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# PASSENGER CAR AND TRUCK SIGNALING AND MARKING RESEARCH:

# I. REGULATIONS, INTENSITY REQUIREMENTS AND COLOR FILTER CHARACTERISTICS


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16. Abstract


This report describes some of the studies conducted in a program of research in automobile and truck marking and signaling. A detailed summary of current U.S. vehicle marking and signaling lighting standards was prepared, and compared with the main features of foreign vehicle marking and signaling standards. These reviews suggested a number of topics that warrant further consideration such as area-intensity relationships of stop and turn lamps, the hazard warning (four-way flashing) signal being rendered inoperative if the brake pedal is depressed, reduced photometric and location requirements of rear turn signals on tractors, tractor clearance lamps indicating cab width rather than the width of the vehicle, the adoption of side turn signal lamps, white for front parking lamps, use of yellow for rear turn signal lamps, etc.

A review of the effectiveness of separation of rear marking and signal lamps by their functions, supports this general concept.

As a preliminary to studies to determine the intensity requirements of signal lamps, an analysis showed that signals should become identifiable at distances up to 2000 feet. The findings of the study of signal intensity requirements showed that these are affected by the system's configuration. Conflicts between the intensities needed for adequate identification of a signal and those causing discomfort glare can be resolved with dual-intensity lamps for systems using separation of function. Flashing lamps caused less discomfort glare than steady-burning lamps of the same intensity. Recommendations for the intensities of lamps of rear signal systems were made.

The final study in this report was a laboratory evaluation of color discrimination and identification by normal and dichromatic observers, on the basis of which preliminary recommendations for chromaticity coordinates of red, yellow and green-blue lamp filters were derived.


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# INTRODUCTION

This report is the first in a series describing continuing research in car and truck marking and signaling. The research program has been broken down into some major phases. The first phase, partly described in this report, deals largely with matters such as: the prevailing vehicle lighting practices and standards, evaluations of collision data to try to infer the driver's information requirements, the development of a mathematical model of situations in which one vehicle approaches another from the rear or is following it with the intent to learn the types of information displays that may usefully reduce rear-end collisions, reviews of previous work concerned with the use of separation of function and colors in vehicle lighting systems, tests concerned with signal intensity requirements in day and night driving conditions, a review of the need for dual-intensity signaling, and preliminary studies of new display formats for presentation of information not now coded in vehicle rear lighting systems.

Associated with these studies was a concomitant effort involving the construction of a simulator which would enable studies to be conducted of vehicle rear lighting systems. The development of this device and the means by which it is used for the construction of rear lighting systems to be evaluated, the generation of forcing functions for the lead car in the simulation, and the data recording and analysis procedures, as well as some preliminary findings of studies carried out to validate the simulator by comparing simulator experimental results with those previously obtained in field studies, are described in a separate report (Campbell and Mortimer, 1972).

Other work to be conducted in the overall program is mainly concerned with the continuation of the development and utilization of the traffic flow model and the utilization of the rear lighting research simulator to evaluate rear lighting system concepts. Subsequent studies will be concerned with evaluations, under actual driving conditions, of the types of systems which the work in Phases I and II identify as warranting further study in field tests.

## A BRIEF OVERVIEW OF PREVIOUS RESEARCH

Research in vehicle marking and signaling has proceeded over a number of decades. Much of this work has led to evolutionary improvements in vehicle marking and signaling standards as well as improved lamp construction to reduce the effects of weathering to maintain lamp performance. In terms of system performance and safety the changes that have been made have been largely concerned with providing a better definition of the intensity and area requirements of lamps mounted on the rear of vehicles, the introduction of yellow turn signals on the front, with stipulations concerning separation of the latter from the headlights for improved detection under night driving conditions, and side marking. The marking requirements for passenger car are, in general, less complex than those for trucks. Trucks are required to have identification lamps mounted on the front and the rear, presumably with the intention of providing other drivers of early recognition of the type of vehicle being approached or followed. Clearance lights are also required at the front and rear of trucks which improve identification of the size of the vehicle involved, as well as the type of carrier, and in that manner can augment the identification of such vehicles. The historical antecedents of identification and clearance lights have not been discerned, but it would seem likely that it was considered important to be able to identify the type of vehicle and its size since this is likely to be related to the speed at which such vehicles are expected to be traveling. This information could be important for other drivers in assessing the safety of an overtaking maneuver, or in approaching a vehicle from the rear, in order to minimize the extent of the relative velocity and hence, rear-end collisions.

Data have been presented previously (e.g., Mortimer, 1970) which clearly show the high frequency of rear-end collisions. These collisions may constitute as high a proportion as 50% of all highway collisions and more than 60% of those involving two or more vehicles. Rear-end, or same direction, collisions account for about 10% of traffic fatalities. It would appear likely that as the traffic density increases the proportion of same direction accidents will also increase. This will also be compounded by the increased mileage being driven on limited access or divided highways which minimize other forms of collisions.

