

DYNAMIC EVALUATION OF AUTOMOBILE
REAR LIGHTING CONFIGURATIONS

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ABSTRACT

The purpose of this study was the evaluation of present and proposed means of coding automobile rear lighting systems. Variables considered in the study were: number of lamps, separation of lamps by function, and color. Also investigated were intensity and flash rate codes currently in use.

Testing was done at night with two specially equipped test vehicles. They were driven both on city streets and on a divided highway to provide "city" and "country" conditions. The lead car, equipped with eight rear lighting systems, displayed the test systems, one at a time, to two subjects in a following car. The test subjects (the driver and passenger) in the second vehicle performed a time-sharing task which required that they respond to turn and stop signals given by the lead car. Their reaction times, the number of missed signals, and subjective ratings were used to evaluate system performance. A total of 66 male and female subjects were used.

Results of the study indicate that the rear lighting system concept presently in use provided the poorest performance of all systems tested. Experimental systems show that the arousal property of signals is directly proportional to the number of lamps used. Separation of lamps by function and color coding of signals were also shown to be factors significantly affecting system performance.

The most effective systems were those in which taillights, turn signals, and stop signals were represented by separate lamps. The findings indicate that the light coding techniques represented by the experimental systems (and not currently employed in rear lighting systems) can lead to significant gains in driver performance.

INTRODUCTION

The automobile rear lighting system performs an important dual function in the prevention of accidents. The system alerts a following driver to an impending maneuver which will change the state of a lead vehicle (or vehicles), and supplies information concerning the nature of this change of state. (Prior studies investigating both aspects of rear lighting systems include Mortimer, 1967; Crosley and Allen, 1966; Rockwell and Treiterer, 1966.)

Although the importance of rear lighting systems in the reduction of accidents and the maintenance of safe traffic flow is generally assumed, there is relatively little available information to support this position. However, accident statistics for 1967 do show that in all two-car accidents in Michigan, rear-end collisions accounted for 17.5% of fatalities, 49.2% of injuries, and 55% of property damage accidents (Michigan State Police, 1968). These data suggest that an improvement in rear lighting system performance has potential for reducing rear-end collisions.

Current automobile rear lighting systems provide the following signals:

- (a) Brake signals, automatically activated when the driver applies his foot to the service brake
- (b) Turn signals, driver-activated by the turn signal switch
- (c) Taillights, driver-activated with the headlight switch to show the presence of a vehicle at night

These signals, all red in color on American cars, utilize changes of intensity or continuity (steady-burning or flashing) to present information. Thus, two basic codes, intensity and flash rate, are utilized in order to present

information to following drivers.

It is well known, however, that there are other light coding systems which offer both high arousal value and efficient means for transmission of information. The number of lights and their placement on the vehicle can be used for coding signals. In addition, a powerful cue frequently utilized in the design of visual displays (Morgan et al., 1963) is the use of more than one color.

Therefore, number and color of lights are additional cues of potential value in the design of rear lighting systems. Shape and area of signal lamps are other potentially useful cues, but their utility was considered doubtful in a previous study (Mortimer, 1967) which also showed lamp number and color codes to be capable of effectively increasing the arousal properties of brake and turn signals.

One purpose of the present study was to determine the value of a code based on number of lamps and the effectiveness of separating lamps according to signal function. The use of number as a code provides an opportunity to separate signal lamps according to the function they perform. For example, in the present system the presence light (taillight), the brake, and the rear turn signals are given by one pair of lamps; any of these signals alone or in combination is represented by no more than two lights.

A change in the number and, therefore, the placement of lights could produce a more effective signaling system. For example, two lights for signaling braking and turning could be provided in addition to the two presence lights. With this system, when only two taillights were seen at night they would indicate only the presence of the vehicle. If more than two lights were visible, the following driver would know that a change-of-state signal was being given:

If four lights were visible, the following driver would know that the brake was being activated; three lights (one of which could be flashing) would indicate the driver intended a turning maneuver. This differs from the present system concept, in which the number (or color) of the lights does not change and signal detection depends upon the ability of the following driver to detect and interpret varying intensities and flashing conditions.

