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EVALUATIONS OF EXPERIMENTAL (INCLUDING HIGH-MOUNTED) CONFIGURATIONS OF BRAKE LIGHTS IN ACTUAL TRAFFIC	November 1979
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16. Abstract

The efficiency of various configurations of brake lights in actual traffic was tested in two daytime experiments. The first experiment investigated the reaction times of informed drivers to 22 configurations of brake signals drawn from a 3 x 3 array of rear lamps. The main finding of this experiment is that adding supplemental (including high-mounted) lamps to the conventional two-lamp configuration did not shorten the reaction times. Other findings indicate that the lateral position of the lamps, the following distance, as well as the sex and age of the driver had significant effects on reaction times, while the mounting height of the lamps did not.

The second experiment evaluated brake responses of unsuspecting drivers to brake-signal presentations using a conventional brake-lamp system with and without supplemental high-mounted brake lamp(s). The signals were presented at speeds of 30-45 mph. The main finding of this experiment is that the signals given by the systems with one or two supplemental high-mounted brake lamps were more likely to produce a brake response by a following driver. On the other hand, the reaction times of the brake responses did not vary between the systems.

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Supplemental High-Mounted Stop Lamps, High-Mounted Brake Lights, Brake Lights, Stop Lamps, SAE J186, Mounting Height, Lateral Position, Number of Lamps, Reaction Time, Response Rate, In-Traffic Evaluation, Unsuspecting Drivers, Naive Drivers, Informed Drivers.	

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1.0 INTRODUCTION

Optimization of the rear lighting and signaling system has been a relatively lively research topic in recent years. (Some of this research is reviewed in Sivak, 1978). One study which has attracted a great deal of interest was performed by Essex Corp. (Malone et al., 1978), investigating the rear-end accident rates of taxicabs equipped with one of four different configurations of rear lights:

- CONTROL SYSTEM - Basic conventional (low-mounted) configuration with one lamp on each side; each lamp serving all three functions (presence, stop, and turn).
- SINGLE-HIGH-MOUNTED SYSTEM - The control system, plus one additional center high-mounted lamp providing a stop signal exclusively.
- DUAL-HIGH-MOUNTED SYSTEM - The control system, plus one additional high-mounted lamp on each side providing stop and turn signals.
- SEPARATION-OF-FUNCTIONS SYSTEM - Two (low-mounted) lamps on each side with one providing presence signal only and the other stop and turn signals only.

The sample included approximately 2,100 taxicabs, which accumulated nearly 60 million miles in and around Washington, D.C.

Malone et al. (1978) concluded that the taxicabs with the single-high-mounted system "sustained an accident rate 54% lower than the control group; and this difference was found to be statistically significant (p. 19)." The rear-end collision rates for the other two experimental systems did not differ significantly from the rate for the control system.

Among the reasons that the single-high-mounted system could have produced such seemingly effective results are the following:

(1) A brake signal given by this system is more likely to evoke a brake response of a following driver than a signal by a conventional system.

(2) A brake signal given by this system results in a faster brake response of a following driver than a signal by a conventional system.

Whether the advantage of the single-high-mounted system is in terms of the response probability or reaction time, the advantage could be due to one or more of the following features of the single-high-mounted and control systems:

(1) The single-high-mounted lamp might be located closer to the normal fixation point of the following driver.

(2) The single-high-mounted lamp was functionally unambiguous: it signaled a brake application only.

(3) The single-high-mounted lamp might capitalize on a learned association of the meaning "stop" with singly presented red lamps in traffic signals.

(4) Intrinsic effectiveness of the triangular configuration of the single-high-mounted system.

(5) Novelty effect. This explanation assumes that the single-high-mounted system is more novel than the dual-high-mounted system because of past exposure of the driving population to variants of the later system.

(It should be pointed out that since this study was conducted in a metropolitan area, a substantial proportion of the rear-end accidents have likely occurred in a bumper-to-bumper low-speed traffic. Collisions under such circumstances will result in property damage but perhaps not in injury. The injury statistics were not presented in the Essex report.)

The present study was designed to investigate the reaction time and response probability of following drivers to presentations of various brake-lamp configurations. The first experiment parametrically evaluated the effects of a signal height, lateral position, number of lamps, and following distance on following drivers' reaction time. The subjects in this experiment were alerted to the task at hand, but were occupied by a secondary (loading) task. The second experiment measured the reaction times of following drivers to brake signals presented by the control, single-high-mounted, and dual-high-mounted systems. The subjects in this experiment were unsuspecting motorists who were "trapped" behind the experimental car.

2.0 EVALUATION OF THE EFFECTS OF SIGNAL HEIGHT, LATERAL POSITION, NUMBER OF LAMPS, AND FOLLOWING DISTANCE ON REACTION TIME

2.1 Configurations of the Brake Lights

The experimental (display) car (a green 1972 Ford station wagon) was equipped with a 3 x 3 array of brake lights as shown in Figure 1. The relevant dimensions of this array are presented schematically in Figure 2. All nine lamps could be individually switched on in any combination. The 22 lamp configurations tested are listed in Table 1.

