway and the headway five seconds later is largely attributable to coasting of the lead car. This is reasonable if it is assumed that the lead car decelerated, in coasting, at about 2 ft./sec.^{2}, as is typical (Mortimer, 1971) for such a vehicle, so that in five seconds the headway would be reduced by about 25 ft. if the following car maintained the same speed as the lead car before it began to coast. Figure 25 shows that headways are reduced by about 15-25 ft, indicating that the following vehicle rarely began to coast within five seconds without the APS.

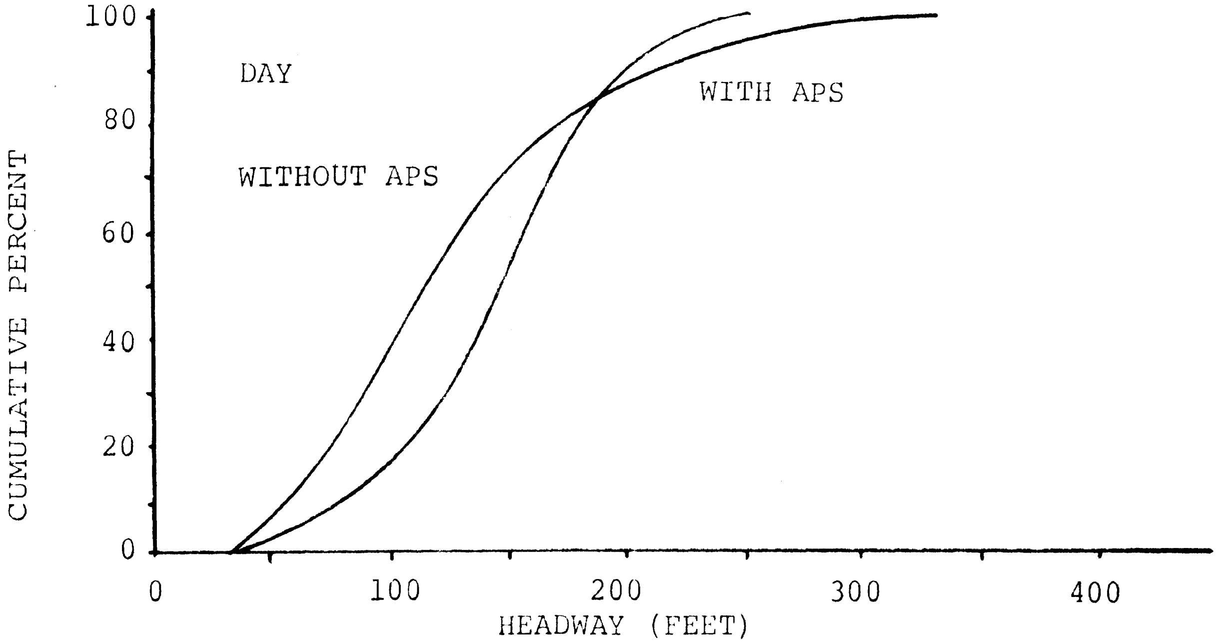
With the APS, the reductions in headways are 10 ft. or less (Figure 25), suggesting that the following car began to coast soon after the onset of the yellow coasting signal.

However, on the second exposure to these conditions (Figure 26) the coasting signal of the APS evoked a coasting response from drivers of the following car less frequently, and about the same as those following the test car without the Accelerator Position Signal.

Car-Following Analysis - In the two-lane road test the headway and relative velocity of each following vehicle was measured for a period of one minute of car-following at intervals of four seconds. The mean and standard deviations of the headways and relative velocities of these vehicles in the day and night tests, with and without the Accelerator Position Signal being used on the test vehicle, are shown in Table 41. The distributions of the headways and relative velocities are shown in Figure 29 and 30. About 90% of the headways were between 70 and 210 ft., and the relative velocities were between ±5 mph.

TABLE 41. MEAN AND STANDARD DEVIATION OF HEADWAY (FEET) AND RELATIVE VELOCITY (FT/SEC) OF FOLLOWING VEHICLE FOR ONE MINUTE OF CAR-FOLLOWING, WITH AND WITHOUT THE ACCELERATOR POSITION SIGNAL (APS), ON THE TWO-LANE ROADS.

	Day		Night	
	With APS	Without APS	With APS	Without APS
Mean Headway	143.8	124.5	141.6	153.1
Standard Deviation Headway	44.3	60.1	54.0	73.0
Mean Relative Velocity	0.39	0.12	0.56	0.04
Standard Deviation Relative Velocity	3.4	4.8	3.69	4.47



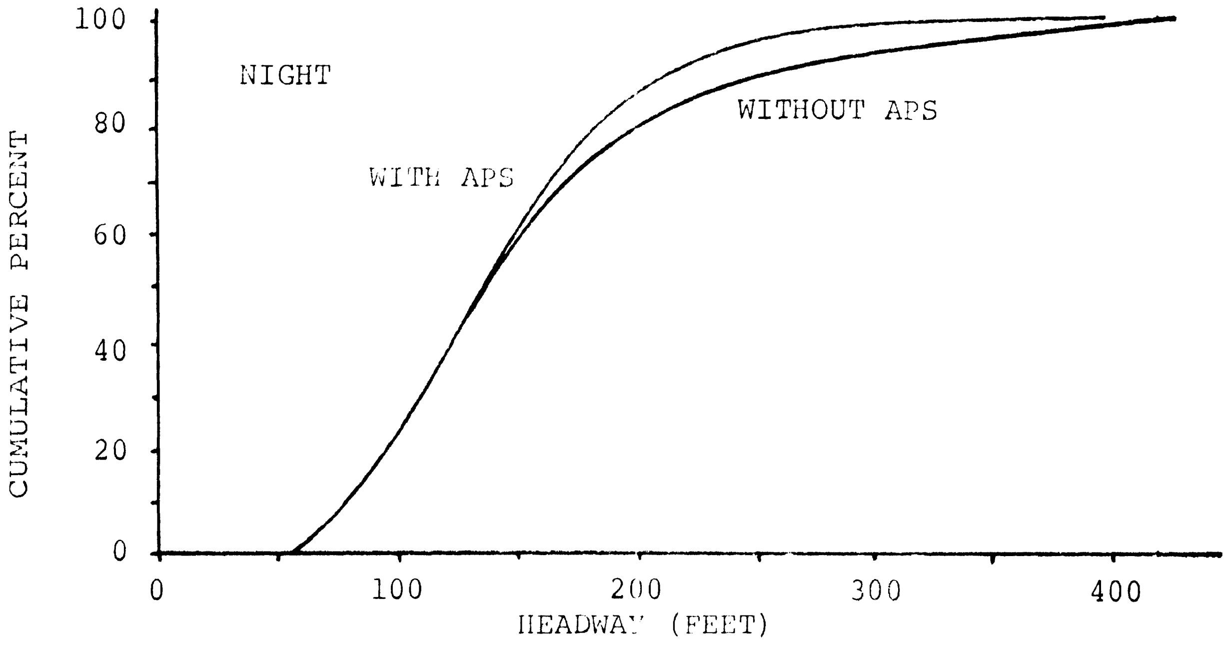
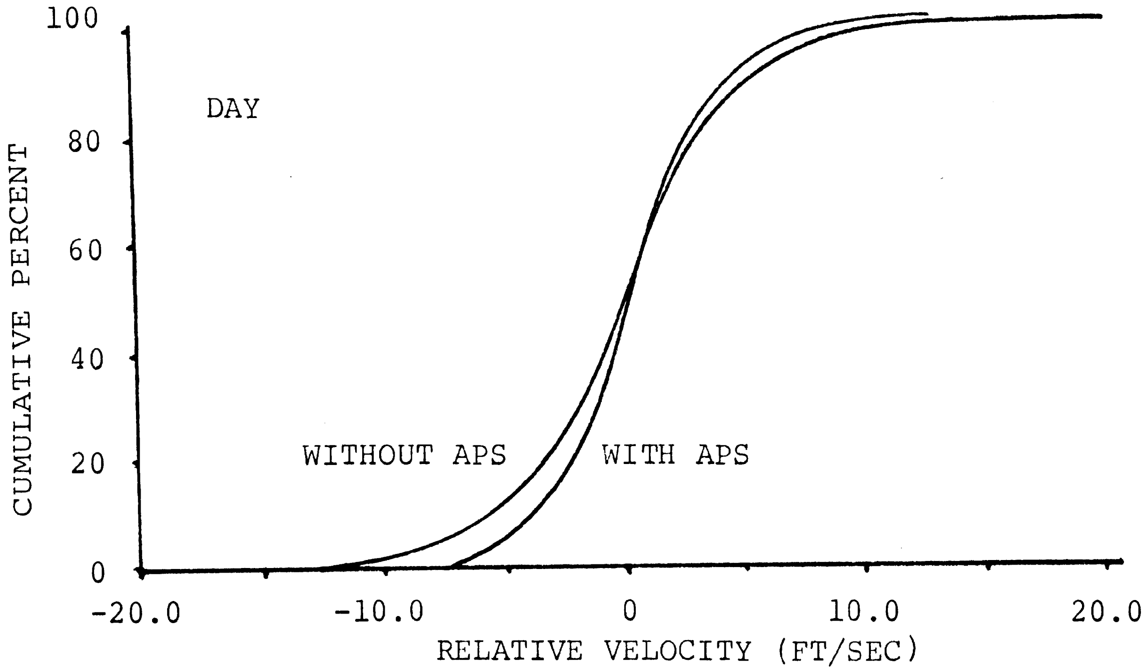


FIGURE 29. CUMULATIVE PERCENT DISTRIBUTION OF HEADWAY DURING ONE MINUTE OF CAR-FOLLOWING IN THE DAY AND NIGHT WITH AND WITHOUT THE APS.



