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HIGH-MOUNTED BRAKE LIGHTS AND THE BEHAVIOR OF FOLLOWING DRIVERS

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16. Abstract This daytime study evaluated in-traffic responses of unsuspecting drivers to supplemental, high-mounted brake lights using two different test vehicles (compact and full size) and two different test routes (suburban and urban). The supplemental lamps were mounted just below the rear window or at roof level. Measures were taken of brake-response and vehicle speed-change frequencies, and of the corresponding reaction times. (The speed changes were measured by radar.) The following main results were obtained:

The frequency of brake responses and of speed changes did not differ statistically among the systems tested in either of the test vehicle/test route combinations.

Brake-reaction times did not vary among the systems tested for any of the test vehicle/test route combinations. Speed-change reaction times also did not vary among the systems tested for any of the test vehicle/test route combinations with the exception of the compact vehicle/urban route combination: Here, a system with a single, supplemental lamp, center-mounted just below the rear window, was associated with statistically shorter reaction times than the control system.

The relation of the present findings to previous behavioral and accident studies of the efficacy of high-mounted brake lights is discussed.

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INTRODUCTION

Recent research evidence (e.g., Malone et al., 1978; Sivak et al., 1979; Reilly et al., 1980; Rausch et al., 1981) suggests that under particular circumstances there might be some benefit in supplementing the conventional rear lighting systems with high-mounted brake lamp(s). The aim of the present investigation was to gather additional information about drivers' responses to brake signals presented by high-mounted brake lights and about combinations of circumstances under which any differences in the behavior of following drivers are observed.

This report documents three experiments investigating in-traffic responses of unsuspecting drivers to brake signals presented by various brake-light systems on three different test cars and two different test routes. The primary measures were the frequency with which following drivers responded to brake signals either by applying the brakes or by slowing down, and the delays of these responses.

EXPERIMENT 1

Experimental Setup

The responses to the brake lamp systems were obtained from unsuspecting "subject" drivers who at the time of the trial were following behind the test car and in front of the monitoring car. A schematic representation of the experimental setup is shown in Figure 1.

Three staff members were involved in running the experiment. The first drove the test 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 an event recorder and noted information about the subject and the subject's vehicle.

A Doppler radar antenna was mounted at the center of the front bumper on the monitoring car (Figure 2). The radar system monitored changes in the speed of the subject vehicle, relative to that of the monitoring car by generating a trace on one track of the event-recorder tape. The telemetered input from the test car produced a pulse on a second track of the tape, marking the start and end of the test car's brake signal. A data sample, showing the two traces, is presented in Figure 3.

Test Vehicles

Two test vehicles were used: a brown 1980 AMC Spirit (a compact car) and a brown 1980 GM Toronado (a full-size car).

Brake Light Configurations

The following three brake-light systems were tested on each of the two test cars (photographs of each are in Figures 4 and 5):

Control system. A conventionally mounted configuration with one lamp on each side; each lamp serving all three functions--presence, stop, and turn. The original equipment on both test cars had one additional redundant lamp on each side. On the GM Toronado both the outboard and inboard lamps were used unmodified. On the AMC Spirit, only the outboard lamp on each side was kept operational for this experiment. Consequently, the rear-light assembly of the AMC Spirit was