The nine lamps were aimed and visually checked for proper horizontal and vertical alignment. Red filters incorporating dispersion lenses were then inserted in the lamp housings. The lamps were then individually photometered and calibrated to each produce 100 candela at the eye point of a driver following at 50 feet. Proper lamp voltage was ensured by special electronic controls that maintained a set voltage to each individual lamp.

2.2 Route Selections and Vehicles

Two different routes were utilized, one for a short-headway (low-speed) condition, and one for a long-headway (high-speed) condition.

The short-headway run followed a seven-mile trapezoidal-shaped route on two-lane streets at the edge of a city. The traffic density was light during the noon to 5 p.m. period during which the testing was conducted. The required number of trials for each subject was obtained in approximately 2.5 loops of the route, which took 1.5 to 2 hours to complete. A speed of 25-30 mph was maintained by the lead (display) vehicle while the subject followed at approximately 25-65', as per the instructions in the Appendix (which called for 50' following distance) and the urgings of an experimenter.

Figure 1. Rear view of the display with all nine lamps illuminated.

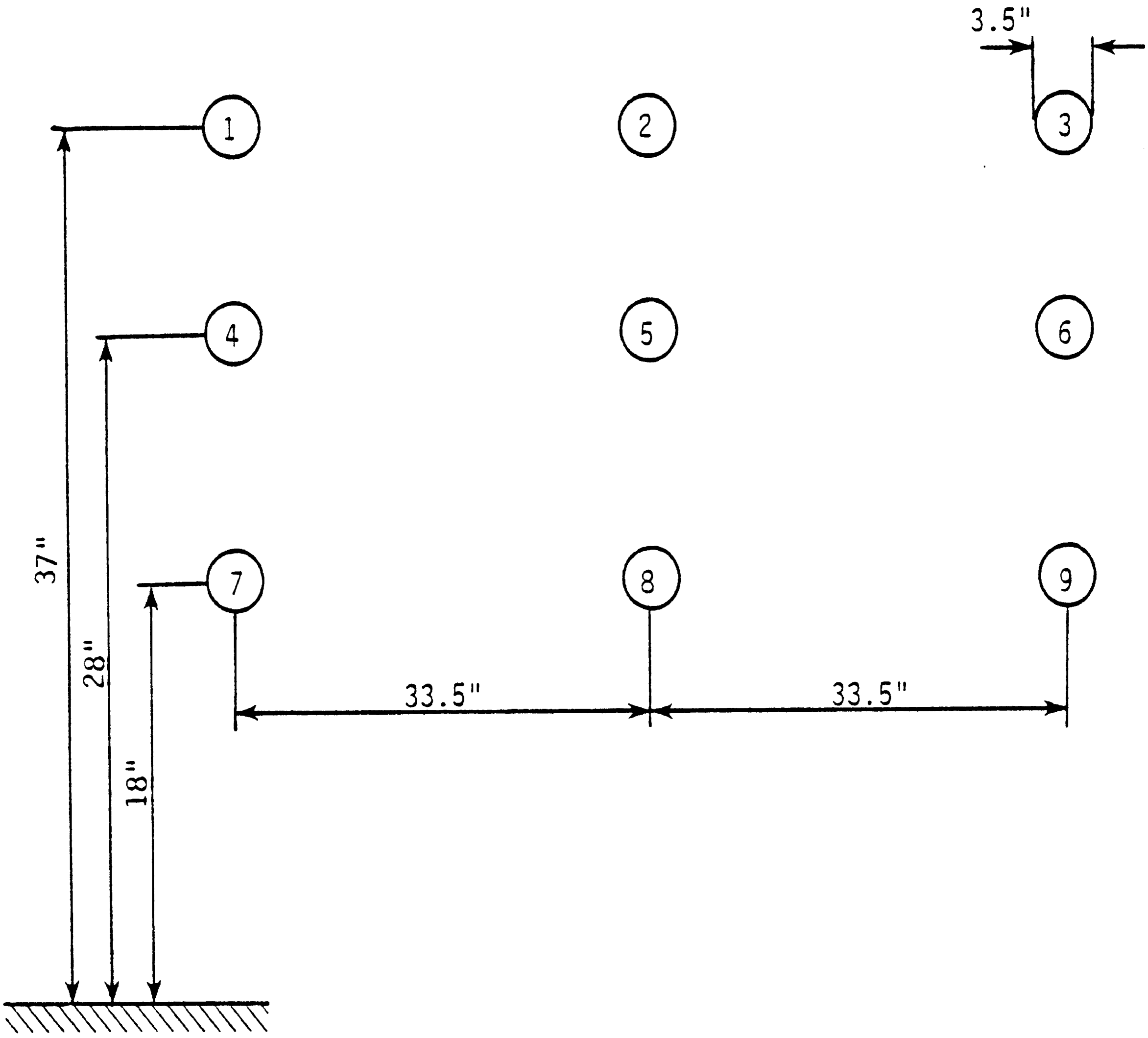

Figure 2. Schematic (not to scale) representation of the 3 x 3 array of brake lights.