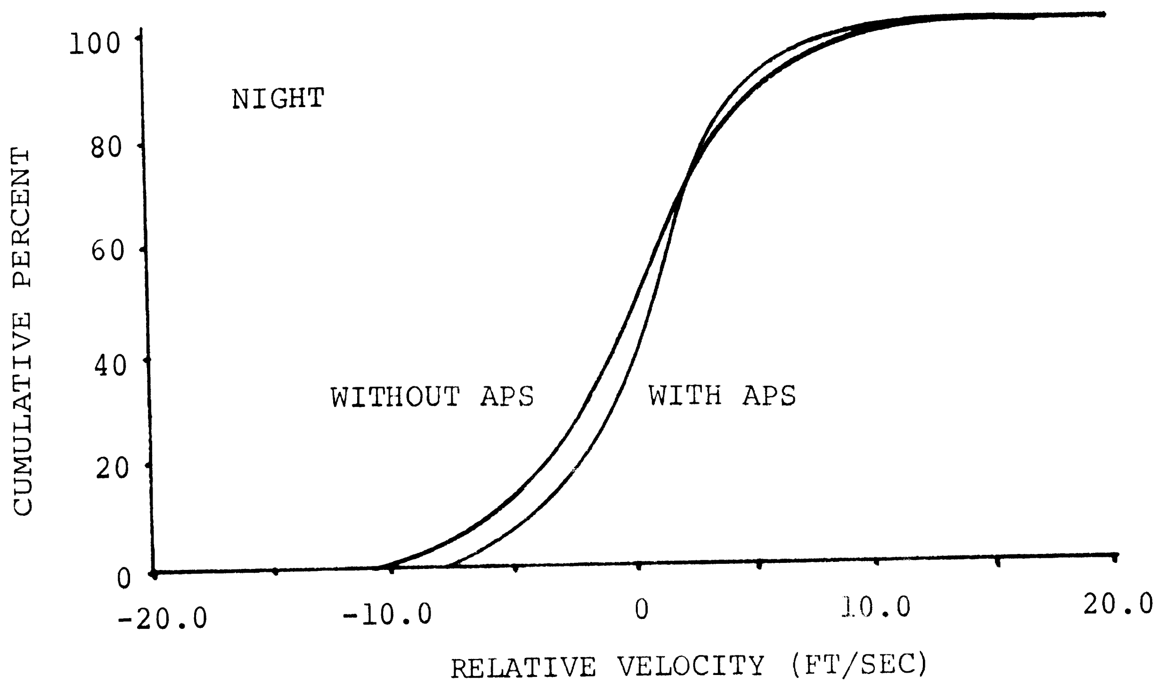


FIGURE 30. CUMULATIVE PERCENT DISTRIBUTION OF RELATIVE VELOCITY DURING ONE MINUTE OF CAR-FOLLOWING IN THE DAY AND NIGHT, WITH AND WITHOUT THE APS.

SUBJECTIVE EVALUATIONS BY DRIVERS OF AN ACCELERATOR POSITION REAR SIGNAL SYSTEM

Objectives

The objectives of this study were to obtain information of the ability of drivers to recognize the intended meaning of signals given by the Accelerator Position Signal System, provide subjective evaluation of their perceived usefulness of such signals in various schedules of signal presentations, and to evaluate, unobtrusively, their modulation of the accelerator and brake controls as another means of evaluating their response to the signals.

Method

Subjects

Six male and 14 female subjects, ranging from 20 to 45 years of age, participated in the present study. All subjects had a valid driver's license and normal color vision. Color vision was tested using plates five and six in section one of the Dvorine Pseudo-Isochromatic Plates (Dvorine, 1953).

Apparatus

Two station wagons were used. The lead car was equipped with an Accelerator Position Signal (APS), and is the same vehicle as used in the previous test (Figure 23).

A pair of mechanical counters was located on the front seat of the lead car (Figure 24). These devices recorded both the number of accelerator releases and the number of brake applications made by the driver. Also located on the front seat was a chart recorder, which made time plot of accelerator and brake applications and releases.

The second car was driven by a subject accompanied by a second experimenter who rode in the back seat. It was equipped with two electronic counters which also recorded the number of accelerator releases and brake applications made by the subject.

Both cars were equipped with citizens band radio transceivers.

Design and Procedure

Each subject drove the second (following) vehicle under a sequence of five conditions, which are described below. The order of conditions 2A and 2B was reversed for half the subjects; otherwise all subjects followed the same procedure. Half the subjects drove during the day, and half drove at night.

The conditions consisted of five combinations of road type, rear lighting system, and lead car driving profile. The roads traveled were either suburban-rural or urban; the rear lighting system was either the APS or a conventional system. "Driving profile" refers to the pattern of foot-pedal maneuvers made by the experimenter driving the lead car. With regard to testing the APS, both accelerator-to-brake (A→B) and accelerator-to-accelerator (A→A) maneuvers were of interest. For example, in an A→B maneuver, the sequence of APS lights is green-yellow-red, the yellow light can be a warning that braking is imminent. But in an A→A maneuver, where the sequence of lights is green-yellow-green, the yellow light can be a false alarm that indicates little change in speed. Thus, the relative proportions of A→B and A→A maneuvers influences the effectiveness of the APS. These proportions were systematically varied by the experimenter driving the lead car.

Subjects were instructed (Appendix 2D) to follow the lead car and to periodically fill out questionnaires concerning the APS. These questionnaires, which were filled out after each of the first four driving conditions, concerned subjects' subjective reactions to the APS. Subjects were not informed about the meaning of the signal lights until after the first condition had been completed. Subjects were never informed that their foot-pedal maneuvers were being monitored.

The first condition was an 8.5-mile warmup drive, during which the subject followed the lead car on a semi-rural route. This was intended to accustom subject to the feel of the car and the nature of the car-following task. The APS was turned on during this drive, in order to give the subject some exposure to it and to allow him to infer the meaning of the signals. The lead car's driving profile was not controlled during this run; experimenter drove as he would normally. The first questionnaire dealt with the subject's understanding of the system. After the subject had filled it out, he was told the meaning of the signal lights.

The second condition (designated as condition 2A) involved a 6.3-mile drive over a suburban-rural route with the APS turned on. For this condition, the experimenter driving the lead car exhibited a driving profile which approximated a ratio of four A→B maneuvers for every one A→A maneuver, with relatively long coasts. Maneuvers were timed to reflect actual road conditions as much as possible, so as not to appear artificial. This driving profile was intended to maximize APS effectiveness, in that the yellow light served as a meaningful warning of an impending brake application a large proportion of the time and of a long coasting period which reduced the vehicle's speed.

The third condition (designated as condition 2B) involved the same route as 2A, driven in the opposite direction. The APS was turned on. Here the lead car exhibited a driving profile which approximated a ratio of seven A→B maneuvers to six A→A maneuvers. The experimenter also attempted to employ three varying lengths of coasting interval between pedal applications: short (.6 secs.), medium (1.2 secs.), and long (2.4 secs.).

This driving profile was intended to simulate "normal" driving habits, as estimated from data collected in an earlier long-term study (Mortimer, 1970). To facilitate his exhibition of such a complex profile, the experimenter followed one of six specific programs of randomly order maneuvers, again adapting them to external road and traffic conditions.

Conditions 2A and 2B were driven in that order for half the subjects and in reverse order for the other half. Identical questionnaires were used for both of these conditions. They asked questions relating to the utility and consistency of information provided by the APS, particularly by the yellow lamp.

Condition 3 (the fourth in the sequence) was an 8.1-mile drive through an urban area. The APS was turned on. The driver of the lead car followed no specific driving profile during this run. The questionnaire following this condition dealt with general questions concerning the subject's various overall reactions to the APS. The sequence in which questionnaires were completed and the driving conditions involved are shown in Table 42.

TABLE 42. LISTING OF QUESTIONNAIRES COMPLETED BY SUBJECTS AFTER EACH OF THE FIRST FOUR DRIVING CONDITIONS.

Questionnaire	Driving Condition	Description of Driving Condition
Q1	1	warmup, APS on, no driving profile
Q2	2A	suburban-rural route, APS on, driving profile of four accelerator-brake maneuvers to one accelerator-accelerator maneuver.
Q2	2B	suburban-rural route, APS on, driving profile of seven accelerator-brake maneuvers to six accelerator-accelerator maneuvers.
Q3	3	city route, APS on, no driving profile.

After the subject had filled out this questionnaire, the experimenter told him that the experiment was over, paid him, and told him to follow the lead car back to the starting point. During this final 6.3-mile drive, the experimenter initiated a casual conversation with the subject to further encourage subject's belief that the experiment was finished. In fact, this return trip was Condition 4 of the experiment. The route was the same as that of 2A or 2B. The APS was turned off; only the conventional rear lighting system was in use. The driver of the lead car exhibited the same driving profile that was used in Condition 2B (seven A→B to six A→A maneuvers). The pedal counters in the subject's vehicle remained on, but no questionnaire was given at the end of the drive. This condition was intended to give a baseline pedal count for subject when driving under normal conditions (i.e., without the APS, and without the awareness that he was still a subject).

Thus, the data collected were in the form of pedal counts for both the subject and the lead car driver, and the subject's subjective questionnaire answers. A time plot of the lead car driver's pedal maneuvers was made during each of the five conditions. Questionnaires were administered after each of the first four conditions. The questionnaires are shown in Appendix 3.