A second objective of this study was to determine the role of color coding, in addition to the presently used intensity and flashing codes. If color is to be used successfully as a code, the colors must be easily discriminated by drivers, a consideration which limits the choice to shades of three--red, amber, and green-blue -- as the most likely candidates in terms of spectral discrimination. Presently available knowledge indicates that normal drivers would be able to easily discriminate between red and blue-green, while amber and red would possibly be confused since they are spectrally much closer. Further investigation, involving spectral and practical considerations, will be necessary to determine the most appropriate colors.

There are numerous criteria that must be considered in the design of automobile rear lighting systems. We shall not belabor this question here, but merely say that a systems-oriented research program is needed to develop an improved rear lighting system. A comprehensive view of this problem has been discussed elsewhere (Mortimer, 1968).

The present study provides a systematic evaluation of number, functional separation, and color as codes for rear lighting systems. The ability of these coding systems to improve the arousal properties of stop and turn signals is compared with the present rear lighting system concept.

METHOD

Two vehicles were involved in this study. A lead car was equipped with the experimental lighting configurations that were to be evaluated. The following car carried the subjects and an experimenter who operated the data-recording equipment.

THE LEAD CAR

Six auxiliary lamps were mounted on the rear of the lead car (Figure 1). The lamps were dual-filament, 4-inch diameter, sealed beam units and were carried in special housings (Figure 2). Three lamps were mounted on each side of the car, and they were placed with 9-inch center-to-center separations. The design of the lamp housings allowed a clear spreading lens, which provided a uniform beam distribution of ± 5 degrees horizontally and ± 2.5 degrees vertically, to be placed in front of the sources. Colored filters and neutral density filters could be fitted in front of the spreading lens. This arrangement allowed the lamp color to be easily changed by changing filters. The controls for these lamps were on the front seat of the lead car (Figure 3) and were operated by the driver.

THE FOLLOWING CAR

The following car was equipped with devices to measure the subjects' response to signals given by the lead car. During each test, two subjects, a driver and passenger, were in the front seat of the following car.

PRIMARY TASK LIGHTS. Mounted on the hood of the following car were two white lights: the primary task lights. They were placed 33 inches forward of the windshield, and had a lateral separation of 31 inches. They would light individually at a rate of ten times per minute, with variable intervals and in a random sequence. A light would