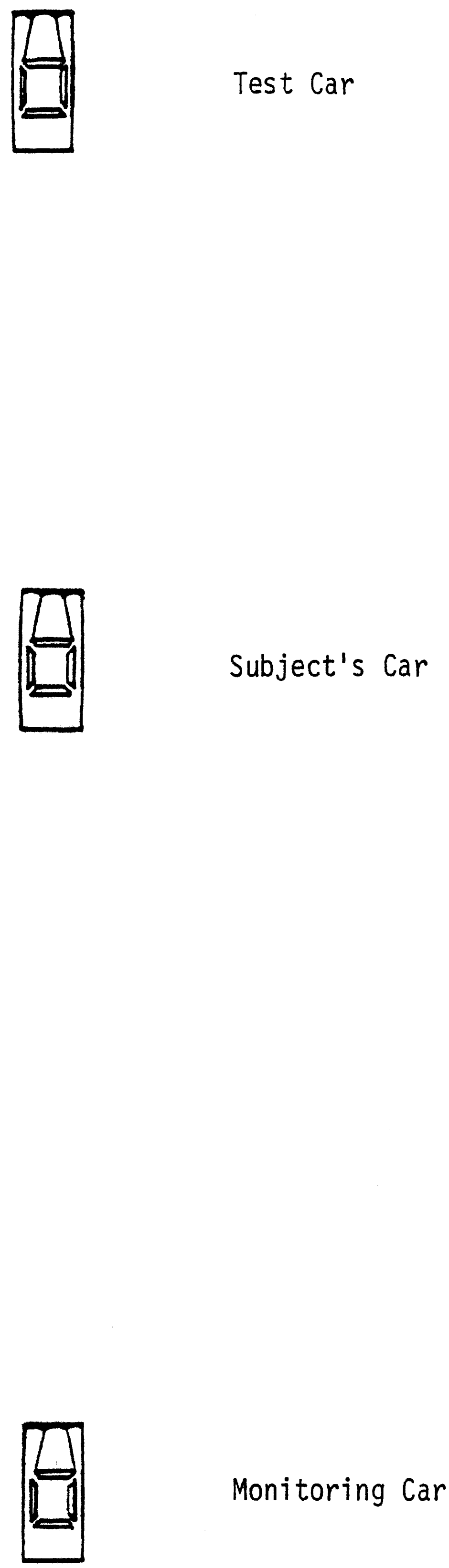

Figure 1. Schematic of the vehicle arrangement during a signal presentation.

Figure 2. Monitoring car with the radar antenna on the front bumper.

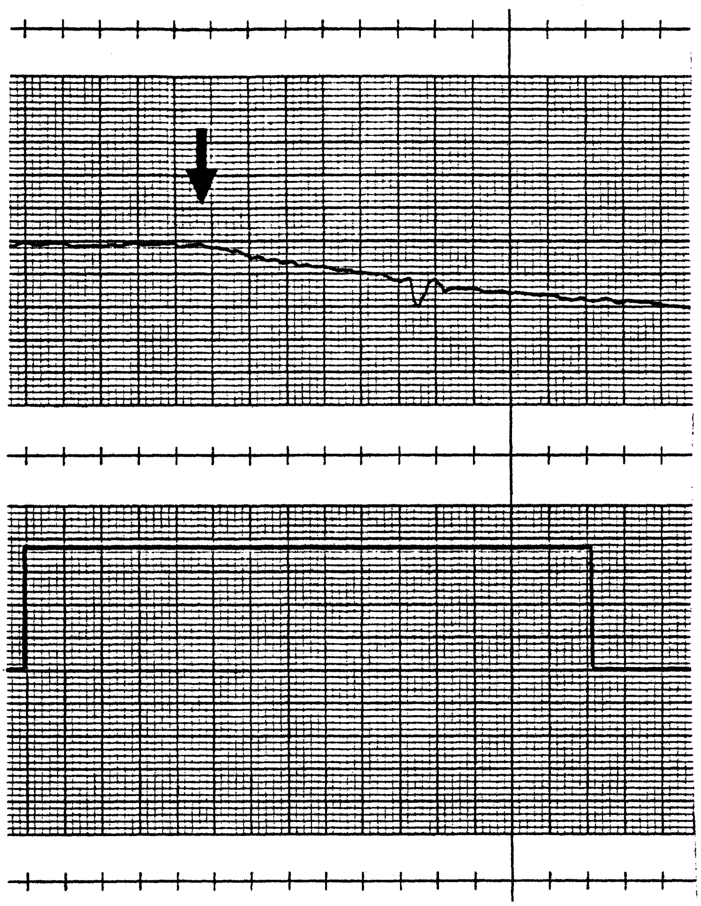

Figure 3. A data sample showing a reaction time of 0.96 s. The top trace indicates the relative speed of the subject's vehicle in relation to the monitoring vehicle. (The smallest vertical division is equal to approximately 0.2 miles/hour. Time increases from left to right; the smallest horizontal division is equal to 0.04 s.) The bottom trace indicates the onset and offset of the brake signal on the lead car. In this example, a change in the speed (see the arrow) occurred 0.96 s after the onset of the signal.