The role of vehicle marking and signaling lights in collisions is difficult to determine because of the multiplicity of factors that are likely to be involved. Therefore, it is more fruitful to consider the role of marking and signaling in affecting the driver's performance. On this basis, improvements in performance which can be shown experimentally and analytically could be assumed to produce reductions in collisions. This is not to minimize the major purpose of changes that may be recommended to vehicle lighting systems, i.e., in affecting collisions, but to suggest that an intermediate criterion, such as driver performance, should be used in experimental studies to determine whether improvements are attainable. Such improvements would take as their baseline the presently used marking and signaling configurations on U.S. vehicles.

In the U.S., vehicles are required to have reflectors at the sides and rear, side marker lights, headlamps for forward illumination and marking, augmented by parking lamps at the front and presence (tail) lamps at the rear. Signaling is carried out at the front by front turn signals and at the rear by rear turn signals and stop signals. Some vehicles also provide an indication of turning visible to the side by flashing the front and some times also the rear side marking lamps. The hazard warning signal is given by flashing all turn signaling lamps. As already mentioned, trucks are required to also have identification and clearance lamps. Two colors, yellow and red, are used in these systems. The major difference between U.S. and European automobile signal systems lies in the use of yellow turn signals on the rear. The manufacturing requirements for lighting systems of vehicles sold in the U.S. market are stipulated in Federal Motor Vehicle Safety Standard No. 108 (1973). Other guidelines are given in SAE Recommended Practices and Standards which pertain to all aspects of lamp construction and performance.

Most of the recently conducted research in vehicle marking and signaling has been concerned with improving the coding of rear signals. These studies (Mortimer, 1970; Case et al., 1969; Projector et al., 1969) have recommended that separating lamps that have different functions should be used as one means of improving the detectability and identification of signals. The use of colors for coding signals, such as yellow for rear turn signals, red for stop signals, and green-blue for presence lamps, has also been found (Mortimer, 1969) to reduce the detection time, and errors in identification of signals. The present U.S. rear lighting system does not incorporate separation of function of color coding.

Studies that have been carried out to determine intensity requirements for lamps (Mortimer, 1970; Forbes, 1966; Kilgour, 1962; and others) have shown that a lamp which is adequately visible in the daytime will be too bright, causing discomfort at night. It should be noted that these studies evaluated the intensities of lamps out of the context of a complete signal system.

In view of the findings showing that color coding and separation of function are desirable characteristics of a rear lighting system for signal detection and identification, it seemed necessary that intensity requirements should be determined utilizing complete systems, as the system characteristics may have a bearing upon the intensities necessary for correct identification of a signal and the intensities giving rise to discomfort glare.

There have been relatively few studies concerned with determining the most necessary types of information that may be coded by signal lamps on the rear of the vehicle, for presentation of following drivers. Work by Rockwell and Treiterer (1966) and Rockwell and Banasik (1968) have shown that car-following performance can be improved if the driver receives better information of the headway and relative velocity with a vehicle he is following. Analytical considerations of traffic flow (Herman and Gardels, 1963) also have shown that these are important cues for drivers in stabilizing traffic flow. Some research (Mortimer, 1970) has shown that sensitivity to changes in headway can be improved by the use of an array of four presence lamps rather than the two lamps normally used. Mortimer (1971) also suggested that, while relative velocity cannot be displayed directly without intervening electronic or other sensors, it is possible to consider the use of a display of vehicle speed on the rear on the basis of which relative velocity can be deduced by the driver. Other studies (Fiala & Wallner, 1967) have used simulation methods to evaluate the utility of a signal denoting an abnormal level of deceleration, but did not find that this improved the driver's performance beyond that which was found without the panic stop signal. In another attempt to present more information of the actions of a lead car driver that is given presently, Rockwell and Treiterer (1966) evaluated a tri-light display in which a green light indicated depression of the accelerator, an amber light accelerator released, and a red signal brake application. While this display improved detection of coasting (accelerator released) it did not appear to improve stability in car-following. A basically similar finding was reported by Rutley and Mace (1969) in evaluating a stop light display which provided information of the deceleration in three discrete steps. In a related experiment Mortimer (1970b) evaluated the desirability of a signal given whenever the accelerator is released, as used in a "tri-light" display, which is modulated by accelerator and brake activity. By collecting data on an instrumented car that was used in normal driving as a motor pool vehicle, he found that brake application followed release of the accelerator in less than 50% of occasions and that most of the coasting durations were of two seconds or less. On this basis, it was concluded that coasting signals would occur frequently with little requirement for a following driver to alter his speed. The signal would, therefore, tend to cause visual noise in the traffic environment. By also evaluating the ability of drivers to detect coasting without such an augmenting signal it was concluded that little benefit would be derived, except in about 10% of coasting events which lasted for more than about five seconds, during which a vehicle would reduce its speed on a level road by an amount sufficient to require an action of a following driver who was following at a normal distance.