Results

Experimenter's Driving Behavior

Table 43 and Figures 31 and 32 show the degree to which the experimenter driving the lead vehicle was able to approximate the driving profiles he was following in Conditions 2A, 2B and 4. The profile for Condition 2A was four A B maneuvers to every one A→A maneuver, with relatively long coasts. The profile for Conditions 2B and 4 was seven A→B maneuvers to six A→A maneuvers

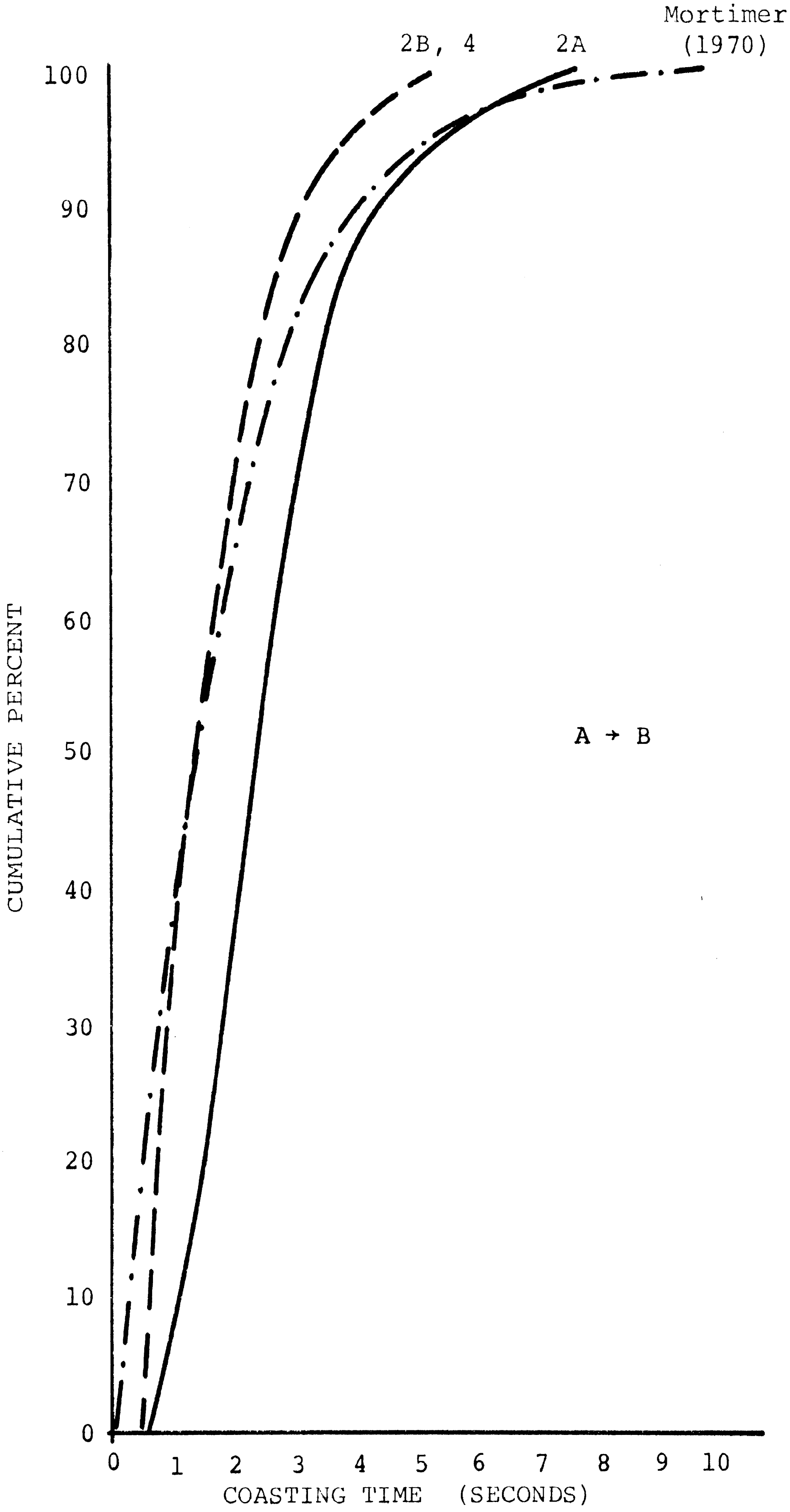


FIGURE 31. CUMULATIVE PERCENTAGE DISTRIBUTIONS OF COASTING TIMES BETWEEN ACCELERATOR RELEASE AND BRAKE APPLICATION FOR DRIVING CONDITIONS 2A, 2B AND 4, AND FOR MORTIMER'S (1970) NORMATIVE STUDY.

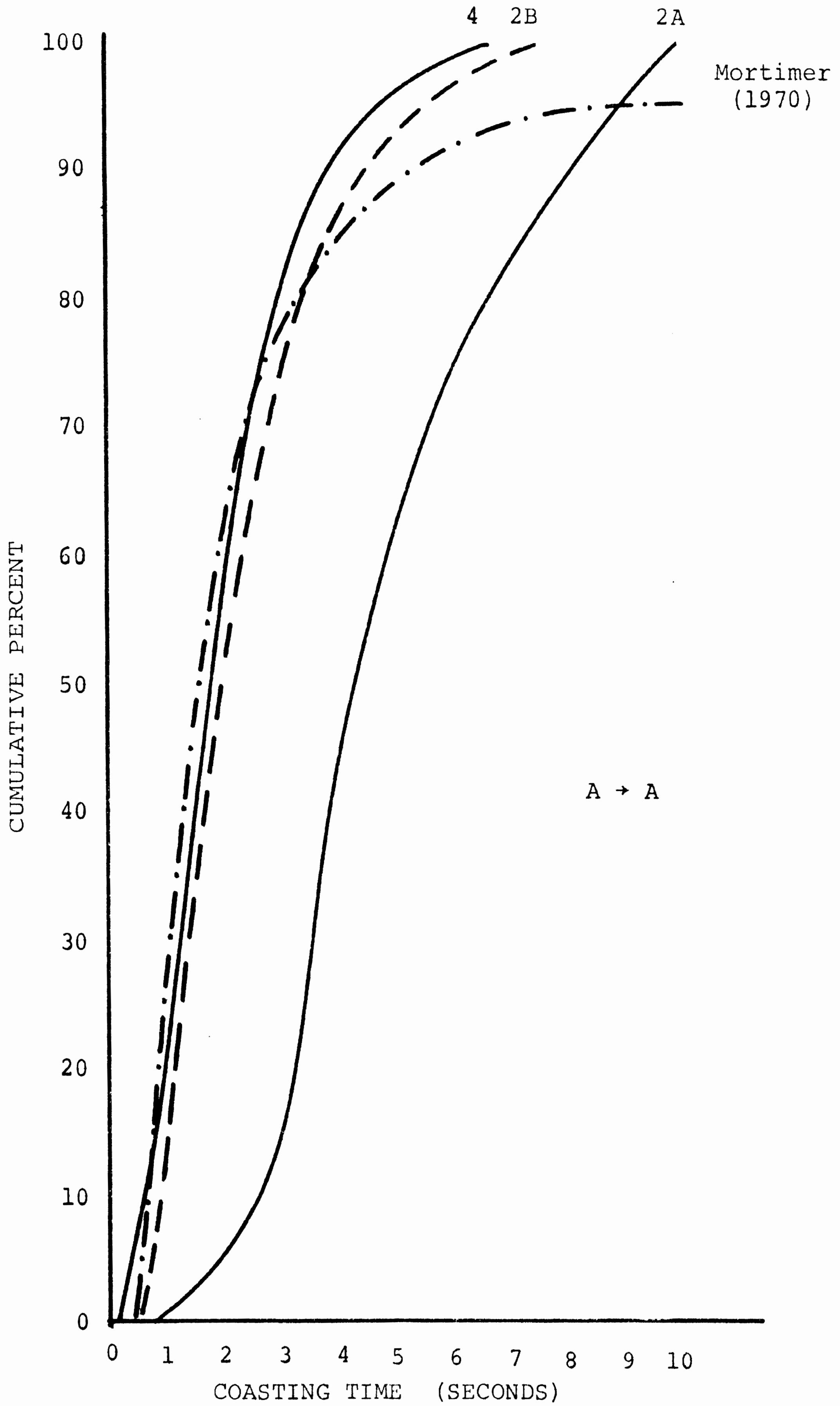


FIGURE 32. CUMULATIVE PERCENTAGE DISTRIBUTIONS OF COASTING TIMES BETWEEN ACCELERATOR RELEASE AND ACCELERATOR APPLICATION FOR DRIVING CONDITIONS 2A, 2B AND 4, AND FOR MORTIMER'S (1970) NORMATIVE STUDY.

TABLE 43. ACTUAL AND TARGET RATIOS OF ACCELERATOR→BRAKE (A→B) MANEUVERS TO ACCELERATOR→ACCELERATOR (A→A) MANEUVERS MADE BY EXPERIMENTER DURING THE FIVE DRIVING CONDITIONS.

A→B/A→A Ratio	Driving Condition				
	1	2A	2B	3	4
Actual	1.33	3.59	0.94	1.99	0.92
Target	-	4.00	1.17	-	1.17

with shorter, varying durations of coasts. The profile for Conditions 2B and 4 was derived from Mortimer's (1970) normative study.

Table 43 shows a comparison between the actual and target ratios of A→B to A→A maneuvers in the five driving conditions. The actual ratios were all slightly smaller than the target ones, but the ratios in Conditions 2B and 4 were quite similar and much smaller than the ratio in 2A, as intended.

Figure 31 shows the cumulative distributions of coasting times for A→B maneuvers in Conditions 2A and 4, and in Mortimer's (1970) study. The coasting durations in Conditions 2B and 4 were the same, and close to the 1970 durations except at the upper end of the distribution. The coasting durations in Condition 2A were longer, as intended.