Figure 4. The AMC Spirit test car with: (from top to bottom) control, single-high-mounted, and dual-high-mounted system.

Figure 5. The GM Toronado test car with: (from top to bottom) control, single-high-mounted, and dual-high-mounted system.

modified by the manufacturer so that each remaining (outboard) lamp alone exceeded the minimum requirements of the FMVSS 108 standard.

Single-high-mounted system. The control system, plus an additional lamp mounted just under the rear window at the center of the lowermost portion of the hatchback lid on the AMC Spirit and at the top of the trunk just behind the window on the GM Toronado. The supplemental lamp provided a stop signal only.

Dual-high-mounted system. The control system, plus two additional lamps mounted outboard just under the rear window on the lowermost portion of the hatchback lid on the AMC Spirit and at the top of the trunk just behind the window on the GM Toronado. The supplemental lamps provided a stop signal only.

The supplemental lamps were Stimsonite HiLites (Model # 30505) manufactured by Amerace Corporation. (These lamps were used by Sivak et al., 1979, and they are identical to the Model # 3050 used by Malone et al. 1978, Reilly et al., 1980, and Rausch et al., 1981). The dimensions of the trapezoidally-shaped lens of these lamps are 16 cm x 13 cm x 2 cm (maximum width x minimum width x height).

The photometric measurements were made at the approximate eyepoint of a driver following at 15 m. These measurements indicated that each of the supplemental high-mounted lamps produced approximately 42 cd.

The supplemental lamps were manufacturer-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. [1978] also switched to these bulbs in the course of their study, and Reilly et al. [1980] and Sivak et al. [1979] used these bulbs exclusively.)

Routes

The data were collected on the following two routes:

Suburban route. A multilane roadway with two lanes in each direction and a center turn lane throughout most of the utilized portion. The roadway has a speed limit of 72 km/h with sections of 56 km/h; the actual traffic speed was 48-80 km/h. Traffic counts performed in 1978 on 13 locations along the test route varied from approximately 20,500 to 41,400 vehicles for a 24-hour period. All trials were presented at speeds of 56-72 km/h.

Urban route. A multilane roadway with two lanes per direction throughout most of the utilized portion. This route has a speed limit of 40 km/h with a small stretch of 56km/h; the actual traffic speed was 32-56 km/h. A traffic count performed in 1978 on one location along the route showed 34,500 vehicles for a 24-hour period. All trials were presented at speeds of 32-40 km/h.

Procedure

Suburban route. On each trial, the test car adjusted its speed and/or lane position to achieve a headway of 3-5 car lengths in front of an unsuspecting driver. Care was taken not to draw the attention of the unsuspecting motorist to the test vehicle. This included not intruding more quickly into the lane ahead of a motorist than was common behavior for other drivers. Normally, this meant that the test-vehicle driver positioned himself in the lane ahead of an approaching vehicle by making a smooth lane change when the subject was within 5-10 car lengths of the 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 allowed the test vehicle to obtain the proper position without alarming the unsuspecting driver or presenting him/her with a brake signal before the actual trial. Simultaneously, the monitoring car moved into a position that placed the subject vehicle within the radar beam. This was done by approaching the subject's vehicle from the rear until a headway of approximately three to six car lengths was obtained. Ensuring that the speed of the monitoring car was between 56 and 72 km/h, the cruise control mechanism on the monitoring car was set. This precaution was taken to assure that the changes in speed recorded by the radar system were those of the subject's vehicle and not of the monitoring car.

The event recorder was then turned on, and when the trace on the radar-system track was sufficiently noise free, the experimenter checked to ensure that the spacing between the test and subject car appeared to be within five car lengths and informed the experimenter in the test car (via radio) that the conditions were right for a trial. The experimenter in the test car, after double-checking the situation in his 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 generated a pulse on one track of the event recorder tape for the duration of the brake signal presentation. The brake signal was presented for 3 seconds, the duration controlled by an electronic timer.