It is evident that there is a good deal of information already available which would suggest that suitable changes could be made to the present rear lighting system, considering only the signals which are now presented, which could lead to improved performance of following drivers and a probable reduction in rear-end collisions. At the same time, it is also clear that more effort is required in order to determine the information that drivers could best utilize in approaching a vehicle from the rear or in car-following to reduce collisions, and that this information may be found to be different from that which is now displayed. The thrust of this research program, in its various phases, is to attempt to determine these information requirements and the means by which they can be displayed, as well as to evaluate intensity requirements for complete rear lighting systems. Finally, in order to supplement the findings of laboratory, simulation and field experiments which suggest improved lighting configurations, a mathematical simulation was considered valuable in order to assist in defining the informational properties that are needed, but also to provide another means of assessing the likely reduction in rear-end collisions that may ensue if such systems were implemented.

# 1. SUMMARY OF U.S. AUTOMOTIVE LIGHTING EQUIPMENT STANDARDS

## THE SOURCES OF THE LIGHTING EQUIPMENT STANDARDS

Federal Motor Vehicle Safety Standard No. 108 (1) [49 CFR 521.108, or FMVSS 108] establishes the current lighting equipment manufacturing requirements for vehicles manufactured for sale in the United States. It incorporates frequent reference to the Standards printed by the Society of Automotive Engineers in their Handbook, although additional requirements are also made in some instances. Only those SAE Standards and Recommended Practices mentioned in FMVSS 108 are legally mandatory, however.

For the purposes of this survey, those SAE Standards made legally binding by reference within FMVSS 108 will be distinguished from those others published by the SAE but not yet adopted by the National Highway Traffic Safety Administration [NHTSA].

The actual operating standards for vehicles in use on public land are established and enforced by the various states, as set forth in their respective State Vehicle Codes; by other lower levels of government (for instance, cities and municipalities); and for interstate commercial vehicles, by the Bureau of Motor Carrier Safety of the Federal Highway Administration [FHWA].

Vehicles manufactured with lighting equipment sufficient to meet FMVSS 108 also meet or exceed the requirements imposed by the individual states in most instances, with the former pre-empting the latter at time of manufacture in case of conflict. Exceptions to this usually are limited to specialized equipment, such as school bus loading and unloading lamps. Most states impose additional requirements and/or restrictions upon the operation of certain lighting equipment, such as on the use of revolving beacon lamps and on the use of auxiliary fog and driving lamps.

An additional source of recommendations for lighting equipment is the industry-sponsored National Committee on Uniform Traffic Laws and Ordinances [NCUTLO]. The Highway Users Federation for Safety and Mobility [HUF] prints a summary of the lighting requirements from the individual State Vehicle Codes,* especially as the latter vary from the NCUTLO recommended operational standards.

Six basic categories of vehicle lighting equipment can be identified, distinguished by their performance or visual effect:

1. Vehicle Signal Lamps (stop and turn signal lamps, warning lamps for emergency vehicles, school bus loading and unloading lamps, etc.). This category includes those lamps which are either voluntarily actuated by the driver to give specific signals, or involuntarily actuated by the vehicle's performance or controls. They intend to convey a signal to other drivers. Where federal safety standards or SAE recommendations exist, these lamps are discussed under the appropriate later part of this chapter.

2. Vehicle Demarcation and Identification Lamps (rear presence lamps, parking lamps, side-marker lamps, clearance lamps, identification lamps, etc.). This category is limited to those lamps specifically or primarily intended to convey information about the presence, dimensions, or orientation of vehicles. Where federal safety standards or SAE recommendations exist, these lamps are discussed under the appropriate later part of this chapter.

3. Vehicle-Mounted Road Illumination Lamps (headlamps, driving lamps, passing lamps, fog lamps, backup lamps). Because these lamps interact with those whose function is specifically signaling and marking, they are given further consideration here. Where federal safety standards or SAE recommendations exist, these lamps are discussed under the appropriate later part of this chapter.

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*Motor Vehicle Law Series, Service No. 3 - Equipment Requirements.

4. Vehicle Interior Lighting (dome lamps, courtesy lamps, map illumination lamps, ashtray lamps, glove-compartment lamps, etc.). Except as noted below, this equipment is not germane to this review and will not be included in the later discussions in this chapter.

5. Vehicle Performance and Monitoring Indicators (engine condition indicators [idiot lights], high-beam indicators, turn signal indicators, etc.). Except as noted below, this equipment is not germane to this review and will not be included in the later discussions in this chapter.

6. Vehicle-Mounted Indirect Lighting or Nonelectrically Powered Equipment (reflex reflectors, license plate illumination lamps, slow-moving-vehicle orange triangles, burning flares and fuses, etc.). Although this category is quite similar to category two above, it is considered separately since the visibility of this equipment is dependent upon conditions somewhat more difficult to define. For instance, reflex reflectors, generating no light on their own, are dependent on the light from other vehicles' headlamps to be seen. Similarly, license plate lamps emit light which observers are supposed to be able to see only indirectly, namely reflected off the license plate itself.

These six categories of lighting equipment are not mutually exclusive. A lamp in one might on occasion serve the function of a different category. Examples of this include the following:

1. Flashing headlamps are used to convey signals. Commercial truck and bus operators use this signal between themselves to indicate they are yielding right-of-way, or that a lane change or passing maneuver can safely be completed, or that a road hazard or check lane is ahead, etc. Some emergency vehicles incorporate simultaneously or alternately flashing headlamps as a warning signal. Although the legality of the flashing headlamp signal has been challenged, this signal is nevertheless in common use.