TABLE 1. Experimental configurations.

Configuration Number	The Lamps Illuminated[1]	Total Number of Lamps Illuminated
1	1	1
2	2	1
3	3	1
4	4	1
5	5	1
6	6	1
7	7	1
8	8	1
9	9	1
10	1, 3	2
11	4, 6	2
12	7, 9	2
13	2, 5	2
14	2, 8	2
15	1, 2, 3	3
16	4, 5, 6	3
17	7, 8, 9	3
18	2, 7, 9	3
19	2, 4, 6	3
20	1, 3, 7, 9	4
21	1, 3, 4, 6	4
22	1-9 (All)	9

[1]The numbers refer to the lamp numbers in Figure 2.

The long-headway run covered about 2.5 loops of a 20-mile round trip route along a two-lane paved rural roadway between two cities. The traffic density was light to moderate during the noon to 5 p.m. time period during which the testing was conducted. The required number of trials for each subject was obtained in approximately 1.5 hours. A speed of 45-50 mph was maintained by the lead test vehicle. An estimated following distance of approximately 180-360' was obtained via the instructions in the Appendix (which called for 200' following distance) and the urgings of an experimenter.

Two vehicles were utilized. In addition to the 1972 Ford which was the display (lead) car, a 1971 red Plymouth was used as the following car, driven by the subject, with an experimenter operating the equipment in the back seat.

2.3 Procedure

A trial consisted of the presentation of from one to nine red signal lights followed by measurement of the subject's response time to the onset of the lights. The subject responded as soon as possible to the light(s) onset by pushing a right-hand button which was conveniently reached with the thumb while maintaining approximately a 2 o'clock hand position on the steering wheel. A similarly placed left-hand button was used by the subject to respond to all traffic signs facing toward the subject vehicle on either side of the road as soon as they were recognized. The subject then briefly described the sign (i.e., "speed limit 35 mph," "pedestrian crossing," etc.). A dash-mounted microphone and the instructions (see Appendix) made the subject feel that this loading task was actually a primary task. (Comments obtained after the study support this notion.) The loading task was devised to occupy the subject so that (s)he did not concentrate his/her attention on the test car ahead and to provide the subject with a task that forced more or less normal eye-scan behavior.

The signals on the lead car were presented by an experimenter pushing a manual switch in the back seat of the lead car. The depression of the switch supplied power for three seconds (an electronically controlled period) to all lamps that were switched on. The delay between successive trials varied from 3 to 120 seconds (with the majority between 8 and 30 seconds). The lead car did not actually brake or decelerate during any of the trials.

The 22 signal configurations were each presented five times per each subject in a randomized block of 110 trials in the short-headway runs and another randomized block of 110 trials in the long-headway runs.

At the beginning of each run the subject was read the instructions in the Appendix. Subsequently, the subject was instructed to follow the lead vehicle and maintain the proper distance. (The orders of short- and long-headway runs were counterbalanced.) Approximately three miles of practice of headway separation ensued before the test trials were started. The subject practiced on the sign-recognition and lights-response tasks during the latter 1-1/2 miles of the practice session. No responses were recorded during the practice session, although the subject was not told that these data were not being recorded or were for practice only.

In addition to the subject, three staff members were involved in the experiment. The first drove the lead (display) car. The second, seated in the back seat of the lead car, selected the configuration of lights to be presented and initiated the trial. The signal that started each trial was also telemetered to the following (subject's) car, where it turned on a digital clock. This clock was stopped by the subject's depression of the right-hand button. The third experimenter, seated in the back seat of the following (subject's) car, recorded the reaction time and reset the clock. In addition to timekeeping, this experimenter was charged with reminding the subject to maintain the proper separation and speed. This was also monitored by the experimenter in the lead car, who was in CB-radio contact with the experimenter in the following car. When the subject's car moved outside of the acceptable following-distance range, the lead experimenter would usually prompt the following experimenter to request that the subject change his headway to the proper distance.

2.4 Subjects

The subjects were recruited from various lists of subject volunteers and were paid for their participation. Out of the total of twelve subjects, eight were between 19 and 31 years of age (four males and four females) and four were between 63 and 71 years of age (two males and two females).

Prior to the actual experimental runs, the subjects were screened for their vision using Dvorine Color Plates and visual acuity tests. All subjects were color-normal with high luminance/high contrast visual acuity of 20/25 or better.

2.5 Results

On 26 trials (out of the total of 2,640 trials) there was no response to the presentation of the signal. The distribution of the missed signals is presented in Table 2. While this data show a trend for lights in the bottom row to be missed more often than in the top and middle row, the differences are not statistically significant. (For the subsequent analysis of reaction times, the 26 missed trials were replaced by the mean reaction times of the remaining trials for the given subject, configuration, and following distance.)

The grand mean reaction time was .73 seconds with a standard deviation of .37 seconds. The range was .22-4.32 seconds. (Five reaction times were longer than three seconds and 32 were between two and three seconds.) Because of the inherent skewness of reaction time data, a $\log_e$ transformation was performed on the raw data to normalize the distribution (Guilford, 1965). The means of the

TABLE 2. Distribution of the missed signals.