Figure 32 shows the cumulative distributions of coasting times for A→A maneuvers in Conditions 2A, 2B and 4, and in Mortimer's 1970 study. Coasting times in Conditions 2B, 4 and the 1970 study were relatively similar, and shorter than in Condition 2A.

Pedal Counts

Two dependent variables were derived for the analysis of the pedal count data: (a) the ratio of a subject's accelerator release count to experimenter's accelerator release count for each driving condition; (b) the ratio of a subject's brake application count to experimenter's brake application count for each driving condition. These ratios reflected how closely the subject's pedal maneuvers matched the experimenter's maneuvers.

The independent variables used in both analyses of variance (ANOVA) were driving condition and ambient light (day vs night). The driving condition variable had three levels: (a) Condition 2A (suburban-rural route, APS on, driving profile of four accelerator→brake maneuvers for every one accelerator→accelerator maneuver); (b) Condition 2B (suburban-rural route, APS on, driving profile of seven A→B maneuvers for every six A→A maneuvers); and (c) Condition 4 (suburban-rural route, APS off, profile of seven A→B to six A→A maneuvers). Conditions 1 (warmup) and 3 (city) were not included in the analyses because the routes and profiles were not comparable. The levels of the ambient light variable were day and night.

The accelerator release count ANOVA showed a significant effect of driving condition ($p<0.01$). Neither the main effect of ambient light nor the interaction was significant at the 0.05 level. The Tukey (b) test was applied as a post-hoc comparison among levels of the driving condition variable. The valid comparisons were between 2A and 2B (same route, same rear lighting, different driving profile), and between 2B and 4 (same route, same driving profile, different rear lighting). The mean ratio for 2A differed from that for 2B at the 0.01 level; the mean for 2B differed from that for 4 at the 0.05 level. The mean ratios are shown in Table 44.

The brake application count ANOVA showed no significant effects of driving condition, ambient light, or of their interaction. The mean ratios are shown in Table 45.

TABLE 44. MEAN RATIOS OF SUBJECT'S ACCELERATOR RELEASES TO EXPERIMENTER'S ACCELERATOR RELEASES MADE UNDER DIFFERENT DRIVING CONDITIONS DURING DAY AND NIGHT DRIVING.

Driving Condition	Ambient Light		Mean
	Day	Night	
2A	2.29	2.47	2.38
2B	1.34	1.40	1.37
4	1.09	1.17	1.13
Mean	1.57	1.68	1.63

Individual Comparisons Between Mean Ratios

Condition 2A significantly greater than 2B.
Condition 2B significantly greater than 4.

TABLE 45. MEAN RATIOS OF SUBJECT'S BRAKE APPLICATIONS TO EXPERIMENTER'S BRAKE APPLICATIONS MADE UNDER DIFFERENT DRIVING CONDITIONS DURING DAY AND NIGHT DRIVING.

Driving Condition	Ambient Light		Mean
	Day	Night	
2A	1.45	1.46	1.46
2B	1.35	1.30	1.32
4	1.32	1.28	1.30
Mean	1.37	1.34	1.36

Questionnaires

The results from questionnaire 1 indicated that 75% of the subjects correctly inferred the meaning of the three APS signal lamps during the warmup drive.

Questionnaires 2A and 2B were identical. They consisted of five questions primarily concerning the consistency of the green and yellow lamps as indicators of impending speed changes. Answers were given as ratings on a 7-point scale; ratings were expected to change as a function of the driving profile of the lead car. Specifically, ratings were expected to decrease in the 2B condition, because the driving profile was seven A→B maneuvers to six A→A maneuvers, thus making the yellow light a less consistent indicator of impending braking. Ratings on the 2A and 2B questions were converted to difference scores (2A-2B) for each subject. The mean difference scores were all positive but very snall, ranging from .05 to .45.

Questionnaire 3 asked eleven questions concerning subjects' overall reaction to the APS. Subjects rated the APS as not very confusing (mean rating 1.95 out of 7), as not causing much apprehension (mean rating 2.15), and as slightly distracting (mean rating 2.80). Subjects claimed that the system led them to unnecessarily apply the brakes infrequently (mean rating 2.15), and to unnecessarily release the accelerator moderately infrequently (mean rating 4.70). A more complete summary of the data from all the questionnaires is given in Table 46 and Appendix 3.

TABLE 46. SUMMARY DATA FOR QUESTIONNAIRES (RATING QUESTIONS ONLY).

Questionnaire and Question Number*	Statistics	
	Mean	S.D.
2A-1	4.75	1.45
2A-3	4.50	1.64
2A-4	3.75	1.45
2A-5	5.40	1.43
2B-1	4.70	1.38
2B-3	4.45	1.88
2B-4	3.30	1.45
2B-5	5.15	1.63
3-1	1.95	1.05
3-2	2.15	1.50
3-3	2.15	1.35
3-4	2.90	1.97
3-5	2.80	1.64
3-6	4.55	1.54
3-7	4.70	1.66
3-10	4.40	1.85

*Corresponding questions and response frequencies can be found in Appendix 3.

SUMMARY AND DISCUSSION

The studies which have been described in the preceding sections have been concerned with the development of a side-task for use in the rear lighting simulator, the evaluation of various rear lighting systems in normal and unusual car-following conditions in the simulator, a limited road test of two of the rear lighting systems for comparison with results obtained in the simulator, and unobtrusive and subjective measurements of the responses of drivers to an accelerator position signal system in road tests.

As an adjunct to some of these studies a preliminary analysis was made of in-depth, multi-disciplinary accident data investigations in order to attempt to obtain a sample of information of the manner in which rear-end collisions have occurred. This analysis showed that a large proportion of the accident cases that were sampled involved rear-end crashes in which the vehicle which was struck was moving slowly or stopped, whereas the striking vehicles had a fairly wide distribution of speeds before the crash. This general result has also been reported previously (Carpenter, 1966). Obviously, rear-end crashes also occur under other circumstances of relative speeds between the vehicles involved (Mortimer and Post, 1972), including cases of high deceleration by the struck vehicle. These considerations, as well as the requirements of an experiment to evaluate the effectiveness of rear lighting systems, led to the development of a set of scenarios for use in a simulator test of rear lighting systems.

Evaluation of a Side-Task

The initial study was concerned with the evaluation of a side-task for use in the rear lighting simulator in order to determine that the task provides suitable informational loading on the subject, to better simulate the conditions prevailing in car-following on the highway in which the cues presented by the vehicle being followed are not the only ones of concern to a driver. The side-task which was selected, consisting of detection of lamps mounted to the left and right of the subject's forward field-of-view, is similar to that which has been used previously in road evaluations in car-following tasks (Mortimer, 1970; 1971). In both the simulator tests and in a road study (Mortimer, 1971) it was found that this task did increase the time required to identify signals given by rear lighting systems, showing that it loaded the subjects in a suitable manner. The extent of the loading, as measured by increase in reaction time to the signals of the rear lighting systems were of a comparable magnitude to those found in the previous road test (Mortimer, 1971). The side-task was then used in a subsequent simulator test of a number of rear lighting systems.

Evaluation of Rear Lighting Systems in Normal, Simulated Car-Following

Three rear lighting systems were evaluated in a daytime simulation and seven in a nighttime simulation of a car-following task. In the day simulation, systems 3 and 11 were found to have significantly lower response times than system 1 in the identification of turn signals which were preceded by stop signals (Table 9). There were more differences in the night test between systems, as shown in Table 8. The experimental rear lighting systems 3, 4, 8 and 11, which had been used in previous tests (Mortimer, 1970; 1974) had significantly lower mean response times only to the stop → turn mode. Previous studies in the simulator (e.g., Campbell and Mortimer, 1972) had found significant effects in other signal modes of these systems compared to system 1, suggesting that further exposure may have provided additional significant findings. The general trend of the response time data was, however, similar to that found in some of the other studies.

Of particular interest was the finding that the accelerator position signal (APS) in combination with system 3 (i.e., system 3+APS) produced a lower mean response time to stop signals than system 3, and in the two combined signal modes (turn → stop, stop → turn) than systems 1 and 1+APS. Since system 3 employed stop lamps which are separated from the combined presence and turn lamps, it is not intuitively clear why these results should have been obtained. It might have been expected that system 1+APS would have provided better stop signal detectability than system 1 due to the addition of the red stop lamp mounted in the center of the rear of the vehicle which forms part of the APS signal lamps. It is, therefore, paradoxical that the APS lamps should aid system 3, which already provides a prominent stop signal.

Various measures of car-following performance were also taken. Subjects were instructed to maintain a constant headway of 150 ft. and achieved an overall mean headway of 146.2 ft. There were no significant differences between the mean headways achieved when following the lead vehicle equipped with any of the rear lighting systems (Table 11). Nor was there a difference attributable to systems in the standard deviation or variability of the headway. The side-task did increase headway variability (Table 12). Since car-following at a fixed headway with the lead car would require that the variability of and relative velocities between the vehicles is maintained as low as possible, the standard deviation of relative velocity was also computed. It was found that system 3+APS produced significantly lower variability of relative velocity than system 4, but no other differences between systems were significant. The side-task increased the variability of headway and relative velocity, thus showing that the loading imposed by it affected these apects of task performance. The variabilities in the velocity or acceleration of the following vehicle were unaffected by any of the test conditions (Tables 14, 15).

Measures of the frequency of accelerator releases and brake pedal applications (Tables 16, 17) primarily showed that there was a wide discrepancy in the frequency with which subjects used the controls.