2. Headlamps in a steady-burning state give significant information about the presence, orientation, and relative velocity of the vehicle on which they are mounted. Prior to the use of front-mounted presence lamps, "running" lamps, or parking lamps which remained on with the headlamps, the latter provided the sole means of determining presence and relative velocity when the vehicle was viewed from the front at night.

3. Brake signal lamps in a steady state, or hazard flashing lamps, also give significant information about the presence and relative velocity of the vehicle on which they are mounted.

4. Backup lamps serve as a signal to other drivers that the vehicle on which they are illuminated is in reverse gear, or is traveling backwards.

5. The observation of a vehicle's interior lighting can warn drivers of other vehicles that its doors may be open or opening, that the hood is raised and the vehicle is disabled, etc. Some interior lighting equipment is specifically designed to project light to other drivers when such doors or hoods are open.

6. Exterior or hood-mounted turn signal indicators also can function as side-mounted, rear-facing supplemental turn signal lamps.

7. The flashing of side-marker lamps has recently been used on some vehicles to augment the turn signal function.

8. The voluntary actuation of clearance, identification, and sometimes side-marker and rear presence lamps is used as a form of communication between commercial truck and bus operators (for instance, to acknowledge observation of the other's blinking headlamps).

DEFINITIONS. Several terms and concepts used in this review should be defined here, to avoid later confusion.

"Vehicle" applies solely to motor vehicles, trailers, and semi-trailers licensed to be operated on public highways. Excluded are construction and industrial vehicles, and highway maintenance vehicles of restricted speed potential, except to the extent that they coincidentally conform to these standards.

"Trailers" include both full trailers (self-standing), and semi-trailers designed to be pulled by truck tractors. However, neither trailers nor semi-trailers designed and intended to serve solely as farm implements or to be towed by farm tractors or vehicles not licensed for operation on public highways are included.

"Motorcycles" include class A, B, C, and D motorcycles when the term is used in the text and the figures. In the tables, the four classes of motorcycles are distinguished.

## TYPES OF LIGHTING EQUIPMENT CONSIDERED AND THE FORMAT USED IN THIS REVIEW

Table 1.1 summarizes some requirements for those lamps for which FMVSS 108 currently establishes manufacturing standards. Notably lacking are maximum candela levels for certain lamps and the existence of any standards for many other lamps.

To understand the interrelationships (for instance, veiling effects, and confusing or distracting arrays) between the various lamps required on motor vehicles, all lamps projecting light in the same direction need to be considered together. Thus, specific lighting equipment components will be considered according to their mounting location and the direction in which they transmit light as follows:

1. Lamps intended to show primarily to the front, ±90° from the forward projection to the vehicle's longitudinal axis.

2. Lamps intended to show primarily to the sides, ±90° from the projection of the axis perpendicular to the vehicle's longitudinal axis.

3. Lamps intended to show primarily to the rear, ±90° from the rearward projection of the vehicle's longitudinal axis.

Each of these three horizontally differentiated ranges includes all vertical points within ±90° from the horizon.

This division is neither inclusive nor exhaustive, since lamps mounted on the front and rear are sometimes visible almost to 90° to the sides, and lamps mounted on the sides are sometimes visible almost to the front and rear. For the purposes of this review, however, the lamps are divided into thess three categories according to the direction in which they are primarily intended to project light. An exception is the side-mounted turn signal lamp, which is intended to project light both to the side of the vehicle on which it is mounted and to the rear, and is therefore included in the tables covering both of these directions.

LAMPS VISIBLE TO THE FRONT OF VEHICLES. The mounting location of lamps visible on the front of vehicles is shown in Figure 1.1. Table 1.2 explains the abbreviations in Figures 1.1, 1.2 and 1.3. Table 1.3 shows the photometric levels for lamps visible on the front of automobiles, trucks and buses, and Table 1.4 for motorcycles, for which federal safety standards or SAE recommendations currently exist. Those requirements established and made binding by reference within FMVSS 108 are printed in standard type; those merely recommended in the 1973 SAE Handbook but not (yet) included within FMVSS 108 are printed in italics.

In these tables, the lamps are organized according to function.

Each of the lamps are described in the following respects:

1. Intent: Information on the function is derived from applicable SAE Standards, or from common usage.

2. Method of Activation: Driver-controlled manual activation is assumed unless other information is specified and attributed.