Configuration (the Lamps Illuminated)	Missed Trials		
	Combined	Short Headway	Long Headway
1	2	1	1
3	1	1	
4	1	1	
5	2	2	
7	1		1
8	1		1
1, 3	2	1	1
4, 6	1	1	
7, 9	3	1	2
2, 5	1	1	
1, 2, 3	1		1
4, 5, 6	1	1	
7, 8, 9	3	2	1
2, 7, 9	3	2	1
2, 4, 6	1		1
1, 3, 4, 6	2	1	1
Total	26	15	11

$\log_e$ reaction times transformed back to the reaction-time domain are shown in Table 3. (All subsequent analysis of this experiment was performed using $\log_e$ reaction-time data.)

As the first step in the statistical evaluation of the data, an analysis of variance was performed using subject, configuration, and following distance as main factors.

The analysis revealed a significant effect of all three main factors: subject, configuration, and following distance (the long following distance yielding longer reaction times): $F(11, 2112) = 127.86$, $p < .001$, $F(21, 231) = 3.46$, $p < .001$, $F(1, 11) = 14.20$, $p < .005$, respectively. Also significant was the effect of the subject x following distance interaction, $F(11, 2112) = 9.44$, $p < .001$.

Importantly, subject x configuration and distance x configuration interactions were not statistically significant: $F(231, 2112) = 1.14$, $p = .085$; $F(21, 231) < 1$, respectively. The absence of subject x configuration interaction implies that the relative effects of the 22 configurations were not statistically different across subjects. The absence of this interaction also implies that the relative effects of the 22 configurations were not statistically different for the two age groups tested or for the two sexes.

The absence of a distance x configuration interaction implies that the relative effects of the 22 configurations were not statistically different for the two following distances. This finding justifies the pooling of the data from the two following-distance routes.

The 3-way interaction (subject x distance x configuration) was also statistically not significant, $F(231, 2112) = 1.11$, $p = .13$.

The presence of a significant main effect of the configuration allowed for post-hoc comparisons of all pairs and selected groups of configurations. The Newman-Keuls range test (Hicks, 1973) revealed

TABLE 3. Mean $\log_e$ reaction times transformed back to the reaction-time domain for the 22 experimental conditions.

Configuration (the Lamps Illuminated)	Combined Reaction Time	Short-Headway Reaction Time	Long-Headway Reaction Time
4, 5, 6	.61	.55	.67
1-9	.61	.56	.67
1, 3, 4, 6	.63	.57	.69
1, 3	.63	.58	.68
7, 9	.63	.58	.67
1, 3, 7, 9	.64	.58	.71
2, 4, 6	.64	.60	.69
4, 6	.65	.62	.68
2, 8	.65	.61	.69
5	.65	.61	.69
7, 8, 9	.65	.59	.72
6	.65	.63	.67
2, 5	.65	.61	.71
2, 7, 9	.66	.60	.72
3	.67	.64	.70
1, 2, 3	.67	.63	.72
2	.68	.64	.73
9	.71	.67	.76
8	.71	.67	.76
4	.73	.70	.76
1	.73	.65	.83
7	.74	.69	.79
MEAN	.66	.62	.71

that several pairwise differences are statistically significant. The pairs that yielded statistically different $\log_e$ reaction times ($p < .05$) are listed in Table 4. As is apparent from Table 4, neither the single-high-mounted configurations ([2, 7, 9], or [2, 4, 6]) nor the dual-high-mounted configurations ([1, 3, 7, 9] or [1, 3, 4, 6]) produced shorter reaction times than the configurations approximating currently utilized low-mounted systems ([7, 9], or [4, 6]).

Multiple comparisons, using the Bonferonni confidence intervals (Morrison, 1976), provided the following results at the $p = .05$ level of statistical significance:

(1) The dual-lamp systems resulted in shorter $\log_e$ reaction times than the single-lamp systems. The mean reaction time for the dual-lamp systems (transformed back to the reaction-time domain) was .64 sec., while it was .70 sec. for the single-lamp systems. The three-, four-, or nine-lamp systems also had reaction times significantly shorter than the single-lamp systems, but they were not significantly shorter than the reaction times to the two-lamp systems.

(2) The signal-height effect was not significant: There was no difference between the systems using a lamp in the top row ([1], [2,], [3], [1, 3,], [1, 2, 3,]) and in either the middle row ([4], [5], [6], [4, 6], [4, 5, 6]) or the bottom row ([7], [8], [9], [7, 9], [7, 8, 9]). Similarly, there was no difference between the systems using the lamps in the middle vs. bottom row.

(3) Configurations using only the lamps in the left column ([1], [4], [7]) yielded statistically longer reaction times than those using only the lamps in the right column ([3], [6], [9]). The corresponding mean reaction times were .73 and .68 sec.,

TABLE 4. Pairs of configurations yielding statistically different $\log_e$ reaction times ($p < .05$).