An additional task of the experimenter in the back seat of the monitoring car was to record whether during the 3-second brake-signal presentation the subject's brake lights became illuminated, and whether the subject changed lanes in response to the brake signal. He also recorded the subject's age (young, middle-aged, old), sex, height (short, medium, tall), and the size of the subject's vehicle (small, medium, large, pickup truck/van). If subject's age, sex, or height could not be clearly ascertained, the experimenter in the test car was asked for assistance via radio.

Only one trial was given to each subject. Two precautions were taken to ensure that the subject was shown the illuminated supplemental lamps (combined with the conventional lamps) for the first time when a trial was presented. First, during actual braking by the test car in traffic, only the conventional lamps were illuminated. Second, when running the high-mounted conditions, drivers who stopped immediately behind the test car in traffic (due to traffic signal, etc.) and so potentially observed the unlit supplemental lamps, were not used as subjects.

The data were collected between 9:00 and 11:30 a.m. and between 1:30 and 4:00 p.m. on days with no precipitation. A major concern was to operate the test and monitoring cars legally and safely, and not to create a stressful situation for the subject driver or other motorists.

Urban route. The procedure was identical to that on the suburban route except for the following: The separation between the test car and a subject car at the time of the trial was 1-2 car lengths at a speed of

32-40 km/h. Since these speeds are below the minimum speed at which the cruise control mechanism on the monitoring car functions properly (approximately 48 km/h), the cruise control was not used. (The driver of the monitoring car made a special effort to keep the vehicle at a constant speed during the trial interval. The experimenter in the rear seat of the monitoring car double-checked the speedometer to ensure that the vehicle was travelling at a fixed speed, somewhere between 32 and 40 km/h.)

Data Analysis

Two aspects of the response of the subject to the onset of the test car's brake signal were of interest: (1) Did the subject respond by either applying the brakes or simply decelerating, and (2) if so, what was the reaction time between signal onset and the braking or speed-change response?

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

1. The subject vehicle did not appear to have braked or decelerated in response to vehicles ahead of or adjacent to the test car, changes in roadway configuration or a traffic control device, or in preparation for turning off the roadway. Responses to vehicles ahead of or adjacent to the test vehicle were assumed to have occurred when a braking or deceleration response occurred after initiation of vehicle control maneuvers (e.g., braking or lane changing) by nearby vehicles. Responses to changes in roadway configuration were assumed to have occurred when a braking or deceleration response continued until negotiation of a curve was executed. Responses to a traffic control device were assumed to have occurred when the subject vehicle braked or decelerated while approaching a red light or other traffic control device. Responses related to preparation of the subject vehicle to turn off the roadway were assumed to have occurred when a braking or deceleration response continued until the beginning of a turning maneuver (as indicated by turn signals or actual turning).

2. The monitoring car did not brake during the 3-second presentation of the test car's brake signal.

3. The roadway was generally flat.

4. The subject vehicle was a passenger car, pickup truck, or van. No passenger vehicles with a trailer attached or commercial vehicles were used.

5. The trial was the first and only signal presentation for each subject driver.

Results

Table 1 presents, for each brake-light system tested, the number of trials in which the subjects responded by speed change (both with and without braking) to the brake signal on the test car, as well as the corresponding mean reaction times. (In all present experiments, only a speed change with a delay of 3 s or less was considered to be a response to a signal presentation.)

Table 1

Types of responses, their frequencies, and the corresponding mean reaction times in seconds. (Summed across both test vehicles and both routes.)

Brake-Light System	Number of Trials	Trials Responded to by a Speed Change					
		With Braking		Without Braking		Total	
		Number	Reaction Time	Number	Reaction Time	Number	Reaction Time
Control	424	62*	1.28	251	1.24	313*	1.23
Single-High-Mounted	424	65*	1.10	247	1.17	312*	1.16
Dual-High-Mounted	424	68*	1.16	242	1.25	310*	1.23

* On 15 trials (two with the control system, ten with the single-high-mounted system, and three with the dual-high-mounted system) there was a brake response, but no discernible speed change.