# TABLE 1.1. Characteristics of Lighting Equipment Required by FMVSS 108.

| LAMP CATEGORY/ LAMP NAME | VEHICLES ON WHICH REQUIRED | SIDE OF VEHICLE | MINIMUM NUMBER | LAMP COLOR | INTENSITY AT LAMP H-V AXIS[2] Maximum CP | Minimum CP |
|---|---|---|---|---|---|---|
| **Road Illumination Lamps:** | | | | | | |
| Headlamps | Motorcycles[3] | Front | 1 | White | 75000[4] *10000* | 10000[4] *3000* |
| | All Other Vehicles (except Trailers) | Front | 2 of 7" | White | 37500[4] *15000* | *20000*[4] *6000* |
| | | | or 4 of 5¾" | | [5] *15000* | *18000*[6] *7000*[4] *6000* |
| Back-Up Lamps | All Vehicles except Motorcycles and Trailers | Rear | 1 | White | 300 | 80 |
| **Signal Lamps:** | | | | | | |
| Turn Signal Lamps | Motorcycles | Front | 2 | Yellow | | 120 |
| | | Rear | 2 | Yellow | 900 | 120 |
| | | | | or Red | 180 | 40 |
| | All Other Vehicles (except Trailers) | Front | 2 | Yellow | | 200 |
| | All Other Vehicles | Rear | 2 | Yellow | 900 | 200 |
| | | | | or Red | 300 | 80 |
| Stop Signal Lamps | Motorcycles | Rear | 1 | Red | 300 | 80 |
| | All Other Vehicles | Rear | 2 | Red | 300 | 80 |
| School Bus Loading and Unloading Lamps | School Busses | Front & Rear | 2[7] | Red | | 600 |
| **Demarcation Lamps:** | | | | | | |
| Parking Lamps | All Vehicles except Trailers, Motorcycles, and MPVTB[8] of ≥ 80" width[9] | Front | 2 | White or Yellow | 125 | 4 |
| Rear Presence Lamps | Motorcycles | Rear | 1 | Red | 15 | 2 |
| | All Other Vehicles | Rear | 2 | Red | 15 | 2 |
| Front Side Marker Lamps | All Vehicles except Motorcycles | Side (near Front) | 2[10] | Yellow | | 0.62 |
| Intermediate Side Marker Lamps | All Vehicles of ≥ 30' Length[11], except Motorcycles | Side (midpoint) | 2[10] | Yellow | | 0.62 |
| Rear Side Marker Lamps | All Vehicles except Motorcycles and Truck Tractors | Side (near Rear) | 2[10] | Red | | 0.25 |
| License Plate Illumination Lamp | All Vehicles | Rear | 1 | White[12] | | |
| Clearance Lamps | MPVTB[8] and Trailers, of ≥ 80" width[9] | Front | 2 | Yellow | | 0.62 |
| | Same, except Truck Tractors | Rear | 2 | Red | 15 | 0.25 |
| Identification Lamps | MPVTB[8] of ≥ 80" width[9] | Front | 3 | Yellow | | 0.62 |
| | MPVTB[8] and Trailers, of ≥ 80" width[9] except Truck Tractors | Rear | 3 | Red | 15 | 0.25 |
| Front Side Reflex Reflectors | All Vehicles except Motorcycles | Side (near Front) | 2[10] | Yellow | | |
| Intermediate Side Reflex Reflectors | All Vehicles of ≥ 30' length[11], except Motorcycles | Side (midpoint) | 2[10] | Yellow | | |
| Rear Side Reflex Reflectors | All Vehicles except Truck Tractors and Motorcycles | Side (near Rear) | 2[10] | Red | | |
| Rear Reflex Reflectors | Motorcycles | Rear | 1 | Red | | |
| | All Other Vehicles | Rear | 2 | Red | | |

[1] In the text is contained a further description of each lamp's mounting requirements (minimum and maximum heights above the road surface, minimum and maximum spacing from other lamps, etc.)

[2] For some of the headlamp requirements, specific levels are not given at the exact H-V axis. Instead, values at the vertically closest corrdinates are given, indicated in *italics*.

[3] Class A and Class B.

[4] The two values given for these headlamps correspond to the requirements for upper and lower beams respectively.

[5] The combined total for the two lamps on each side must not exceed 37500 CD at the ½D-V point for either lamp.

[6] The two minimum values belong respectively to the single- and dual-beam bulbs of the "quad headlamp" array.

[7] Another School Bus Loading and Unloading Lamp array required in some states also contains a yellow lamp paired with each red one, but mounted inboard of it. These yellow lamps have standards which are 2.5 times the similar standards for the red lamps. Their use and method of activation is described in the text.

[8] MPVTB = Multipurpose Passenger Vehicles, Trucks, and Buses. (This does not include trailers.)

[9] ≥80" width = "of 80 or more inches in overall width."

[10] One lamp apiece on the Left and Right sides of the vehicle.

[11] ≥30' length = "of 30 or more feet in overall length, inclusive of the tongue on trailers, and irrespective of the vehicle's width."

[12] The light from the license plate illumination lamp must be directed onto the license plate. As further described in the text, most states' Vehicle Codes prohibit this lamp from projecting light rearward into the eyes of other drivers.