Configuration (the Lamps Illuminated) With the Longer Reaction Time		Configuration (the Lamps Illuminated) With the Shorter Reaction Time
7	vs.	4, 5, 6
7	vs.	1-9
7	vs.	1, 3, 4, 6
7	vs.	1, 3
7	vs.	7, 9
1	vs.	4, 5, 6
1	vs.	1-9
1	vs.	1, 3, 4, 6
1	vs.	1, 3
1	vs.	7, 9
4	vs.	4, 5, 6
4	vs.	1-9
4	vs.	1, 3, 4, 6
4	vs.	1, 3,
4	vs.	7, 9
8	vs.	4, 5, 6
8	vs.	1-9
9	vs.	4, 5, 6
9	vs.	1-9

respectively. The differences between the configurations with the lamps in the left vs. middle column approached statistical significance ($p = .05$); the differences between the middle and right column were statistically not significant.

(4) The $\log_e$ reaction times of females were longer than those of the males. Similarly, the $\log_e$ reaction times of the older subjects were longer than those of the younger subjects. The corresponding times (after the transformation to the reaction-time domain) were .77 sec. for the females, .57 sec. for the males; .78 sec. for the older subjects, .61 sec. for the younger subjects.

3.0 EVALUATION OF THE EFFECTS OF SINGLE- AND DUAL-HIGH-MOUNTED BRAKE SYSTEMS ON THE REACTION TIME OF UNSUSPECTING DRIVERS

3.1 Configurations of the Brake Lights

A platinum 1979 Pontiac Grand LeMans was used to display a control and two experimental brake-light systems (see Figure 3):

- CONTROL SYSTEM - A conventional (low-mounted) configuration with one lamp on each side; each lamp serving all three functions -- presence, stop, and turn. (The original equipment on the car had one additional redundant lamp on each side, but only the outboard lamp on each side was kept operational for this experiment. Consequently, the rear-light assembly was modified by the manufacturer so that each remaining [outboard] lamp alone exceeded the FMVSS 108 standard of 80cd minimum intensity measured at H-V.)
- SINGLE-HIGH-MOUNTED SYSTEM - The control system plus an additional center lamp mounted at the top of the trunk. This supplemental lamp provided a stop signal only.
- DUAL-HIGH-MOUNTED SYSTEM - The control system plus two additional lamps mounted outboard at the top of the trunk. These supplemental lamps provided a stop signal only.

The supplemental lamps were Stimsonite HiLights (Model # 30505) manufactured by Amerace Corporation. (These lamps are identical to the Model # 3050 used by Malone et al., 1978). The dimensions of the trapezoidally-shaped lens of these lamps are 6 1/4" x 5 1/8" x 13/16" (maximum width x minimum width x height.) These lamps are designed to comply with SAE Recommended Practice J186.

Figure 3. The display car with (from top to bottom): control, single-high-mounted, and dual-high-mounted brake-lamp systems. (Note, the lamps on either side of the license plate are non-illuminated white back-up lamps.)

The supplemental lamps were originally equipped with # 1004 bulbs. However, because of the high failure rate of this bulb in the Malone et al. study, # 1142 bulbs were used throughout the present experiment. (Malone et al. also switched to these bulbs in the course of their study.)

The photometric measurements were made at the approximate eyepoint of a driver following at 50 feet and were determined with all lamps of a given system simultaneously illuminated. The two lamps of the control system produced a total of 219 cd. The single high-mounted system produced a total of 261 cd of which the supplemental high-mounted lamp contributed 42 cd. The dual high-mounted system produced a total of 304 cd of which the supplemental high-mounted lamps contributed 85 cd.

3.2 Experimental Setup, Vehicle, and Equipment

The responses to the brake-lamp systems were obtained from unsuspecting, "trapped" drivers who happened to be following behind the lead (display) car (the above-mentioned 1979 Grand LeMans) and in front of the monitoring car (a light-blue 1975 Ford Maverick). A schematic representation of the experimental setup is shown in Figure 4.

Three staff members were involved in running the experiment. The first drove the lead car and presented the signals. The second drove the monitoring car. The third staff member, seated in the back seat of the monitoring car, operated the video equipment.

Two TV cameras were used. One was pointing through the windshield of the monitoring car to record the onset of the brake lights of the "trapped" car. This camera was camouflaged from passing motorists by covering it with a cardboard box which appeared to be sitting in the front seat (see Figure 5). The second camera, housed in the back seat of the monitoring car, viewed a digital clock. This clock was started telemetrically by the initiation of the trial (i.e., by the onset of the brake-light switch in the lead car). A special-effects generator allowed a split-screen, simultaneous taping of both video recordings.