Thus, the performance measures indicated that the side-task had the expected effect in loading the subjects and producing increases in response times to the signals as well as affecting some of the car-following measures. In general, the differences found between rear lighting systems are in accord with previously obtained results, although there were fewer significant differences between systems in the various signal modes. Where significant differences in response times were found, the effectiveness of system 1 was generally less than of other systems. The paradoxical finding that system 3+APS produced lower mean response times in the two signal modes involving the stop signal, than some other systems, is difficult to explain, particularly since no benefit accrued to system 1+APS compared to system 1 in the analogous conditions.

There were virtually no differences in the performance of any system on the basis of car-following measures. System 3+APS had significantly lower mean variability of relative velocity than system 4, but no other systems, suggesting that this result is not particularly meaningful. It had been expected that the systems employing the accelerator-position signals would have provided an improvement in car-following behavior, but this was not found.

Subjective evaluations of the systems made by the subjects at the completion of testing clearly showed that they considered system 1 to be least effective. Systems 4, 8 and 11 were consistently rated as most effective and more preferred than the other systems. Interestingly, system 3+APS was considered more effective in providing stop and turn signals than system 1+APS.

The study indicated some benefit in the identification time of signals attributable to some of the experimental rear lighting systems, compared to the conventional system. The addition of the APS to the conventional system provided no noticeable improvements in any performance measures, while some improvements were noted when this concept was added to system 3, which at this time is considered a paradixical and unstable result. The lack of positive findings in car-following behavior of the APS systems, which was their primary expected benefit, combined with the subjects' poor rankings of them, indicated little likely benefit of such a concept, based on this study.

Road Test Evaluation of Systems 1 and 11

The findings of the road test evaluation of the identification of stop and turn signals of systems 1 and 11 were quite analogous to those obtained for those systems in the normal car-following simulator test. The only significant effect was found in the S → T mode in which system 11 provided significantly lower mean response times than system 1, as found in the simulator test. Since measurements of car-following behavior in the road test were not made it is not possible to make a comparison of them with the simulator tests. Within the limits of the road test, the agreement with the simulator system evaluations appears to be reasonable, and the effect of the side-task was also quite similar.

Evaluation of Rear Lighting Systems in Unusual Simulated Car-Following Conditions

A series of scenes were developed based, in part, on the analyses of accident data and upon the requirements imposed by the nature of the type of simulation that it was intended to achieve. In presenting scenes which are intended to allow evaluations of the effectiveness of signal systems in the avoidance of rear-end crashes it is necessary to use conditions in which such crashes are likely to occur unless appropriate action is taken by the driver. However, if all the scenes were of this type the test subjects would rapidly realize that the obvious response is immediate braking in every case. Therefore, it was necessary to also utilize conditions in which braking would be inappropriate, and which also would be useful for the evaluation of the various characteristics of the rear lighting systems. Therefore, conditions were used which incorporated both acceleration and deceleration of the lead vehicle, as well as positive, zero and negative relative velocities. These conditions were used in conjunction with a pay-off scheme, whereby the initial response made by the subject on being presented with the scene affected the extent of payment he would receive for participation. It was evident that subjects' responses were greatly influenced by this consideration, since very few errors were made. For example, an error would be defined as releasing the accelerator while a positive relative velocity (i.e., headway increasing) existed.

When the initial condition was a positive 0.1 g acceleration from relative velocities of 0, +10 and -10 mph there were no differences in the performance of systems 1, 8 and 1+APS (Table 25). In the case where the lead car was coasting at -0.1 g there were also no differences between these systems. Similarly, when the initial relative velocity was 0, +10 or -10 mph with an initial deceleration in each case of -0.2 g there were no differences between systems 1, 8, 1+APS, 3 and 3+APS.

There were also no differences between the conventional and a number of experimental rear lighting systems including those with the APS and the high deceleration signal (HDS) in that group of conditions where the vehicle incurred a deceleration of -0.4 g at initial relative velocities of 0, +10 and -10 mph. In order to test the effect of repeated exposures of subjects to system 1+HDS, which is the conventional system with the brake lamps flashing at

4 Hz when the deceleration exceeds -0.3 g, subjects were given four exposures to this system when the initial relative velocity was 0 mph and a deceleration of -0.4 g was incurred by the lead car after a few seconds. There was no change in the performance of the subjects over the four exposures in this condition. Thus, there were no learning effects to suggest that performance with the system might improve with time.

The only indication that the high deceleration signal, incorporated in the various ways with system 1 or system 3, was providing some benefit to subjects' performance, is shown in Table 33. It will be noted that the table shows that in the +10 mph relative velocity condition, the mean minimum times to crash achieved during each of these exposures are longer when the HDS systems are used compared to the other systems. However, none of these differences were statistically significant, and may be attributed to the response behavior of a few subjects who responded soon after the onset of the high deceleration signal even though the relative velocity may have still been positive. With initial relative velocity of +10 mph and a deceleration of -0.4 g, about 1.1 seconds will elapse before the relative velocity is zero and begins to go negative, so that the gap starts to close. Subjects were specifically instructed not to respond by removing their foot from the accelerator or braking unless they noticed that the headway was decreasing, and for this reason many subjects may have failed to respond immediately even though they noted the high deceleration of the lead car. In a sense, this produced an artifact in the results. On the other hand, where there was 0 relative velocity and a relative velocity of -10 mph, subjects would have been expected to respond immediately at the onset of the deceleration since the gap would begin to decrease at that instant. No differences between systems were noted in the 0 and -10 mph relative velocity conditions, as shown in Table 33, so that the effectiveness of the high deceleration signal was not noticeable in those conditions.

The test conditions in which there were significant differences found between systems are those of groups 2, 3 and 7.

In group 2 conditions, the initial relative velocity was either 0 or +5 mph. It was found that the standard deviation of the headway was significantly less with system 1+APS than system 8, but not system 1. Also, when the relative velocity was +5 mph, the mean headway with system 1+APS was less, and closer to the target value of 200 feet, than with systems 1 and 8 in the time period 9-14 seconds from the initiation of the scene. In addition, in the time interval from 11-14 seconds from the initiation of the scene, the mean headway with system 8 was less than with system 1.

The lower standard deviation of headway with system 1+APS than system 8 suggests a benefit in performance, but it is not clear why the same finding was not obtained for system 1. It should be noted that the interaction of relative velocity and system did not reach statistical significance, although Table 26 would suggest that it should. In addition, the conditions in group 2 are not much different from those in group 1 in which there were either 0 or +10 mph relative velocities with a 0.1 g acceleration. In both of these conditions, where there was either 0 or a positive relative velocity, the APS system would display the green lamp throughout the trial, thereby providing subjects with the same information. Thus, the finding of a benefit in a reduction of headway variability in the group 2 conditions does not appear to be a stable result.

That the headway was stabilized earlier (Figure 22) with system 1+APS than systems 8 and 1, and system 8 than system 1, can be seen by noting the point at which the slope of the curves is reduced. Visual inspection suggests that subjects responded to the existence of the +5 mph relative velocity at about 4 seconds after the shield opened with system 1+APS, 5 seconds with system 8 and 6 seconds with system 1, and that the magnitude of their acceleration differed to cause a variation in the final headway at the end of 14 seconds from the shield opening. The figure also explains the greater standard deviation in the headway found with system 8 in the 0 mph initial relative velocity condition, as shown in the upper part of Figure 22 and the close match between system 1 and system 1+APS in that condition. The lower part of Figure 22, when relative velocity was +5 mph, indicates the reason for the larger standard deviation in headway obtained with system 1 than system 8 and the larger variation of system 8 than 1+APS, as shown in Table 26. These results suggest that the APS aided earlier responding to the existence of a +5 mph relative velocity, but do not clarify the reason for the greater final headways being found at the end of 12 seconds with system 8 and system 1. This is because once the existence of the positive relative velocity has been established by the drivers, the cues to distance of the lead vehicle are the same for all three systems, and are largely available from the visual angle subtended by the presence lamps. Conceivably, the additional presence lamp provided by the green lamp of the APS may have given some additional cue for distance judgments. This is somewhat supported by an earlier study (Mortimer, 1968) in which it was found that an array of four presence lamps with two mounted above the other two, and a triangular array of presence lamps, provided improved cues to changes in headway than two presence lamps mounted in conventional locations.

In the group 3 conditions there were negative relative velocities of -5, -20 and -35 mph, with the finding that at the lowest relative velocity the mean minimum time to crash with system 8 was greater than systems 1 or 1+APS. The signals displayed in this condition are exactly the same as those in group 1 and group 2 conditions, the only difference being the relative velocities involved. There is no clear explanation why this system should have provided better performance than systems 1 or 1+APS in this condition.

A reversal of the former finding was obtained in the group 7 conditions in which subjects were exposed to an initial relative velocity of 0 mph followed by -0.4 g deceleration, without a stop signal being given because an inoperative stop lamp switch was being simulated. In the case of system 1 and system 8 only the presence lamps remained lighted, and in system 1+APS the yellow lamp of the APS system was turned on and the green lamp turned off when the deceleration was initiated.

It was found that system 1 achieved a significantly greater time remaining to crash at the instant that subjects responded by releasing the accelerator than system 8. In addition, both systems 1 and 1+APS achieved a smaller mean headway standard deviation and greater mean minimum headway and mean minimum time to crash than system 8. The explanation for these findings is not clear and is contradictory to those found in the group 3 conditions which are fundamentally similar to the ones presented in group 7.

It is evident that the findings of this study have found no clear-cut benefits of one rear lighting system over another in the variety of conditions to which the subjects were exposed. As already indicated, some of the results tend to be somewhat contradictory, but no explanation can be found as to the existence of some of the significant effects that were obtained.