TABLE 1.2. Explanation of Symbols Used in Figures 1.1, 1.2, and 1.3.

| Symbol | Explanation | |
|---|---|---|
| (B) | White Back-Up Lamp(s) | |
| (BR) | Red Brake Signal Lamp | |
| (H) | White (Clear) Headlamp(s) | |
| (L) | License Plate Lamp(s) | |
| (PY) | Yellow Presence Lamp: | Parking Lamp<br>Front Clearance Lamp<br>Front Identification Lamp<br>Front Side Marker Lamp<br>Intermediate Side Marker Lamp (when required) |
| (PR) | Red Presence Lamp: | Rear Clearance Lamp<br>Rear Identification Lamp<br>Rear Side Marker Lamp<br>Rear Presence Lamp |
| (TY) | Yellow Turn Signal Lamp | |
| (TR) | Red or Yellow Turn Signal Lamp | |
| (XY) | Yellow Reflex Reflector | |
| (XR) | Red Reflex Reflector | |

TABLE 1.3. Photometric Performance Standards or Recommended Values of Lamps Intended to Show Primarily to the Front of Motor Vehicles (Except Motorcycles).

| Coordinates | ROAD ILLUMINATION LAMPS | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SUPPLEMENTARY DRIVING LAMPS | | SUPPLEMENTARY PASSING LAMPS | | FOG LAMPS | | HEADLAMPS | | | | | | | | | |
| | | | | | | | 7 Inch Type 2 | | | | 5 3/4 Inch Type 1 | | 5 3/4 Inch Type 2 | | | |
| Vert. Horiz. | White Max | White Min | White Max | White Min | White to Yellow Max | White to Yellow Min | Upper Beam White Max | Upper Beam White Min | Lower Beam White Max | Lower Beam White Min | Upper Beam White Max | Upper Beam White Min | Upper Beam White Max | Upper Beam White Min | Lower Beam White Max | Lower Beam White Min |
| 90 U ↔ 10 U : 90 L ↔ 90 R | | | | | | | | | 125 | | | | | | 125 | |
| 10 U : 45 L | | | | | | | | | | | | | | | | |
| 10 L | | | | | | | | | | | | | | | | |
| 5 L | | | | | | | | | | | | | | | | |
| V | | | | | | | | | | | | | | | | |
| 5 R | | | | | | | | | | | | | | | | |
| 10 R | | | | | | | | | | | | | | | | |
| 45 R | | | | | | | | | | | | | | | | |
| 90 U ↔ 8 U : 90 L ↔ 90 R | | | | | 75† | | | | | | | | | | | |
| 5 U : 90 L ↔ 90 R | | | | | | | | | | | | | | | | |
| 5 U : 20 L | | | | | | | | | | | | | | | | |
| 10 L | | | | | | | | | | | | | | | | |
| 5 L | | | | | | | | | | | | | | | | |
| V | | | | | | | | | | | | | | | | |
| 5 R | | | | | | | | | | | | | | | | |
| 10 R | | | | | | | | | | | | | | | | |
| 20 R | | | | | | | | | | | | | | | | |
| 4 U : 90 L ↔ 90 R | | | | | 125 | | | | | | | | | | | |
| 3 U : 3 L | | | | | | | | 500 | | | | 450 | | 300 | | |
| 3 L ↔ 3 R | 3000 | | | | | | | | | | | | | | | |
| 3 R | | | | | | | | 500 | | | | 450 | | 300 | | |
| 2½ U : 90 L ↔ 90 R | | | | | | | | | | | | | | | | |
| 90 U ↔ 2 U : 1 R ↔ 90 R | | | 1000† | | | | | | | | | | | | | |
| 2 U : 90 L ↔ 90 R | | | | | 250 | | | | | | | | | | | |
| 3 L | | | | | | | | 1000 | | | | 750 | | 750 | | |
| 3 L ↔ 3 R | 5000 | | | | | | | | | | | | | | | |
| 3 R | | | | | | | | 1000 | | | | 750 | | 750 | | |
| 1½ U : 1 R ↔ 90 R | | | | | | | | | 1000 | | | | | | 1000 | |
| 90 U ↔ 1 U : 90 L ↔ 1 L | | | 400† | | | | | | | | | | | | | |
| 1 U : 90 L ↔ 90 R | | | | | 360 | | | | | | | | | | | |
| 90 L ↔ 1 L | | | | | | | | | 500 | | | | | | 500 | |
| 3 L | | | | | | | | 2000 | | | | 3000 | | 2000 | | |
| 3 L ↔ 3 R | 8000 | | | | | | | | | | | | | | | |
| 1 R ↔ 90 R | | | 3000 | | | | | | | | | | | | | |
| 3 R | | | | | | | | 2000 | | | | 3000 | | 2000 | | |
| ½ U : 90 L ↔ 1 L | | | 500 | | | | | | 800 | | | | | | 800 | |
| 1 R ↔ 3 R | | | | | | | | | 2000 | | | | | | 2000 | |