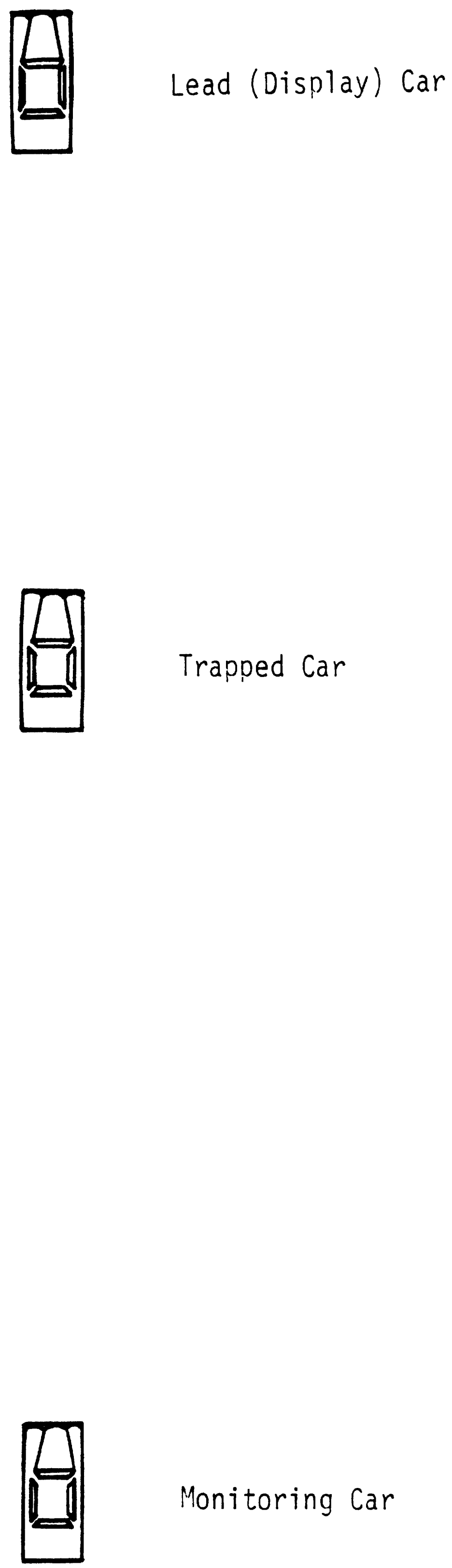

Figure 4. Diagram of a typical situation during a signal presentation.

Figure 5. The monitoring car with the camouflaged camera in the front seat.

3.3 Route Selection and Environmental Conditions

The data were collected on a multi-lane roadway with two lanes per direction and a center turn lane throughout most of the utilized portion. This roadway has a speed limit of 45 mph with sections of 35 mph; the actual traffic speed was 30-50 mph. All trials were presented at speeds of 30-45 mph.

The experiment was performed between 1:15 p.m. and 4:45 p.m. on clear sunny days. (One day's data were collected on a cloudy day. The data from this day did not differ from those for the same brake-light system obtained on sunny days and therefore were included in the analysis.)

3.4 Procedure

On each trial, the lead car adjusted its speed and/or lane position to achieve a headway of three (± two) car lengths in front of an unsuspecting driver. Care was taken to create car-following situations without unduly drawing the attention of the unsuspecting motorist to the test vehicle. This included not intruding more quickly into the clear headway ahead of a motorist than was common behavior for other drivers. Normally, this meant that the lead-vehicle driver positioned himself in the lane ahead of an approaching vehicle by making a smooth lane change when the motorist got within 5-10 car lengths of the lead test car. In so doing, the experimenter was generally able to match his speed to that of the car approaching from the rear when about 3-5 car lengths separated the vehicles. He continued to gradually modulate his speed without braking to obtain a headway of about 3 car lengths. This gradual lane intrusion and speed modulation usually allowed the lead vehicle to obtain the proper position without alarming the unsuspecting driver or presenting him with the brake signal before the actual timed trial. Simultaneously, the monitoring car proceeded to get into position to record the trapped vehicle on a video screen. This was done by approaching it from the rear until a headway of approximately three to eight car lengths was obtained.

When the monitoring vehicle was in position for data collection, the experimenter in that vehicle checked to ensure that the speed was between 30 and 45 mph and that the spacing between the lead and trapped car appeared to be within five car lengths. He then started a video tape recorder and informed the experimenter in the lead car (via CB radio) that the conditions were right for a trial. The experimenter in the lead car, after double-checking the situation in the rear-view mirror, initiated a trial via a switch which both turned on the brake-light configuration being tested (without actually braking or decelerating), and started the clock in the monitoring car. The trapped driver's response was videotaped for slightly more than three seconds after the onset of a brake signal by the lead car, and then the trial was terminated. The experimenter aimed at a four-second brake-signal presentation; it was estimated that the actual durations were between three and five seconds.

A major concern was to operate the lead and monitoring car legally and safely, and not to create a stressful situation for the trapped driver.

3.5 Data Reduction

Two aspects of the response of the trapped driver to the onset of the lead car's brake signal were of interest: (1) Whether the trapped driver applied his brakes, and (2) if so, the reaction time between signal initiation and the brake response.

The data were reduced by examining the split-screen video tape containing the digital time elapsed from the onset of the lead car's brake signal, as well as the picture of the rear of the trapped car. The time of the first detectable onset of the brake lights of the trapped car was taken to be the reaction-time. With a single-frame playback, the accuracy of the reaction-time measure was approximately .03 sec.