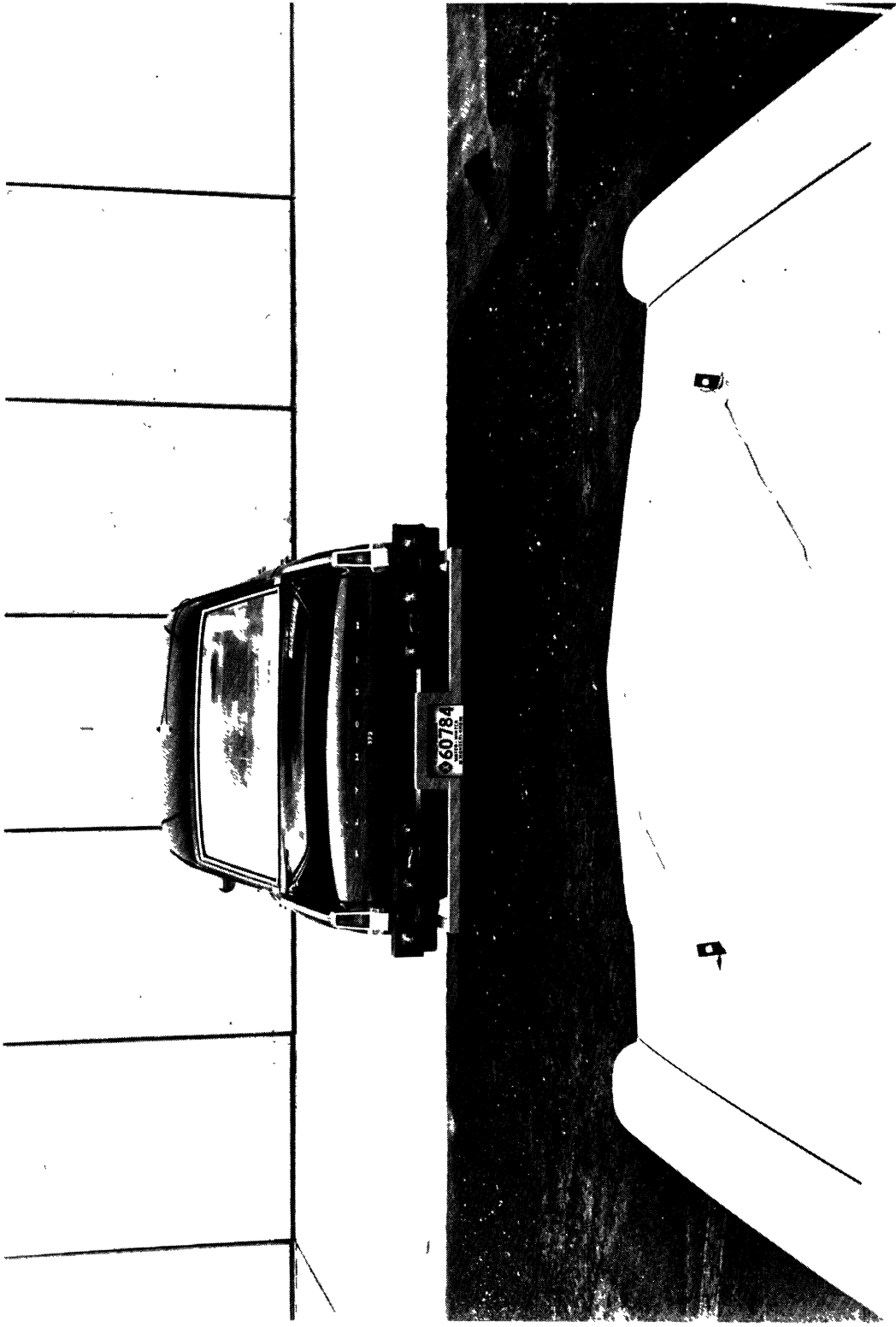


Figure 1 The test lamps mounted on the lead car.