The Pearson test of association (Hays, 1963) indicates that the probability of responding to a signal (whether by braking or otherwise) did not differ among the systems tested. Similarly, analyses of variance indicate that there were no statistically significant differences in the corresponding reaction times. (Throughout this report the statistically significant level was set at $p < 0.05$.) The distributions of the reaction times of all responses to the three brake-light systems are shown in Table 2.

Tables 3 and 4 present cross-tabulation according to the brake-light system, subject's age, sex, height, and car size, and whether the subject changed lanes in response to the brake signal. The results of analyses of variance indicate that none of these variables produced statistically significant interactions with the reaction times to the three different brake-light systems.

The mean reaction-time data (summed across all three brake-light systems) are presented in Table 5. While these data show several trends, analyses of variance revealed none of these to be statistically significant.

All of the above analyses were performed on the data summed across both test cars and both test routes. Tables 6-9 present the principal results for each test car/test route combinations. The Pearson test of association indicates that the number of responses did not vary among the three brake-light systems for any of the test car/test route subdata. Similarly, analyses of variance and t-tests for contrasts indicate that none of the differences in the reaction times were statistically significant, with the exception of the AMC Spirit/urban route combination. The t tests for contrasts indicate that for this combination both the speed-change responses without braking and the total set of speed-change responses to the control system were statistically longer than those to the single-high-mounted system or to the combined group of the single-high-mounted and dual-high-mounted system. Interestingly, these differences were present only in the data collected during mornings and not in the data collected during afternoons. (Differences in the morning and afternoon traffic, which might have contributed to this finding, are discussed below.)

Table 2

Reaction-time distributions of all responses for each brake-light system. (Summed across both test vehicles and both routes.)

Interval Midpoint (s)	Frequency*			
	Control System	Single-High-Mounted System	Dual-High-Mounted System	Total
0.1	0	0	0	0
0.3	7	23	15	45
0.5	35	38	31	104
0.7	48	44	34	126
0.9	43	37	46	126
1.1	36	34	41	111
1.3	31	25	30	86
1.5	28	12	28	68
1.7	21	14	26	61
1.8	12	15	12	39
2.1	17	8	11	36
2.3	14	12	12	38
2.5	8	7	10	25
2.7	11	1	6	18
2.9	0	0	5	5
Mean	1.23	1.16	1.23	1.21
S.D.	0.62	0.64	0.63	0.63

* On 15 trials (two with the control system, ten with the single-high mounted system, and three with the dual-high-mounted system) there was a brake response, but no discernible speed change.

Table 3

Mean reaction times for each brake-light system according to the subject's age, sex, and height. The numbers in parentheses are the corresponding frequencies. (Summed across both test vehicles and both routes.)

Brake-Light System	Subject's Age			Subjects's Sex		Subject's Height		
	Young	Middle-Aged	Old	Male	Female	Short	Medium	Tall
Control	1.30 (124)	1.20 (157)	1.13 (30)	1.20 (199)	1.28 (112)	1.21 (33)	1.24 (169)	1.23 (109)
Single-High-Mounted	1.16 (101)	1.17 (177)	1.10 (24)	1.16 (192)	1.16 (110)	1.17 (23)	1.14 (171)	1.19 (108)
Dual-High-Mounted	1.23 (135)	1.21 (144)	1.39 (28)	1.21 (190)	1.27 (117)	1.19 (33)	1.25 (169)	1.23 (105)

Table 4

Mean reaction times for each brake-light system according to the subject's car size, and the presence/absence of a lane change as a part of the response. The numbers in parentheses are the corresponding frequencies. (Summed across both test vehicles and both routes.)

Brake-Light System	Subjects's Car Size				Lane Change	
	Small	Medium	Large	Pickup/ Van	Yes	No
Control	1.20 (46)	1.29 (102)	1.17 (110)	1.28 (53)	1.20 (11)	1.23 (300)
Single-High-Mounted	0.94 (34)	1.20 (82)	1.17 (123)	1.20 (63)	1.09 (13)	1.16 (289)
Dual-High-Mounted	1.28 (37)	1.18 (107)	1.23 (110)	1.31 (53)	1.03 (9)	1.24 (298)

Table 5

Mean reaction times according to the subject's age, sex, height, and car size, and presence/absence of a lane change. The numbers in parentheses are the corresponding frequencies. (Summed across all three brake-light systems, both test vehicles, and both routes.)