Only trials meeting the following criteria were included in the analysis:

(1) The trapped car was not laterally displaced more than 1/2 of a car width in relation to the lead car. (Generally, the lateral displacement was within 1/4 of a car width.)

(2) The trapped vehicle did not appear to have braked in response to vehicles ahead or adjacent to the lead car, changes in the roadway configuration, or a traffic-control device. Responses to vehicles ahead of or adjacent to the lead vehicle were assumed to have occurred when a braking response occurred after initiation of vehicle control maneuvers (e.g., braking or lane changing) by nearby vehicles. Braking responses to changes in roadway configuration were assumed to have occurred when a braking response continued until a turning maneuver or negotiation of a curve was executed. Responses to a traffic-control device were assumed to have occurred when the trapped vehicle braked while approaching a red light or other traffic-control device.

(3) One or more brake lights on both sides of the trapped car were illuminated, or one light was illuminated and was subsequently observed to function as the only operational brake light. (Occasionally, the trapped car displayed only one brake light, or brake lights only on one side of the vehicle, or very dimly illuminated brake lights, or no operating brake lights at all. In such a case, the car was observed subsequent to the trial presentation to investigate the operation of the brake lights. Such observations determined whether the responses seen during the brake-light presentation were the same as upon subsequent deceleration or stopping. If no brake lights were seen during the trial presentation and during subsequent deceleration or stopping, the presentation was not counted as a trial.)

(4) The trial was the first timed signal presentation for each trapped driver.

3.6 Results

Table 5 presents the results for each system, including the two primary measures of interest: percent of trial presentations responded to, and the reaction time. (Only an onset of brake lights with a delay of 3 sec. or less was considered to be a response to a signal presentation.)

The response rate for the single and dual high-mounted systems (54.8%, and 53.2%, respectively) were approximately 72% higher than the response rate to the control system (31.4%). The Pearson test of association (Hays, 1963) indicates that the probability of responding to a signal was significantly affected by the addition of high-mounted brake light(s), (X^2 [2] = 36.4, $p < .001$).

The mean reaction times for the control, single-, and dual-high-mounted systems were 1.38 sec., 1.39 sec., and 1.30 sec., respectively. Analyses of variance indicate that the differences between the systems were not significant (F [2, 339] < 1), whether using the raw or the $\log_e$ transformed data.

TABLE 5. Response rates and reaction times to the control and experimental brake-light systems.

System	Number of Trials	Number of Trials Responded to	Percentage of Trials Responded to	Mean Reaction Time	Standard Deviation of the Reaction Time
CONTROL	277	87	31.4	1.38	.56
SINGLE-HIGH-MOUNTED	281	154	54.8	1.39	.52
DUAL-HIGH-MOUNTED	190	101	53.2	1.30	.46

4.0 SUMMARY, DISCUSSION, AND CONCLUSIONS

The first experiment investigated reaction times of informed drivers to 22 configurations of signals drawn from a 3 x 3 array of rear lamps. The results indicate the following:

- Neither the system with single-high-mounted or dual-high-mounted supplemental lamps produced shorter reaction times than did the systems representing currently utilized low-mounted lamps.
- While the two-lamp configurations yielded shorter reaction times than did the one-lamp configurations, additional lamps (beyond two) did not further reduce the reaction times.
- The signal-height effect was not significant: There was no significant difference in reaction times between configurations consisting exclusively of lamps in the top, middle, or bottom rows of the lamp array.
- The lateral position of lamps did have a significant effect: The reaction times to the single-lamp configurations using lamps only in the right column produced shorter reaction times than did the configurations using lamps only in the left column. This result suggests that reaction time may be a function of the distance of a brake lamp from the mean eye-fixation location of drivers during car-following, which Mourant and Rockwell (1970) have shown to be above the right road edge marker and slightly higher than the horizon.
- The reaction times of the male subjects were significantly shorter than those of the female subjects. This finding is in agreement with most of the previous studies (e.g., Teichner, 1954).

- The reaction times of the younger subjects (19 to 31 years of age) were significantly shorter than those of the older subjects (63 to 71 years of age). This result is consistent with previous research (e.g., Welford, 1977).

- The reaction times for the shorter following distance (50') were faster than those for the longer following distance (200'). The following distance, however, was confounded with speed (the trials using the shorter following distance were run at slower speeds). Therefore this effect could be due to the following distance and/or the speed difference between the two conditions.

The second experiment evaluated the responses of unsuspecting drivers to brake-signal presentations using three systems: (1) control system with conventional brake lamps, (2) control system plus one supplemental high-mounted brake lamp, and (3) control system plus two supplemental high-mounted brake lamps. The results from this experiment indicate the following:

- The response rates to the single- and dual-high-mounted systems were 72% above those to the control system. This difference is both statistically and practically significant, and is consistent with the data obtained by Allen Corporation (1978). However, Allen Corp. found much higher response rates than the present study, i.e., 65% and 84% for the control and single-high-mounted system, respectively. The corresponding response rates in the present study are 31% and 55%. This difference could be due to the different ambient conditions in the two studies. The present study was run exclusively during the daytime. On the other hand, in the Allen Corp. study a substantial proportion of the trials was apparently run during the hours of dusk and/or darkness, since the study was performed between 4 p.m. and 10 p.m. Also, traffic density and roadway type were shown by Allen Corp. (1978) to affect response rates. There may have been a substantial difference between the traffic conditions in the two studies under consideration which would have influenced the response rates.