Figure 2 The test lamps, showing spreading lens and filters

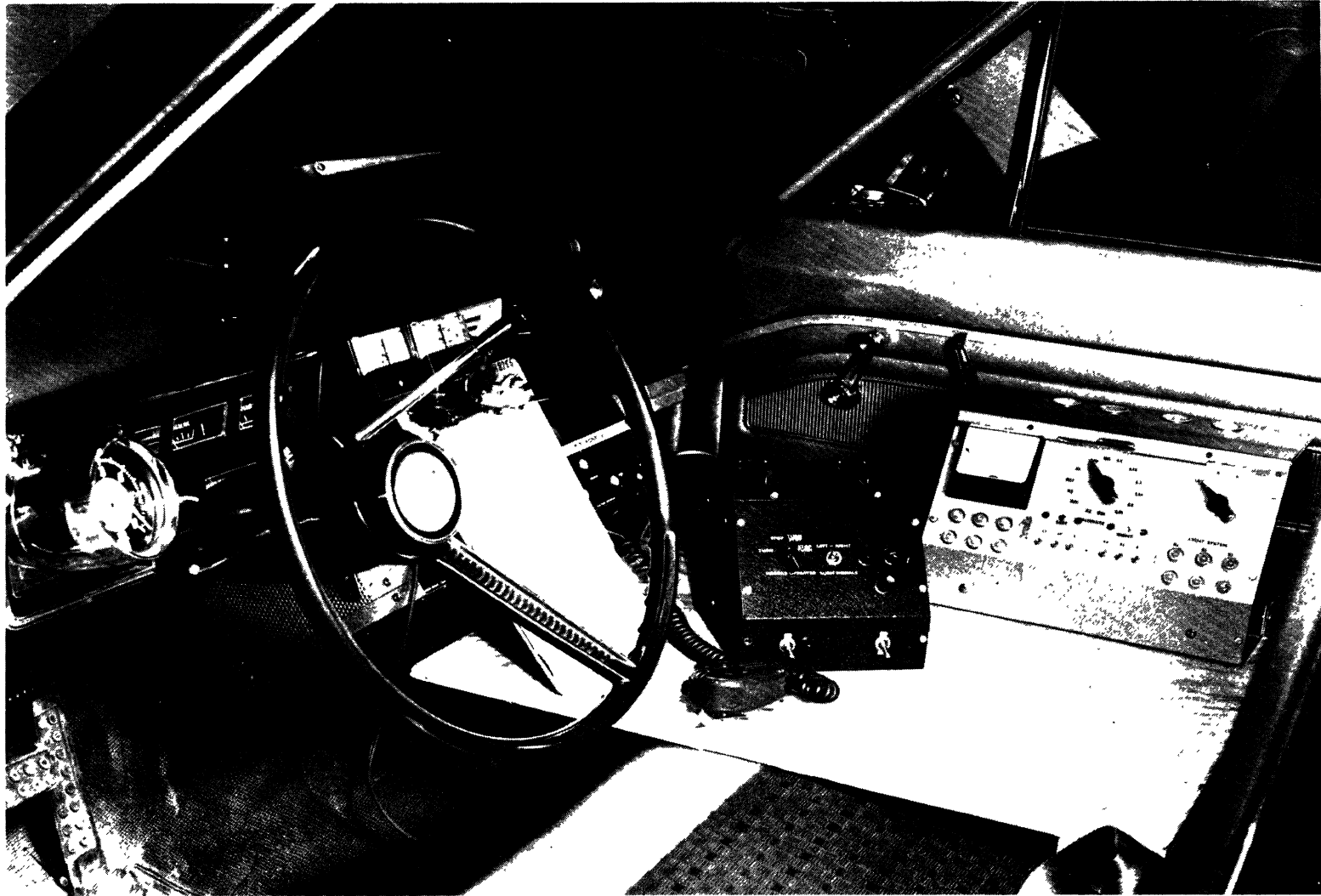


Figure 3 The control and calibration systems in the lead car

remain on until both subjects had responded to it, or for a maximum of four seconds.

SUBJECTS' RESPONSE SWITCHES. Two dash-mounted switches were placed so that they were easily operated by a driver/subject with his hands at the ten and two o'clock positions on the steering wheel. He responded to the primary task lights on the hood by depressing the switch on the same side as the light. A foot switch, conveniently located near the driver's left foot, was activated by the driver when he detected a signal from the lead car.

The passenger held a switchbox containing three switches. Two switches, activated by the left thumb, were for responding to the primary task lights, and the third switch, operated by the right thumb, indicated the subject's response to signals from the lead car.

RECORDING EQUIPMENT. An experimenter sat in the rear seat of the following car and monitored the recording equipment, which consisted of two digital clocks. A transmitter-receiver was provided for communication between experimenters in the test vehicles. Figure 4 illustrates the special equipment used in the following car.

LIGHTING SYSTEMS

The study compared the following eight rear lighting configurations:

1. All red; presence, stop and turn signals in one lamp
2. All red; presence separated from stop and turn
3. All red; presence and turn in one lamp, stop in a separate lamp
4. All red; presence, stop and turn in separate lamps
5. Presence, green, in one lamp; stop and turn, red, in a separate lamp



Figure 4 The set-up in the following car

6. Presence and turn, green, in one lamp; stop, red, in a separate lamp
7. Presence, green; stop, red; turn, red; all in separate lamps
8. Presence, green; stop, red; turn, amber; all in separate lamps

In each system the presence lights remained on at all times. The lighting configurations are shown in Figure 5.

THE DEPENDENT VARIABLE

The reaction time of each subject to the stop and turn signals was measured to the nearest 0.001 second.

SIGNAL MODES

The reaction time to four types of signals were measured:

1. Turn signal, both left and right
2. Stop signal
3. Turn-stop signal (stop signal, when a previously initiated turn signal was still flashing)
4. Stop-turn signal (turn signal, when a previously initiated stop signal was still being shown)

TURN SIGNAL FLASH RATE

Turn signals were the conventional flashing type. The flash rate was 1 cps, with 75 percent "on" time.

PHOTOMETRY

Neutral density filters were used for major adjustments, and potentiometers for minor adjustments, of the presence and signal light intensities. To ensure similar warm-up and delay characteristics of signal light filaments, voltage was kept between 12 and 12.5.

A Spectra Pritchard photometer was used to measure

P - Presence (Taillight)