Category		Mean Reaction Time
Subject's Age	Young	1.23 (360)
	Middle-Aged	1.19 (478)
	Old	1.21 (82)
Subject's Sex	Male	1.19 (581)
	Female	1.24 (339)
Subject's Height	Short	1.19 (89)
	Medium	1.21 (509)
	Tall	1.21 (322)
Subject's Car Size	Small	1.15 (117)
	Medium	1.22 (291)
	Large	1.19 (343)
	Pickup/van	1.26 (169)
Lane Change	Yes	1.11 (33)
	No	1.21 (887)

Table 6

Types of responses, their frequencies, and the corresponding mean reaction times in seconds. (Vehicle: AMC Spirit; route: Suburban.)

Brake-Light System	Number of Trials	Trials Responded to by a Speed Change					
		With Braking		Without Braking		Total	
		Number	Reaction Time	Number	Reaction Time	Number	Reaction Time
Control	106	14	1.04	60	1.25	74	1.21
Single-High-Mounted	106	16*	1.04	56	1.17	72*	1.14
Dual-High-Mounted	106	14	1.14	65	1.29	79	1.26

* On two trials with the single-high-mounted system there was a brake response, but no discernible speed change.

Table 7

Types of responses, their frequencies, and the corresponding mean reaction times in seconds. (Vehicle: AMC Spirit; route: Urban.)

Brake-Light System	Number of Trials	Trials Responded to by a Speed Change					
		With Braking		Without Braking		Total	
		Number	Reaction Time	Number	Reaction Time	Number	Reaction Time
Control	106	17*	1.22	62	1.36	79*	1.33
Single-High-Mounted	106	22*	1.27	58	1.06	80*	1.11
Dual-High-Mounted	106	29*	1.18	50	1.19	79*	1.19

* On six trials (one with the control system, four with the single-high-mounted system, and one with the dual-high-mounted system) there was a brake response, but no discernible speed change.

Table 8

Types of responses, their frequencies, and the corresponding mean reaction times in seconds. (Vehicle: GM Toronado; route: Suburban.)

Brake-Light System	Number of Trials	Trials Responded to by a Speed Change					
		With Braking		Without Braking		Total	
		Number	Reaction Time	Number	Reaction Time	Number	Reaction Time
Control	106	10	1.32	68	1.19	78	1.21
Single-High-Mounted	106	15*	1.07	68	1.25	83*	1.22
Dual-High-Mounted	106	12	0.98	63	1.24	75	1.20

* On one trial with the single-high-mounted system there was a brake response, but no discernible speed change.

Table 9

Types of responses, their frequencies, and the corresponding mean reaction times in seconds. (Vehicle: GM Toronado; route: Urban.)

Brake-Light System	Number of Trials	Trials Responded to by a Speed Change					
		With Braking		Without Braking		Total	
		Number	Reaction Time	Number	Reaction Time	Number	Reaction Time
Control	106	21*	1.25	61	1.16	82*	1.18
Single-High-Mounted	106	12*	0.88	65	1.21	77*	1.17
Dual-High-Mounted	106	13*	1.32	64	1.28	77*	1.29

* On six trials (one with the control system, three with the single-high-mounted system, and two with the dual-high-mounted system) there was a brake response, but no discernible speed change.

EXPERIMENT 2

This experiment evaluated the effects of roof-mounted brake lights on the response frequency and response delay of following drivers.

Experimental Setup

Identical to the procedure in Experiment 1.

Test Vehicle

The 1980 AMC Spirit from Experiment 1 was used.

Brake Light Configurations

The following two systems were tested (photographs of each are in Figure 6):

Single-roof-mounted system. The control system (see Experiment 1), plus an additional center lamp mounted on the uppermost portion of the hatchback lid. This supplemental lamp provided a stop signal only.