- The obtained reaction times to brake signals did not differ statistically across the three systems tested. (The mean reaction times were 1.38, 1.39, and 1.30 sec. for the control, single-high-mounted, and dual-high-mounted system, respectively.) The (statistically nonsignificant) difference between the mean reaction times to the control and dual-high-mounted system (4%) is compatible with that obtained by Schmidt-Clausen (1977) with alerted drivers (3%). On the other hand, Allen Corp. (1978) found a substantial and statistically significant difference between the reaction times to the control and single-high-mounted system (1.45 and 1.10 sec., respectively). The discrepancy between these data and the data from the present study might be due to the different ambient light and/or traffic conditions in the two studies.

The present results imply that the finding of a reduction in rear-end collisions of taxicabs equipped with a supplemental single-high-mounted brake lamp (Malone et al., 1978) might not be due to a reduction in the reaction times of the following drivers to the brake signals. This conclusion is based on the absence of any significant reduction in reaction time using either informed or unsuspecting drivers.

On the other hand, the present data suggest that the obtained reduction in the rear-end collisions might be due to the higher probability of a brake response within the first few seconds after presentation of a brake signal by a high-mounted system. This conjecture, however, leaves unexplained the discrepancy in performance of the dual-high-mounted system in this and in Malone et al. (1978) study. Malone et al. found no benefit in the dual-high-mounted system in terms of rear-end accident rates; the present study found a significant increase in the brake-response rate to this system. The two studies differ in that the present study evaluated a single-function supplemental lamp(s), whereas the lamps used by Malone et al. (in the dual-high-mounted system) functioned as both brake and turn lamps. Also, the present study used the same vehicle to display all systems tested, while Malone et al. used numerous vehicle models. The influence that these factors might have had on the results of the two studies is unknown.

It is important to point out that by measuring only brake applications, the present study monitored only one of the possible reactions to the onset of brake lights on a car ahead. Other reactions (e.g., taking the foot off the accelerator but not applying the brakes, changing lanes, etc.) were not measured and need to be evaluated in future studies to more fully understand the effects of brake-light systems on driver behavior. An additional aspect that deserves future research is the degree of the novelty effect. This could be evaluated by monitoring driver responses to repeated presentations of brake signals. Finally, the effect of the absence of actual deceleration during signal presentations on the obtained results should also be empirically assessed.

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APPENDIX

SUBJECT'S INSTRUCTIONS
(First Experiment)

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(First route instructions)

This study deals with drivers' ability to recognize traffic signs and to detect various configurations of lights. You will be driving on two separate routes. On the first one, you should follow our green station wagon at a distance of about 3 (12) car lengths (approximately 50 [200] ft). The speed of the green station wagon as well as your speed should be about 25-30 (50) mph. You will make several loops around a test route. The entire course will take about 2 hours to complete. You may take one or more breaks, as desired. The procedure for the second route will be explained later.

In addition to following our green station wagon at the prescribed distance and speed, you will be doing two additional tasks. The first task involves responding to all traffic signs (e.g., NO PASSING zone) as soon as you recognize them by pressing the left hand button and by naming the sign. All traffic signs are included with the exception of NO PARKING and street name signs. Pay attention to signs on both sides of the road as long as they are facing you. Some poles might have more than one sign; please respond to each sign which meets our criteria (i.e., all but NO PARKING and street name signs). Are there any questions about the use of the left hand button?

The second task consists of responding to the red lights on the rear of the green station wagon as soon as they light up. These lights will be presented in various combinations; please respond regardless of the number or pattern of the lights. As soon as you detect a light (lights), press the right hand button. Are there any questions about the use of the right hand button?

There will be an experimenter with you in the car sitting in the back seat writing and pushing buttons to control the equipment related to the red lights. Your responses to the lights and traffic signs are recorded automatically.

Please do both tasks alertly, accurately, and as quickly as you can. Note, however, that you are operating a car on public roads and you are responsible for driving it in a safe and responsible manner, as this car does not have a dual braking system. Furthermore, the lead car (the green station wagon) has no working brake lights. Whenever its' driver steps on the brakes, no lights would light up. Therefore the only way for you to note that it is actually braking is to observe that it is slowing down or that you are getting closer to it. While we do not expect that the traffic situation will force the green station wagon to decelerate rapidly, you should keep in mind the lack of actual brake lights.

If at any time you have any problems or questions, please report them to the experimenter. If you feel unsafe or wish to quit the study at any time, you may do so.

Do you have any questions?

(Second route instructions)

Your tasks on this second route are the same as on the first one except the following: You should follow our green station wagon at a distance of about 12 (3) car lenghts which is approximately 200 (50) ft. The speed of the green station wagon as well as your speed should be about 50 (25-30) mph.

Do you have any questions?