S - Stop

T - Turn

R - Red

G - Green

A - Amber

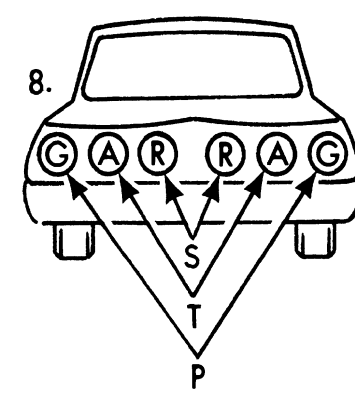
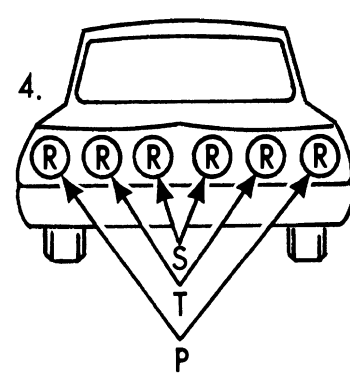
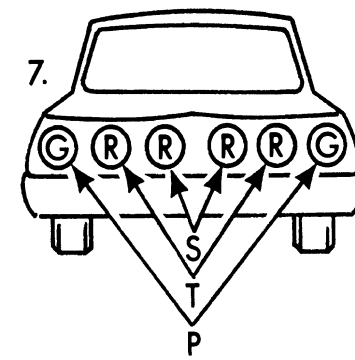
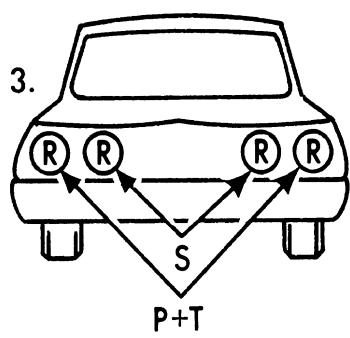
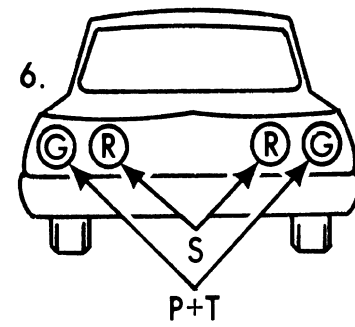
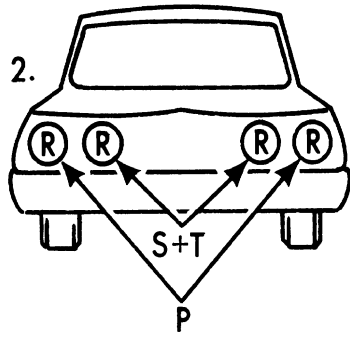
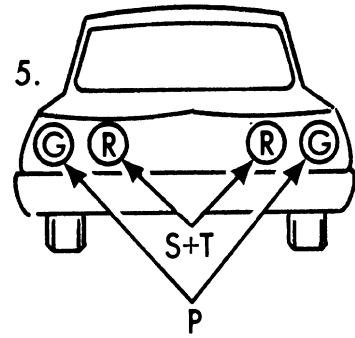
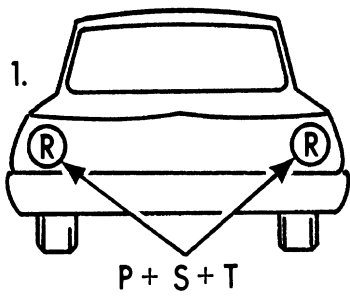


Figure 5

intensities. Prior to use, it was cross-calibrated with a Macbeth illuminometer to ensure that the readings obtained would not be contaminated by nonlinearities of the photometer's photomultiplier tube and filters, and to avoid criticisms that have been made about the use of this instrument for the calibration of signal lights (Allen et al., 1967).

The presence light intensity, measured as the final output through the filters, was 7 cp for all systems. The stop and turn signal intensity was 35 cp.

TELEMETRY

During the experiments, the normal rear signaling system of the lead vehicle was covered and all signals were given by the experimental system. The initiation of a stop or turn signal caused a transmitter in the lead car to relay a signal to a receiver in the following car. The receiver, upon receiving this signal, started the reaction-timing clocks in the following car. When the subjects responded to the stop or turn signals by depressing their switches, they stopped the timers.

In modes three and four, when two signals were given at an interval of two to seven seconds, the transmitter was triggered only when the second signal was presented. For example, in mode three (turn-stop) a turn signal was first presented, and while it was still flashing a stop signal was given. The system was designed to activate the clocks on the second signal (stop signal), and thereby only measure the reaction time to the second signal. Similarly, in mode four the reaction time to the turn signal, not the previously initiated stop signal, was measured. Therefore, although the subjects responded to both signals in modes three and four, only their response to the second signal was measured.