Dual-roof-mounted system. The control system, plus two additional lamps mounted outboard on the uppermost portion of the hatchback lid. These supplemental lamps provided a stop signal only.

Route

The data were collected on the suburban route used in Experiment 1.

Procedure

Identical to the procedure for the suburban route in Experiment 1.

Data Analysis

Identical to the data analysis in Experiment 1.

Results

Table 10 presents, for each system tested, the number of trials in which the subjects responded by speed change (both with and without braking) to the brake signal on the test car, as well as the corresponding mean reaction times. (For comparison, the results for the two roof-mounted systems are presented together with the results for the control and the two high-mounted systems tested by using the same car and the same route in Experiment 1.) The Pearson test of association

Figure 6. The AMC Spirit test car with single-roof-mounted system (top) and dual-roof-mounted system (bottom).

indicates that the probability of responding to a signal (whether by braking or otherwise) did not differ among the systems tested. Similarly, analyses of variance indicate that there were no statistically significant differences in the corresponding reaction times.

Table 10

Types of responses, their frequencies, and the corresponding mean reaction times in seconds. (Vehicle: AMC Spirit; route: Suburban.)

Brake-Light System	Number of Trials	Trials Responded to by a Speed Change: With Braking		Without Braking		Total	
		Number	Reaction Time	Number	Reaction Time	Number	Reaction Time
Control	106	14	1.04	60	1.25	74	1.21
Single-High-Mounted	106	16*	1.04	56	1.17	72*	1.14
Dual-High-Mounted	106	14	1.14	65	1.29	79	1.26
Single-Roof-Mounted	106	10*	1.40	66	1.27	76*	1.28
Dual-Roof-Mounted	106	9*	1.14	65	1.13	74*	1.13

* On four trials (two with the single-high-mounted system and one each with the single-roof-mounted and dual-roof-mounted system) there was a brake response, but no discernible speed change.

EXPERIMENT 3

The obtained response rates in the two above experiments are substantially lower than the average 46% response rate in the study by Sivak et al. (1979). Therefore, this experiment evaluated the efficiency of high-mounted brake lights on a test vehicle of the same make, model, and year as the test vehicle used in the 1979 study.

Experimental Setup

Identical to the procedure in Experiment 1.

Test Vehicle

A green 1979 GM LeMans was used. As with the AMC Spirit in Experiment 1, only the outboard brake lamp was kept operational on each side.

Brake Light Configurations

The control and single-high-mounted systems were tested (photographs of each are in Figure 7).

Route

The data were collected on the suburban route used in Experiment 1.

Procedure

Identical to the procedure for the suburban route in Experiment 1.

Data Analysis

Identical to the data analysis in Experiment 1.

Results

Table 11 presents, for both systems tested, the number of trials in which the subjects responded by speed change (both with and without braking) to the brake signal on the test car, as well as the corresponding mean reaction times. The Pearson test of association indicates that the probability of responding to a signal (whether by braking or otherwise) did not differ among the systems tested. The

Figure 7. The GM LeMans test car with control system (top) and single-high-mounted system (bottom).

results of an analysis of variance indicate that the brake-reaction times to the single-high-mounted system were statistically shorter than those to the control system. However, this result should be interpreted with caution because of the extremely small number of observations involved.

The brake response frequencies are in the same range as in the other two present experiments and considerably lower than those measured by Sivak et al. (1979) using the same make, model, and year of test car.

Table 11

Types of responses, their frequencies, and the corresponding mean reaction times in seconds. (Vehicle: GM LeMans; route: Suburban or Urban.)

Brake-Light System	Number of Trials	Trials Responded to by a Speed Change: With Braking – Number	With Braking – Reaction Time	Without Braking – Number	Without Braking – Reaction Time	Total – Number	Total – Reaction Time
Control	80	11*	1.64	48	1.18	59*	1.25
Single-High-Mounted	80	7	0.91	50	1.28	57	1.23

* On 3 trials with the control system there was a brake response, but no discernible speed change.