These minor differences that were found to exist between some of the systems can be compared with some of the quite large differences obtained that are attributable to the differences among the conditions. For example, the group 6 condition in which an initial relative velocity of 0 mph was followed by a deceleration of -0.4 g is identical to the condition used in the group 7 tests. In the group 7 tests the vehicle stop lamps were inoperative. Comparison of the results in these two conditions indicates the effect of the stop lamp on the performance of the test subjects. Similarly, the group 5 conditions, in which there was a deceleration of -0.2 g with an initial relative velocity of 0 mph, can be compared with the analogous group 6 and group 7 conditions. These comparisons are shown in Table 47, and clearly indicate that there is a degradation in performance as the level of deceleration increases from -0.2 g to -0.4 g, by comparing group 5 and group 6 results; and the effect of the stop lamps is shown to also have a large effect in reducing performance by comparing the results of group 6 and group 7. Thus, in group 7 the mean headway standard deviation is greatest, the mean time to crash, mean minimum headway and mean minimum time to crash are all lowest. By comparison with differences attributable to the rear lighting systems, the effects of these variables are large.

TABLE 47. COMPARISON OF PERFORMANCE IN UNUSUAL SIMULATED CAR-FOLLOWING TEST: GROUP 5 (-0.2g), 6 and 7 (-0.4g) CONDITIONS, WITH 0 MPH INITIAL RELATIVE VELOCITY.

Condition	Mean H SD	Mean TC at Response	Mean Min. H	Mean Min. TC
Group 5 (-0.2g)	22.5	23.8	140.2	11.9
Group 6 (-0.4g)	31.1	12.1*	110.4	7.5
Group 7 (-0.4g, no stop signal)	40.	7.6	83.1	5.0

*Computed from mean response time shown in Table 32.

Evidently, the type of information presented by the APS and HDS systems, as evaluated in these specific test conditions, did not assist the drivers in providing performance which would be useful in the avoidance of crashes. By comparison, the loss of stop lamps on a vehicle appears to be a far greater factor, and these data therefore indicate that stop lamps alone, in their present mode of operation, offer a significant source of information for drivers in pre-crash situations. These results also show that the general technique that was used was sufficiently sensitive to detect important factors that can affect the performance of drivers, but that the more subtle differences between the lighting systems that were tested were of little significance.

Unobtrusive Measurements of the Response of Drivers to an Accelerator Position Signal System

The study was carried out in order to attempt to evaluate the effect of the APS upon naive drivers in order to determine whether there are any beneficial or deleterious effects of the APS system. The major finding was that there was an initial effect of the coasting signal. It appeared that, on the first exposure to the APS, drivers released their accelerators soon after the appearance of the signal (Figure 25). But, this effect did not occur on the second exposure to the same condition (Figure 26). There were no noticeable changes in the response of the drivers of the following cars to braking of the lead car, whether it was equipped with the APS or not. The one minute of car-following made of each of the naive drivers showed (Table 41) that the standard deviations of headway and of relative velocity were less with the APS, but none of these differences were statistically significant.

Subjective Evaluations by Drivers of the APS

As an adjunct to the other studies conducted to evaluate the

APS, a subjective evaluation test was conducted to obtain reports of drivers concerned with the effectiveness of components of that signal system. It was interesting to note that the drivers generally considered the APS signals to be useful, but measurements of the frequency with which they released the accelerator and applied the brakes in proportion to those used by the driver of the test car they were following, indicated some degree of dissonance between their reports and their actual performance.

Furthermore, the subjective reports of the drivers in this road test did not agree with those made by the drivers used in the simulation studies, whose overall preference was for other of the experimental rear lighting systems which did not employ signals that are modulated by the position of the accelerator pedal.

Subjects' pedal counts in condition 4 can be considered as baseline counts for subjects driving under normal conditions - the APS was off, the experimenter was following a "normal" driving profile, and subjects thought that they were no longer under scrutiny because as far as they were concerned the experiment was over. Thus, the ratio of a subject's accelerator count to the experimenter's accelerator count in this condition showed how often he normally released the accelerator in a car-following mode relative to an "average" driver (the experimenter who followed the "normal" driving profile). A comparison of the mean ratios for conditions 2B and 4 in Table 44 shows that subjects over-responded in terms of accelerator releases in the presence of the APS (2B), as compared with their normal driving behavior (4). The manner in which the vehicle equipped with the APS was driven also affected the frequency of accelerator releases of the subjects. It can be seen from Table 44 that subjects made fewer accelerator releases relative to the experimenter in condition 2B than they did in condition 2A. This decrease in relative response frequency was appropriate: in 2B the experimenter's driving profile included a high proportion of A $\rightarrow$ A maneuvers (seven A → B to six A → A); in 2A, experimenter made a lower proportion of A → A maneuvers (four A → B to one A → A). The yellow lamp which was lighted when the experimenter released the accelerator was a less reliable indicator of impending braking in 2B than it was in 2A, and subjects accordingly released the accelerator relatively less often.

However, it is unlikely that subjects consciously learned that conditions 2A and 2B were characterized by different types of lead car driver behavior. The data from questionnaires 2A and 2B demonstrated this, since subjects gave the coasting lamp practically the same rating after both 2A and 2B on questions concerning its consistency as an indicator of impending speed changes. This implies that they did not consciously realize the difference - but they did, apparently subconsciously, respond differently to the two conditions.

The day or night driving conditions did not affect the frequencies of accelerator releases or brake applications, which was expected because changes in headway were detected equally well in a previous test (Mortimer, 1971) in the day and night.

It is concluded that subjects did not consciously notice a difference in the potential value of the coasting signal, although they responded differently with the accelerator in the two conditions 2A and 2B, indicating that their responses to the questionnaire may be biased by irrelevant factors. Possibly, the novelty of the APS system influenced their reports. Thus, the subjective ratings of effectiveness should be considered as of dubious value.

During the hour or so of exposure to the APS system, subjects tended to over-respond with accelerator releases to the APS signal, compared to the conventional signal system. When the schedule of signals was as might be expected in a variety of car-following conditions, the subjects' relative response rate declined, showing that they recognized that many of the signals were of no relevance to them. But their response rate was still higher than with the conventional system alone, showing that the APS acted as a distracting signal source.

This is an undesirable characteristic of the system since it results in probably unnecessary accelerator control activity, with the potential introduction of added variance to car speed.

While the effect may not be serious in a two-car-following case, it could be a condition which is amplified down a stream of vehicles in dense traffic, causing potentially severe perturbations in traffic flow. This could happen if it is true that each following car driver releases the accelerator more often than the driver in front, as occurred in this test with the APS.

For both the APS and conventional system the relative frequency of braking by the subjects was about the same, showing that when more highly relevant information is provided, i.e., braking rather than coasting, drivers responded to it consistently. This effect was also unaffected by the schedule of APS signal presentations.

It is not known if the drivers would respond less frequently with more exposure to the APS. One subjective study of multiple car-following (Valasek, 1961) in a test of a coasting signal reported that drivers ignored the coasting signal after repeated exposures. Thus, the signal only added visual "noise" in that case. However, based on a previous study (Mortimer, 1970) it is expected that a coasting signal would be of little value because of the short duration of most coasting events and the relatively low probability of coasting signals followed by braking. The results of this experiment tend to confirm those earlier findings.

Table 41 shows that the standard deviation of headway with the APS is less in both the day and night tests than without the accelerator position signal. The mean relative velocities are quite close to zero in all cases. The standard deviation of relative velocity is also less with the APS than without it. But, neither the headway or relative velocity standard deviations are significantly different whether the APS was used or not used. This confirms the findings of the simulator studies in which no benefits of the APS were noted upon car-following performance.

CONCLUSIONS

1. The results of these studies have shown that alternatives to the present signal configuration appear to offer some benefits in signal identification, as measured by response time in these simulator and road driving tests. The extent of the benefits found in these studies is less than has been reported for some of the same systems in prior studies, and were largely found on the combined signal modes involving the presentation of a stop or turn signal when preceded by the other. It would be expected that similar results to those obtained earlier would have been obtained had more subjects been used in order that more data could have been collected to stabilize variability in the response measures.

2. Based on measures of car-following performance, the simulator tests conducted in both normal and unusual, pre-crash, situations showed that there were few differences between the rear lighting systems evaluated that can be considered to consistently indicate that any one of the systems would provide better protection in situations leading to a rear-end crash than any of the others.

3. While differences between the lighting systems on car-following performance in the simulator tests were found to be negligible, other differences in the predisposing conditions, such as the levels of deceleration or relative velocities involved, were found to have significantly measureable effects. This indicates that there is a good degree of sensitivity in the test procedure, and the failure to find differences attributable to the rear lighting systems is probably largely due to the relatively small effect that the variations in their operational characteristics had upon the measures of performance that were used.

4. The findings of the simulator and the road driving studies to evaluate an Accelerator Position Signal (APS) do not

provide any evidence that such a rear lighting system will be of benefit either in assisting in the stabilization of the car-following performance of drivers or in the reduction of rear-end collisions. On the other hand, there was some evidence obtained in the subjective evaluation test, in which accelerator releases and brake applications of the following-car driver were also measured, that the APS encouraged more than usual releases of the accelerator on the part of the following driver. This effect would create visual noise in the drivers' environment, and potentially lead to disturbances in traffic flow in a stream of vehicles, if each driver in the stream responded as was found in the two-car evaluation made here. The alternative behavior that may be expected, based also on some preliminary other results obtained by Valasek (1961), suggests that drivers will ultimately tend to ignore the signal, thereby not affecting the traffic flow; but still being exposed to a frequently appearing signal indicating accelerator application or release by the preceding driver which could be distracting and lead to loss of other stimuli or minimally, which could just be annoying, as also suggested by Rutley and Mace (1969). While this must remain as an hypothesis, because of the generally little data available to confirm the behavior of drivers in the more complex, dense traffic situation, the findings of this study have not been able to indicate any positive benefits that may accrue from the system.