SUBJECTS

The subject group consisted of 25 females and 41 males between the ages of 19 and 43 years. In the city test 34 subjects were used, and in the country test 32 were used.

PROCEDURE

The subjects, seated in the front seat of the following car, were initially assigned driver and passenger positions to be kept throughout the test. The driver of the following car was told to maintain a normal, safe distance behind the lead car. Subjects were instructed to respond as rapidly as possible to their own car's hood-mounted lights, and to the lead car's stop and turn signals. They were then given both static and dynamic practice with the currently used rear lighting system (system 1) until they became familiar with the task they were to perform. When the subjects were acquainted with the system, and judged ready to begin testing, they were shown the presence lights, stop signals and turn signals of the system that had been randomly selected as the first with which they would work.

The cars, equipped with the first lighting system, were then run until 16 reaction times (4 in each mode) had been obtained. The signal modes were randomly ordered in each system for each pair of subjects. When the testing of each system was completed, the subjects made a rating, using a ten-point scale, of the "effectiveness in giving signals" of the system they had just used.

The presence and signal lights of the next randomly selected system were then demonstrated and the procedure repeated until all eight systems had been used. Testing time was approximately three hours for each group of subjects. A rest period was given at the halfway mark.

CITY DRIVING

The city test was run on Stadium Blvd. and Washtenaw Avenue in the City of Ann Arbor, between 9 p.m. and midnight. The tests were run only on weekday nights under clear weather conditions. The route selected for the city test ensured

that the subjects would encounter a visual background of storefront illumination, traffic signals, street lighting, neon signs, and the lights of other vehicles. Traffic density was generally high at the times involved. A distance of 867 miles was driven in the city test.

COUNTRY DRIVING

The country test was run on US-23 between the Washtenaw Avenue Interchange in Ann Arbor and the I-96 Interchange in Brighton. The roads are four-lane, divided highways with a 70 mph speed limit. The speed of the lead car was maintained between 50 mph and 60 mph. The distance driven during the country test was 1424 miles.

RESULTS

REACTION TIME ANALYSIS

The reaction time data were transformed to Log_e in order to satisfy the normality and homogeneity of variance assumptions underlying the analysis of variance. The city and country driving tests were treated by independent analyses of variance, and the results will be described separately.

CITY DRIVING. The analysis of variance (not shown here) of the reaction times to the lead car signals in city driving revealed highly significant effects due to the signal systems, the signal modes, and the systems \times modes interaction.

Table 1 shows the geometric mean reaction time for each cell in the systems \times modes interaction, and the main effect means.

The results of Newman-Keuls tests (Winer, 1962) showed that:

(1) In the turn mode, reaction times for system 2, 4, 5, 7, and 8 were significantly shorter than those for systems 1, 3, and 6. Also, reaction times for system 1 and 3 were shorter than those for system 6.

(2) In the stop mode, there were no statistically significant differences between systems.

(3) In the turn-stop mode, in which reaction time to the stop signal only was measured, system 1 was significantly inferior to the others. Also, system 8 was more effective than system 2.

(4) In the stop-turn mode, system 1 was significantly poorer than any other. Systems 4, 7, and 8 were significantly superior to systems 2, 3, 5, and 6. System 6 was better than 2, 3, and 5, and system 3 was better than system 2 and 5.

COUNTRY DRIVING. The analysis of variance of the country driving reaction times also showed highly significant signal systems and signal modes main effects, and a significant systems \times modes interaction.

Table 2 shows the geometric means of the systems \times modes interaction, and the overall system and modes means.

A Newman-Keuls test on the systems \times modes interaction showed:

(1) In the turn mode, system 7 was significantly more effective than systems 1, 3, 4, and 6 and systems 2 and 5 were better than system 6.

(2) In the stop mode, there were no significant differences between systems.

(3) In the turn-stop mode, system 8 was significantly superior to all other systems except system 7. System 7 was significantly better than systems 1, 2, and 5, and systems 3, 4, and 6 were better than system 2.

(4) In the stop-turn mode, system 7 was superior to all other systems except system 8. System 4 and 8 were superior to systems 1, 2, 3, 5, and 6; system 6 to 1, 2, 3, and 5; and system 3 to 1, 2, and 5.

CITY AND COUNTRY DRIVING. For both city and country tests, the longest mean reaction time, across modes, was for system 1. The mean reaction times for turn signals, especially in the stop-turn mode, were longer than for stop signals, and the overall mean reaction time was longer for the city condition than it was for the country condition.