| H : 90 L ↔ 1 L | | | | | 500 | | | | | | | | | | | |
| 45 L | | | | | | | | | | | | | | | | |
| 30 L | | | | | | | | | | | | | | | | |
| 20 L | | | | | | | | | | | | | | | | |
| 10 L | | | | | | | | | | | | | | | | |
| 5 L | | | | | | | | | | | | | | | | |
| 3 L ↔ 3 R | | 7500 | | | | | | | | | | | | | | |
| V | 25000 | 15000 | | | | | | | | | | | | | | |
| 1 R ↔ 90 R | | | 7000 | | 1000 | | | | | | | | | | | |
| 5 R | | | | | | | | | | | | | | | | |
| 10 R | | | | | | | | | | | | | | | | |
| 20 R | | | | | | | | | | | | | | | | |
| 30 R | | | | | | | | | | | | | | | | |
| 45 R | | | | | | | | | | | | | | | | |
| ½ D : 90 L ↔ 1 L | | | 1000 | | | | | | 2000 | | | | | | 2000 | |
| 12 L | | | | | | | | 750 | | | | 750 | | 750 | | |
| 9 L | | | | | | | | 1500 | | | | 2000 | | 1000 | | |
| 6 L | | | | | | | | 3250 | | | | 3000 | | 2000 | | |
| 3 L | | | | | | | | 10000 | | | | 12000 | | 3000 | | |
| V | | | | | | | | 20000 | | | †† | 18000 | †† | 7000 | | |
| 2 R | | | | | | | | | 15000 | 6000 | | | | | 15000 | 6000 |
| 3 R | | | | | | | | 10000 | | | | 12000 | | 3000 | | |
| 6 R | | | | | | | | 3250 | | | | 3000 | | 2000 | | |
| 9 R | | | | | | | | 1500 | | | | 2000 | | 1000 | | |
| 12 R | | | | | | | | 750 | | | | 750 | | 750 | | |
| 1 D : 6 L | | | | | | | | | | 1000 | | | | | | 1000 |
| 6 L ↔ 6 R | | 2500 | | | | | | | | | | | | | | |
| 1½ D : 90 L ↔ 1 L | | | 3000 | | | | | | | | | | | | | |
| 9 L | | | | | | | | | | 1000 | | | | | | 1000 |
| 3 L ↔ 1 L | | | | | 8000 | | | | | | | | | | | |
| 1 R ↔ 3 R | | | | | | 2000 | | | | | | | | | | |
| 2 R | | | | | | | | | | 15000 | | | | | | 15000 |
| 2 R ↔ 4 R | | | | 1000 | | | | | | | | | | | | |
| 3 R ↔ 9 R | | | | | | 1000 | | | | | | | | | | |
| 9 R | | | | | | | | | | 1000 | | | | | | 1000 |
| 2 D : 15 L | | | | | | | | | | 700 | | | | | | 700 |
| 9 L | | | | | | | | 1500 | | | | 1250 | | 750 | | |
| 6 L ↔ 6 R | | 1500 | | | | | | | | | | | | | | |
| V | | | | | | | | 5000 | | | | 3000 | | 2000 | | |
| 9 R | | | | | | | | 1500 | | | | 1250 | | 750 | | |
| 15 R | | | | | | | | | | 700 | | | | | | 700 |
| 2½ D : 90 L ↔ 90 R | | | | | | | | | | | | | | | | |
| 3 D : 15 L ↔ 15 R | | | | | | 1000 | | | | | | | | | | |
| 12 L | | | | | | | | 750 | | | | 600 | | 400 | | |
| V | | | | | | | | 2500 | | | | 1500 | | 1000 | | |
| 12 R | | | | | | | | 750 | | | | 600 | | 400 | | |
| 4 D : V | | | | | | | 5000 | | | | 2500 | | 2500 | | | |
| 4 R | | | | | | | | | 12500 | | | | | | 12500 | |
| 5 D : 90 L ↔ 90 R | | | | | | | | | | | | | | | | |
| 30 L | | | | | | | | | | | | | | | | |
| 20 L | | | | | | | | | | | | | | | | |
| 10 L | | | | | | | | | | | | | | | | |
| 5 L | | | | | | | | | | | | | | | | |
| V | | | | | | | | | | | | | | | | |
| 5 R | | | | | | | | | | | | | | | | |
| 10 R | | | | | | | | | | | | | | | | |
| 20 R | | | | | | | | | | | | | | | | |
| 30 R | | | | | | | | | | | | | | | | |
| 10 D : 45 L | | | | | | | | | | | | | | | | |
| 10 L | | | | | | | | | | | | | | | | |
| 5 L | | | | | | | | | | | | | | | | |
| V | | | | | | | | | | | | | | | | |
| 5 R | | | | | | | | | | | | | | | | |
| 10 R | | | | | | | | | | | | | | | | |
| 45 R | | | | | | | | | | | | | | | | |
| OVERALL MAXIMUM | | | | | | | 37500 | | | | | | | | | |
| SOURCE OF STANDARDS | SAE J581††† | | SAE J582 | | SAE J583c | | SAE J579a | | | | | | | | | |