A road test of this concept ("Tri-Light") in car-following maneuvers (Rockwell and Banasik, 1968) only found a significant reduction in the time needed to detect coasting, i.e., onset of the yellow signal, but not in the variability of the headway or relative velocity. When considered in the context of that study and others (e.g., Nickerson et al., 1968; Mortimer, 1970, 1971) and this study, it is suggested that no positive aspects of the system have been reported, while the system may have negative effects on safe car-following behavior.

5. Another rear lighting system signal which was evaluated in these studies was a high deceleration signal, such as might be given whenever the deceleration exceeds about 0.3 g. This signal was evaluated in only one phase of the studies in the rear lighting simulator. Within the range of conditions that were studied, the results did not indicate any significant benefit that could be attributed to the information provided by such a signal, compared to the signals, provided by stop lamps of the conventional or other experimental rear lighting systems. This does not obviate the possibility that there are other conditions, not evaluated in this program, in which such a signal system may provide some advantages in providing earlier indications to a following driver that the vehicle ahead is undergoing a high level of deceleration in order to allow more time in which to make a suitable response.

The results found in this study can be considered with those reported by other researchers. Rutley and Mace (1969) made a driving experiment on a test-track in which subjects followed a car equipped with seven red lamps arranged in a horizontal row at the rear. The innermost three lamps were lighted when the deceleration was at least 0.04 g, five lamps at 0.15 g and seven lamps at 0.3 g. They compared the responses of the driver of the following car to various deceleration maneuvers of the lead car with the "multi-brakelights," normal stop lamps, and no stop lamps. The response time to onset of mild ($\simeq$ 0.08 g) braking was not significantly different with the multi-brakelights or the normal stop lamps, but both produced earlier release of the accelerator by the subject than no stop lamps on the lead car. At about 0.46 g, the severe braking condition, there were no differences in the time to release the accelerator among the three signal system conditions. Nor were any significant differences found between normal stop lamps and the multi-brakelights in measures of car-following performance (maximum relative velocity/headway distance; ratio of accelerations of lead car and following car). Thus, no benefits were obtained of providing deceleration information beyond that available from normal stop lamps. The authors concluded that a two-level brakelight system may be found effective primarily in a "surprise" condition, presumably one wherein the driver has no reason to expect severe deceleration of the vehicle being followed.

A simulation study by Wallner (1967) used an oscilloscope to project the image of the combined presence (tail) and stop lamps of a car being followed. He evaluated car-following behavior with a two-level braking deceleration signal, compared to conventional stop lamps. Variations in the braking deceleration levels were indicated by the apparent intensity of the stop lamps. Their intensity was increased when deceleration exceeded 0.5 g. It was found that subjects selected a greater mean headway when following the car with the two-level braking signal and there was some reduction in crashes. Statistical analyses of these data were not made, and the author concluded that there was no noticeable advantage in the two-level braking signal.

A subsequent study by Wallner (1969) in the simulator, discussed by Engels et al. (1970) and Bol (1971), reported a reduction in "crashes" when the two-level braking signal was used simultaneously with an anti-locking brake system, compared to conventional stop lamps and brake system. The study was criticized by Engels et al. (1970) on a number of grounds, including the confounding of the variables of interest by the brake systems, which precludes the effect of the two-level braking signal to be inferred.

It is concluded that the limited amount of data collected with the high deceleration signal in this study should be augmented by additional experiments, in which similar predisposing conditions, as used in this study and others, could be used, and augmented by road tests. In the interim no benefits of this concept have been demonstrated.

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Appendices

Appendix 1

ACCIDENT REPORT INVESTIGATION TEAM AND REPORT NUMBERS OF SELECTED REAR-END COLLISIONS BY ACCIDENT GROUP TYPE

1. Struck Vehicle had Stopped for Traffic, Signals, Etc.

Investigator	Report No.	Investigator	Report No.
Ann Arbor - HSRI-III	00105	Oakland County-HSRI-III	00017
Baylor	00421		00059
CAL III-A	00058		00133
CAL III-B	71031		00149
	71-50		00202
GA Tech.	00104		00267
HSRI	00054		00282
	00187		00313
	00190		00414
	00222	Rochester	00127
	00340	Research Tri.	00018
	00468	Tulane	71015
	00571	UM	00615
	00582		00684
	00589	U New Mexico	00019
	00643		00032
	00667		00077-1
	00784		00078
Oakland County-HSRI-III	00009	USC	00028
	00009		00029
	00010		

2. Struck Vehicle was Stopped Waiting to Make Left Turn

Investigator	Report No.	Investigator	Report No.
CAL III-A	00066	Oakland County-HSRI=III	00022
CAL III-B	71044		00030
HSRI	00017		00033
	00261		00074
	00407		00208
	00625		00236
	00733		00352
	00874	UM	00639

3. Struck Vehicle Stopped Due to Failure, Out of Gas, Etc.

Investigator	Report No.	Investigator	Report No.
GA Tech.	00064	Stanford U.	00035
Research Tri.	00028	UCLA	01263
Stanford U.	00022		01265

4. Struck Vehicle was Making Right Turn

HSRI	00893	UM	00384
	00919		

5. Struck Vehicle Stopped Quickly, Etc.

HSRI	00782	UM	00532
UM	00418		

Appendix 2A

INSTRUCTIONS TO SUBJECTS IN EVALUATION OF REAR LIGHTING SYSTEMS IN NORMAL CAR-FOLLOWING CONDITIONS

(All subjects had or were given prior experience in the operation of the simulator. These instructions were then read to the subjects to familiarize them with the specific tasks we wished them to perform during this Normal Car-Following Study.)

In this experiment, you are requested to follow the lead vehicle at a simulated distance of 150 feet, at which distance the lead vehicle is now set. You will have several driving experiences in this experiment, each lasting about ten minutes, with a short break between.

Your primary task is to respond to the side-task lights, to the left and to the right of the main roadway, whenever such lights are in operation. When the left light comes on, depress the upper left button on your response box, with your left thumb, and that light will immediately go out. When the right light comes on, depress the upper right button with your right thumb, and that light will immediately go out. Your speed and accuracy in turning these lights out will be monitored continuously, so please pay attention to them. In some of the trials, these side-task lights will not be used. I shall tell you before each trial whether or not the lights shall be in operation.

Your second task, which will be your primary task when the side-task lights are not in operation, is to respond to the signals on the lead vehicle. You will be seeing stop signals, turn signals, and in some experiences, the signal system we call the "Accelerator Position Signal," which I shall explain a little later.

Whenever the stop signal on the lead vehicle comes on, we wish you to depress the foot switch under your left foot in the driving console. Please keep your left foot gently restin on this switch at all times, so that you may respond as quickly as possible. Please depress that switch a couple times so that I may check your operation of it. (Check.)

In addition to responding to the stop signal, we wish you to respond to the turn signals when they come on. As soon as you detect that the lead vehicle is displaying a left turn signal, immediately depress the lower left button on your response box with your left thumb. Similarly, as soon as you detect the lead vehicle is displaying a right turn signal, immediately depress the lower right button on your response box with your right thumb. If you respond to a stop signal or a turn signal by depressing the wrong button, correct yourself by pressing the proper button as soon as you realize your mistake. Each stop or turn signal will be displayed by the lead vehicle for several seconds.

In subsequent driving experiences on the simulator different rear lighting systems will be used which have different lamps or different colors for stop and turn signals. Prior to each driving experience, I will demonstrate when the stop signal and turn signals, separately and combined, will look like with that particular system.

Do you have any questions so far? (Answer.)

In addition to the stop and turn signals, in some driving experiences the "Accelerator Position Signal" will also be displayed by the lead vehicle. I shall demonstrate on the lead vehicle what that signal is. Whenever the driver of that simulated vehicle has the accelerator depressed, a green light will be displayed. When he releases to accelerator to slow down, a yellow light comes on like this. (Demonstrate.) Further, when he applies the brakes, a red light comes on, along with the vehicle's normal brake lights, like this. (Demonstrate.) Just because he releases the accelerator does not necessarily mean he is about to apply the brakes, however.

Do you have any questions about the Accelerator Position Signal? (Answer.)

Each driving experience starts with the lead vehicle at a standstill at a distance of 150 feet, like the vehicle is located at this time. The lead vehicle will then gradually accelerate to about 50 miles per hour, and the speed will then vary somewhat until the end of that experience, when the lead vehicle will decelerate to a stop again. Your third-priority task, which will be second priority whenever the side-task lights are not in operation, is to maintain that 150 foot distance behind the lead vehicle. About once a minute or so, I shall call out the actual simulated distance, so that you may correct any error which has developed.

Do you have any questions about the driving task? (Answer.)

Some of these driving experiences will be under nighttime conditions, when the taillights of the lead vehicle will be on. Others will be in dusk or daytime conditions, when the taillights will not be on. At the beginning of each driving experience, I shall demonstrate the conditions which will be used.

If there are no further questions, I shall not give you a practice run. (Administer.)

Appendix 2B

INSTRUCTIONS TO SUBJECTS IN ROAD TEST OF SYSTEMS 1 AND 11

Please begin by adjusting the seat and mirrors. The passenger has a control box with buttons labeled stop, turn, left and right. The stop and/or turn buttons should be depressed as soon as you see **any** of these signals. The left and right buttons are to turn off the left and right green lights on the hood of our car. The driver has stop and turn buttons on the steering wheel yoke which should be depressed as soon as the signals are presented. The driver has a foot pedal to the left of the brake pedal which should be depressed each time either green light on the hood comes on to turn it off. As soon as you have both depressed the appropriate button, the lights on the hood will go off.

The driver is to follow the lead car at a distance of 150 feet. You must strive to maintain this distance during the entire study. If you vary from 150 feet we will have to correct your separation distance.