MISSED SIGNALS ANALYSIS

When a subject did not respond within 10 seconds to a signal given by the lead car, the response time was recorded as a missed signal. The missed signal was repeated at a later time during the trials. Therefore, there were no

missing data in the analyses of variance just presented.

The systems and modes in which misses occurred were analyzed. In the country condition the number of misses was only one fifth that of the city condition, and misses were evenly dispersed among all systems.

In the city condition, 40 percent of the misses occurred with system 1. A Chi-Square analysis showed that there were significantly more misses in system 1 than any other. Also, system 1, a two-lamp system, had significantly more misses than all four- and six-lamp systems, and four-lamp systems incurred significantly more misses than six-lamp systems.

SUBJECTIVE RATING ANALYSIS

The ratings made by the subjects produced the following rank-ordering of perceived system-effectiveness:

- (1) System 8
- (2) System 7
- (3) System 4
- (4) System 5
- (5) System 2
- (6.5) System 3 and 6
- (8) System 1

DISCUSSION

An analysis of reaction time data revealed statistically reliable performance differences among the tested rear-lighting systems. Only the stop mode, of the four signal modes, produced no significant differences in system performance.

In the turn, stop-turn, and turn-stop modes (Tables 1 and 2) the present system coding concept was shown to be inferior to experimental systems using additional codes such as number, color, and functional separation.

In the turn mode, those systems which combined the presence and turn signals in one lamp (systems 1, 3, and 6) produced the poorest performance, and the green turn signal-presence combination (system 6) was not as effective as the red equivalent (system 3).

In the turn-stop mode, which allowed an evaluation of the arousal properties of the stop signal during turn-signaling, separation of the stop lamp from the presence-turn lamp led to significant improvements when:

- (1) The red presence-turn lamp was separated from the red stop lamp. (compare system 2 and 3; see Table 2)
- (2) The green presence-turn lamp was separated from the red stop lamp (system 6)
- (3) The red lamps were all separated (system 4)
- (4) The most effective method, complete separation and color coding, was used (systems 7 and 8)

In the stop-turn mode, in both city and country tests, systems employing complete functional separation of lamps (systems 4, 7, and 8) were superior to all others. System 6 was superior to 3 and both were better than systems 2 and 5.

An overall appraisal of the findings shown in Tables 1 and 2 indicates that systems 7 and 8 were consistently superior to the present concept (system 1) and to most of the other systems. System 4, which utilized complete functional

separation in an all-red configuration, was also effective. Further evidence for the effectiveness of number coding and functional separation was supplied by the missed-signal analysis. This measurement indicated that there were significant reductions in missed signals as the functional separation of lamps was increased, although little further benefit was derived from color coding.

Although the addition of color coding did not significantly reduce the number of missed signals, there was evidence that color coding, in addition to complete functional separation, was useful in reducing reaction times, since system 8 was significantly superior to system 4 in the turn-stop mode, and system 7 was superior to system 4 in the stop-turn mode (Table 2). Also, overall mean reaction times for systems 5 and 6 were lower than those for the comparable all-red systems 2 and 3.

The subjects indicated, through their subjective ratings, that they found color coding, change in number of lights, and functional separation to be beneficial to rear-lighting system performance. The subjects rated the present concept (system 1) lowest, and tended to prefer systems which made maximum use of all three techniques.

On the basis of these studies it can be concluded that the use of number as a code is effective. The functional separation that becomes possible as the number of lamps is increased has an effect on system performance. The benefits to be derived from function separation are exemplified by a comparison of system 6 with 5, and system 3 with 2. These data suggest that it is better to separate the stop lamps from the presence-turn lamps than to separate the presence lamps from the stop-turn lamps.

Some European cars use presence-stop lamps separated from turn lamps and, although this arrangement has limitations,

such partial separations are an improvement over the current domestic design. However, for night driving it would be preferable to separate the stop lamp from other lamps, because the stop signal is probably the most important element of the rear lighting system.

The data clearly show that the best lighting systems employed both full functional separation and color coding. Prior data (Mortimer, 1967) have shown that partial functional separation with color coding is significantly more effective than currently used systems.