SUMMARY AND DISCUSSION

This daytime study evaluated in-traffic responses of unsuspecting drivers to supplemental, high-mounted brake lights using two different test vehicles (compact and full size) and two different test routes (suburban and urban). The supplemental lamps were mounted just below the rear window or at roof level. Measures were taken of brake-response and speed-change frequencies, and of the corresponding reaction times. (The speed responses were measured by radar.) The following main results were obtained:

Response frequency. The frequency of brake responses and of speed changes did not differ statistically among the systems tested in either of the test vehicle/test route combinations.

Reaction time. Brake-reaction times did not vary among the systems tested for any of the test vehicle/test route combinations. Speed-change reaction times also did not vary among the systems tested for any of the test vehicle/test route combinations with the exception of the compact vehicle/urban route combination: Here, a system with a single, supplemental lamp, center-mounted just below the rear window was associated with statistically shorter reaction times than was the control system.

In comparison to a study by Sivak et al. (1979), which obtained an average 46% brake-response rate, the present study obtained a substantially lower brake-response rate (14%). This difference remained even for conditions using a test car of the same make, model, and year (GM LeMans) on the same type of route (suburban). However, this difference may be accounted for by the fact that the two studies differed in some important respects. First, the actual test routes were not the same: The 1979 study utilized only the busiest portion of the route used in the present study. Second, the 1979 study was run exclusively in the afternoons, while the present study was run both in the mornings and afternoons. Traffic counts from 1978 indicate that the afternoon traffic on test routes of both studies is substantially heavier than the corresponding morning traffic. Third, the data collection in the 1979 study extended until approximately 4:45 p.m., while the data collection in the present study was terminated at approximately 4:00 p.m. Traffic counts from 1978 for the two test routes indicate that the traffic on the respective routes is substantially heavier between 4:00 and 5:00 p.m. than the corresponding traffic in mid and late mornings or early afternoons. It is likely that these differences in traffic conditions affected the brake-response frequencies in the two studies. This explanation is in agreement with the reported sensitivity of brake-response frequency to the roadway and traffic conditions (Allen Corporation, 1978).

An additional difference between the results of the present study and those of Sivak et al. (1979) concerns the relative brake-response frequencies among the various brake-light systems. In contrast to the results of the 1979 study, the present study did not yield higher response frequencies to single- and dual-high-mounted systems than to the control system. While the reason for this difference is not clear, it also could be due to the traffic-condition differences discussed above.

In terms of the brake-reaction times, the present study confirmed, in general, the finding by Sivak et al. (1979) that systems with high-mounted brake light(s) did not yield faster reaction times than did the control system, although the present study found the average reaction time to be 0.18 s shorter than that obtained in the 1979 study.

Speed-change reaction times also did not vary among the systems tested for any of the test vehicle/test route combinations with the exception of the compact vehicle/urban route combination: Here, a system with a single, supplemental lamp, center-mounted just below the rear window, was associated with statistically shorter reaction times than the control system.

For the compact vehicle/urban route combination, the mean difference in the speed-change reaction times between the control and the single-high-mounted system was 0.3 s. This difference may be sufficient to account for the rear-end-collision reductions observed in accident studies (Malone et al., 1978; Reilly et al., 1980; Rausch et al., 1981).

In conclusion, the results of three recent studies on responses of unsuspecting drivers to brake signals by various brake-light systems (Allen Corporation, 1978; Sivak et al., 1979; and the present study) suggest the following:

1. If in reality the single-high-mounted brake-light system increases the probability of a response by following drivers, this benefit does not appear to hold across all types of vehicles and across all route/traffic situations: Increases in brake-response probability were obtained under the conditions of both the Allen and Sivak et al. studies, but not under the conditions of the present study. Furthermore, speed-response probability was found not to differ among the systems tested in all test vehicle/test route combinations in the present study.

2. If in reality the single-high-mounted brake-light system results in shorter response times of following drivers, this benefit does not appear to hold across all types of vehicles and across all route/traffic situations: Shorter brake-response times were obtained under the conditions of the study by Allen Corporation but not under the conditions of the study by Sivak et al. or the present study. Shorter speed-response times were obtained in the present study, but only in the data collected during mornings in the compact vehicle/urban route condition.

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