The priority of tasks is driving followed by extinguishing the side-task lights when they are used, followed by responding to the signals from the lead car.

The lead car will be driving at 50 mph inbetween trials. Use your right foot to accelerate and brake. Do not use your left foot to brake.

Do you have any questions? Do not smoke or wear tinted glasses during the study.

Appendix 2C

INSTRUCTIONS TO SUBJECTS IN EVALUATION OF REAR LIGHTING SYSTEMS IN UNUSUAL SIMULATED CAR-FOLLOWING CONDITIONS

(All subjects had or were given prior experience in the operation of the simulator. These instructions were then read to the subjects to familiarize them with the specific tasks we wished them to perform during this Accident Simulation Study.)

In this experiment you will be viewing a number of scenes, each lasting at least five seconds and as long as thirty seconds. Each scene begins when the viewing shield is raised, and ends when the shield closes. Approximately two minutes will lapse between each scene.

Between scenes, we want you to maintain exactly 50 mph, as indicated on the speedometer visible to the right of the viewing shield. This is your primary task whenever the viewing shield is closed.

When the viewing shield is opened, you should determine as quickly as possible the appropriate response in order to maintain the same headway as when the shield opens. When the shield opens, the lead vehicle may be pulling away from you, may be going the same speed, or may be going slower than you, so that you are catching up to it. Furthermore, the lead vehicle may then, or may at some subsequent point during the scene, either accelerate or decelerate.

Your task when the viewing shield is open is to maintain the same headway as when the shield first opened at the beginning of that scene.

Do you have any questions so far?

I want to stress the importance of making a rapid but correct response concerning the speed of the vehicle you are driving.

To encourage that this response is correct, an incentive scheme controlling the amount of pay you shall receive for serving as a subject shall be used.

A basic hourly rate of $1.25 per hour will be paid. In addition, for each "correct" response, an additional sum of 20¢ will be added to the total, and for each "incorrect" response, $1 will be subtracted. An "incorrect" response is one in which you release the accelerator or apply the brake when the simulated lead vehicle is traveling the same speed you are or is going faster than you are. In other words, although we want you to respond as rapidly as possibly, the penalty for responding incorrectly is rather severe, and you should be sure that the response, namely, taking your foot off the accelerator or applying the brake, is the correct one.

A second type of incorrect response, with the same $1 penalty, will also be used. If you should get so close to the lead vehicle that a crash is imminent, which is when the lead vehicle is this close (demonstrated), then we shall call that "crash" an incorrect response. On the other hand, if the lead vehicle gets so far away that you are obviously not following correctly (demonstrated - lead vehicle at end of simulator belt, simulated 600 feet), that shall also be deemed to be an "incorrect response." In our previous simulator studies, these latter two types of incorrect responses have rarely occurred, and they certainly need not occur if adequate attention is paid to the tasks we have asked you to perform.

Do you have any questions?

One additional request. During this experiment we would like you to wear these headphones. You will normally hear a simulation of highway road noise, although when I talk to you on the intercom, you will also hear me on these headphones.

(Adjust phones for subject. Demonstrate sound.)

If there are no further questions, I shall give you a couple of practice runs, and then we shall begin.

Appendix 2D

INSTRUCTIONS TO SUBJECTS IN SUBJECTIVE EVALUATION BY DRIVERS OF AN ACCELERATOR POSITION SIGNAL SYSTEM

The purpose of this study is to enable us to obtain the subjective reactions of drivers to an experimental rear lighting or tail lighting system. To do this, we would like you to follow the vehicle which is immediately ahead of us now on a drive through Ann Arbor and the surrounding area. Your task will simply be to follow that car at a safe distance. Now, the distance at which you follow should be close enough to keep other drivers from cutting in between you and the lead car, but far enough away to enable you to stop safely should the lead car have to brake or decelerate rapidly. The lead car will not purposely make any unusual maneuvers, but you should be alert at all times to what the rest of the traffic is doing.

At certain times during the experiment, I will ask you to fill our questionnaires concerning the experimental lighting system in use.

Before we start the actual experiment, we will first take a short drive to let you get the feel of the car, the general idea of the car-following task, and some exposure to the experimental system. When driving, please use your right foot only when operating the brake and accelerator. At the conclusion of this first drive, I will give you a questionnaire to fill out concerning the function and your understanding of the experimental system. I will not, therefore, give you any further information about the lighting system at this time - - It will be your job to decide what the system indicates. Are you ready to begin? Any questions about the procedure?

(Check mirrors, seat position)

Perform warm-up run

Administer Questionnaires

Explain function of APS

Now we will go on a slightly longer drive on a different type of road. Your task will again be to follow the lead car and to fill out a questionnaire at the end of the drive. Any questions?

Perform following runs, administer Questionnaires.

Appendix 3.

THE INSTRUCTIONS TO SUBJECTS, AND THE QUESTIONNAIRES USED IN THE SUBJECTIVE DRIVING STUDY EVALUATION OF THE ACCELERATOR POSITION SIGNAL

Q 1

Name____________________ Date____________ Time______

1. What information do you think each of the lamps of the experimental system was intended to convey when lighted - i.e., what did each lamp mean?

   Red Lamp____.

   Amber Lamp______________________________________.

   Green Lamp______________________________________.

2. What actions of the possible actions listed below did each lamp indicate when lit? Choose as many answers as applicable for each lamp.

   Red Lamp________________

   Amber Lamp______________

   Green Lamp______________

   Possible Actions

   1) Mild deceleration
   2) High deceleration

   3) Mild acceleration
   4) High acceleration

   5) Accelerator applied
   6) Accelerator released

   7) Brake applied
   8) Brake released

Q 2

Name ______________________ Date ______________ Time _____ Series _____

1. How much useful information did the experimental lighting system provide to you?

Very Little (1) — A Great Deal (7) — CIRCLE NUMBER

No. of Resp.	1	2	3	4	5	6	7
Condition A		1	5	0	8	4	2
Condition B		1	3	5	5	4	2

2. What information, specifically, did it provide?

____

____

____

____

3. Did the yellow light consistently indicate that the other vehicle was slowing down?

Very Inconsistently (1) — Very Consistently (7) — CIRCLE NUMBER

No. of Resp.	1	2	3	4	5	6	7
Condition A		3	2	6	3	3	3
Condition B	1	2	5	2	2	5	3

4. Did the presence at the yellow light consistently indicate that the lead car was about to brake?

Very Inconsistently (1) — Very Consistently (7) — CIRCLE NUMBER

No. of Resp.	1	2	3	4	5	6	7
Condition A	1	3	5	5	3	3	
Condition B	2	4	5	6	2		1

5. Did the experimental lighting system reliably aid you in forecasting speed changes of the lead car?

Very Unreliably (1) — Very Reliably (7) — CIRCLE NUMBER

No. of Resp.	1	2	3	4	5	6	7
Condition A		1	1	3	4	3	5
Condition B		1	3	3	4	3	6

Q 3

Name ______________________ Date ______________ Time ________

1. Did the experimental system confuse or mislead you in any way?

	Not At All Confusing-Misleading						Greatly Confusing-Misleading	
	1	2	3	4	5	6	7	CIRCLE NUMBER
No. of Resp. →	9	5	4	2				

2. Did the experimental system make you feel more apprehensive or nervous than you usually do when driving?

	Not At All More Nervous						Much More Nervous	
	1	2	3	4	5	6	7	CIRCLE NUMBER
No. of Resp. →	10	3	4	1	1	1		

3. Do you feel that the experimental lighting system led you to apply your brakes unnecessarily?

	Very Infrequently						Very Frequently	
	1	2	3	4	5	6	7	CIRCLE NUMBER
No. of Resp. →	7	9	1		3			

4. Did it encourage you to take your foot off the gas pedal unnecessarily?

	Very Infrequently						Very Frequently	
	1	2	3	4	5	6	7	CIRCLE NUMBER
No. of Resp. →	8	3	1	1	5	2		

5. Did the experimental system distract you unnecessarily?

	Not At All						Very Much	
	1	2	3	4	5	6	7	CIRCLE NUMBER
No. of Resp. →	5	6	3	1	4	1		

6. If your task was to follow the experimental vehicle at a constant distance, do you think the experimental lighting system would have aided you?

	Very Little						Very Much	
	1	2	3	4	5	6	7	CIRCLE NUMBER
No. of Resp. →		3	2	4	4	6	1	

7. Did you feel that the experimental system became more useful as you became more accustomed to it?

	Did Not Become At All More Useful						Became Much More Useful	
	1	2	3	4	5	6	7	CIRCLE NUMBER
No. of Resp. →	1	1	2	5	4	4	3	

8. Do you see any advantages or disadvantages in the use of the experimental system on all cars?

____

____

____

9. If the experimental system was optional on a car you were buying how much would you pay for it?

	$15	$30	$60	Would Not Want It At All	Would Not Want To Pay For It	CHECK ONE
No. of Resp. →	2	5	3	1	9	

10. Would you be in favor of legislation which would require the system to be installed on all new cars by the manufacturer with the cost passed on to the consumer?

	Would Definitely Not Be In Favor						Would Definitely Be In Favor	
	1	2	3	4	5	6	7	CIRCLE NUMBER
No. of Resp. →	1	3	2	4	5	1	4	

11. How would you rate the intensity or brightness of each of the experimental lamps?

Red Lamp

1	2	3	4	5	6	7
Too Dim			OK			Too Bright

CIRCLE NUMBER

Yellow Lamp

1	2	3	4	5	6	7
Too Dim			OK			Too Bright

CIRCLE NUMBER

Green Lamp

1	2	3	4	5	6	7
Too Dim			OK			Too Bright

CIRCLE NUMBER