Inspection of Tables 1 and 2 shows that the longest reaction times in system 1 were associated with the turn, turn-stop and, most markedly, the stop-turn modes. Therefore, coding should concentrate on the reduction of reaction times in these modes. The coding scheme used in system 6 does this most effectively for four-lamp systems. All the six-lamp systems, especially those employing some degree of color coding, provided considerable reductions in reaction times.

The systems used in this study were selected to provide a systematic evaluation of coding concepts. No attempt to evaluate particular rear lighting configurations was made. If the data are used to help make design decisions for an improved system, other considerations must be taken into account. Such considerations would include cost, compatibility with existing vehicles and roadway elements, and the desirability of future changes in the rear lighting system to produce the most valuable and practical message content.

In the meantime, the present study has shown that considerable improvements can be made in the arousal properties of the signals presented by currently used rear lighting systems.

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The special lamps were loaned to us by the Guide Lamp Division, General Motors Corporation, Anderson, Indiana.

TABLE 1. CITY DRIVING. GEOMETRIC MEAN REACTION TIME FOR EACH SYSTEM BY SIGNAL MODE^a

MODE	SYSTEM								MEAN
	1	2	3	4	5	6	7	8	
Turn	1.170	.988	1.206	.988	.930	1.334	1.007	.949	1.072
Stop	.903	.894	.841	.858	.841	.867	.858	.825	.861
Turn-Stop	1.007	.894	.825	.800	.850	.809	.809	.761	.844
Stop-Turn	2.155	1.816	1.661	.939	1.873	1.473	.927	.894	1.467
MEAN	1.309	1.148	1.133	.896	1.123	1.121	.900	.857	1.061

Individual Comparisons by Newman-Keuls Tests:

1. Turn Mode: Systems 5, 8, 4, 2, 7 significantly^b better than 6, 3, 1.
 Turn Mode: Systems 1, 3^x significantly better than 6.
2. Stop Mode, No differences were significant.
3. Turn-Stop Mode: Systems 8, 4, 7, 6, 3, 5, 2 significantly better than 1.
 Turn-Stop Mode: System 8 significantly better than 2.
4. Stop-Turn Mode: Systems 8, 4, 7 significantly better than 1, 5, 2, 3, 6.
 Stop-Turn Mode: System 6 significantly better than 1, 5, 2, 3.
 Stop-Turn Mode: System 3 significantly better than 1, 5, 2^x.
 Stop-Turn Mode: Systems 2, 5 significantly better than 1.

^aData are in seconds, for 34 subjects in city driving. The results of individual comparison of systems in each mode are also shown.

^bSignificant at $P \leq .01$ unless marked with asterisk to indicate $P \leq .05$.

TABLE 2. COUNTRY DRIVING. GEOMETRIC MEAN REACTION TIME FOR EACH SYSTEM BY SIGNAL MODE^a

MODE	SYSTEM								MEAN
	1	2	3	4	5	6	7	8	
Turn	.958	.885	.978	.978	.894	.997	.850	.912	.932
Stop	.761	.800	.835	.800	.785	.777	.754	.777	.786
Turn-Stop	.876	.903	.800	.792	.858	.800	.761	.717	.813
Stop-Turn	1.782	1.677	1.401	.921	1.695	1.049	.825	.867	1.277
MEAN	1.094	1.066	1.004	.873	1.058	.906	.798	.818	.952

Individual Comparisons by Newman-Keuls Tests:

1. Turn Mode: System 7 significantly^b better than 6, 3, 4, 1.
Turn Mode: Systems 2, 5 significantly better than 6^x.
2. Stop Mode: No differences were significant.
3. Turn-Stop Mode: System 8 significantly better than 2, 1, 5, 3^x, 6^x, 4^x.
Turn-Stop Mode: System 7 significantly better than 2, 1, 5^x.
Turn-Stop Mode: Systems 4, 6^x, 3^x, significantly better than 2.
4. Stop-Turn Mode: System 7 significantly better than 1, 5, 2, 3, 6, 4^x.
Stop-Turn Mode: Systems 8, 4 significantly better than 1, 5, 2, 3, 6.
Stop-Turn Mode: System 6 significantly better than 1, 5, 2, 3.
Stop-Turn Mode: System 3 significantly better than 1, 5, 2.

^aData are in seconds, for 32 subjects in country driving. The results of individual comparisons of systems in each mode are also shown.

^bSignificant at $P \leq .01$ unless marked with asterisk to indicate $P \leq .05$.