| Coordinates | SIGNAL LAMPS | | | | | | | | | DEMARCATION LAMPS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FRONT TURN SIGNAL LAMPS† | | | SCHOOL BUS LOADING & UNLOADING LAMPS | | EMERGENCY VEHICLE FLASHING LAMPS | | 360° REVOLVING BEACON LAMPS | | PARKING LAMPS | | CLEARANCE & ID. LAMPS |
| | Number of Sections | | | | | | | | | | | |
| Vert. Horiz. | One Yellow Min | Two Yellow Min | Three Yellow Min | Yellow Min | Red Min | Yellow Min | Red Min | Yellow Min | Red Min | White or Yellow Max | White or Yellow Min | Yellow Min |
| 90 U ↔ 10 U : 90 L ↔ 90 R | | | | | | | | | | | | |
| 10 U : 45 L | | | | | | | | | | | | 0.62 |
| 10 L | 25 | 30 | 35 | | | | | | | 125 | 0.8 | |
| 5 L | | | | | | 60 | 20 | | | | | |
| V | 60 | 75 | 90 | | | 150 | 50 | | | 125 | 0.8 | 0.62 |
| 5 R | | | | | | 60 | 20 | | | | | |
| 10 R | 25 | 30 | 35 | | | | | | | 125 | 0.8 | |
| 45 R | | | | | | | | | | | | 0.62 |
| 90 U ↔ 8 U : 90 L ↔ 90 R | | | | | | | | | | | | |
| 5 U : 90 L ↔ 90 R | | | | | | | | 175 | 60 | | | |
| 5 U : 20 L | 25 | 30 | 35 | 375 | 150 | 60 | 20 | | | 125 | 0.4 | |
| 10 L | 75 | 88 | 100 | 750 | 300 | 150 | 50 | | | 125 | 0.8 | |
| 5 L | 125 | 150 | 175 | 750 | 300 | 300 | 100 | | | 125 | 1.4 | |
| V | 175 | 205 | 225 | 750 | 300 | 450 | 150 | | | 125 | 2.8 | |
| 5 R | 125 | 150 | 175 | 750 | 300 | 300 | 100 | | | 125 | 1.4 | |
| 10 R | 75 | 88 | 100 | 750 | 300 | 150 | 50 | | | 125 | 0.8 | |
| 20 R | 25 | 30 | 35 | 375 | 150 | 60 | 20 | | | 125 | 0.4 | |
| 4 U : 90 L ↔ 90 R | | | | | | | | | | | | |
| 3 U : 3 L | | | | | | | | | | | | |
| 3 L ↔ 3 R | | | | | | | | | | | | |
| 3 R | | | | | | | | | | | | |
| 2½ U : 90 L ↔ 90 R | | | | | | | | 500 | 200 | | | |
| 90 U ↔ 2 U : 1 R ↔ 90 R | | | | | | | | | | | | |
| 2 U : 90 L ↔ 90 R | | | | | | | | | | | | |
| 3 L | | | | | | | | | | | | |
| 3 L ↔ 3 R | | | | | | | | | | | | |
| 3 R | | | | | | | | | | | | |
| 1½ U : 1 R ↔ 90 R | | | | | | | | | | | | |
| 90 U ↔ 1 U : 90 L ↔ 1 L | | | | | | | | | | | | |
| 1 U : 90 L ↔ 90 R | | | | | | | | | | | | |
| 90 L ↔ 1 L | | | | | | | | | | | | |
| 3 L | | | | | | | | | | | | |
| 3 L ↔ 3 R | | | | | | | | | | | | |
| 1 R ↔ 90 R | | | | | | | | | | | | |
| 3 R | | | | | | | | | | | | |
| ½ U : 90 L ↔ 1 L | | | | | | | | | | | | |
| 1 R ↔ 3 R | | | | | | | | | | | | |
| H : 90 L ↔ 1 L | | | | | | | | | | | | |
| 45 L | | | | | | | | | | | | 0.62 |
| 30 L | | | | 75 | 30 | | | | | | | 0.62 |
| 20 L | 35 | 45 | 50 | 450 | 180 | 90 | 30 | | | 125 | 0.4 | 0.62 |
| 10 L | 100 | 120 | 140 | 1000 | 400 | 225 | 75 | | | 125 | 1.4 | 0.62 |
| 5 L | 200 | 240 | 275 | 1250 | 500 | 600 | 200 | | | 125 | 3.6 | |
| 3 L ↔ 3 R | | | | | | | | | | | | |
| V | 200 | 240 | 275 | 1500 | 600 | 900 | 300 | | | 125 | 4.0 | 0.62 |
| 1 R ↔ 90 R | | | | | | | | | | | | |
| 5 R | 200 | 240 | 275 | 1250 | 500 | 600 | 200 | | | 125 | 3.6 | |
| 10 R | 100 | 120 | 140 | 1000 | 400 | 225 | 75 | | | 125 | 1.4 | 0.62 |
| 20 R | 35 | 45 | 50 | 450 | 180 | 90 | 30 | | | 125 | 0.4 | 0.62 |
| 30 R | | | | | | | | | | | | 0.62 |
| 45 R | | | | | | | | | | | | 0.62 |
| ½ D : 90 L ↔ 1 L | | | | | | | | | | | | |
| 12 L | | | | | | | | | | | | |
| 9 L | | | | | | | | | | | | |
| 6 L | | | | | | | | | | | | |
| 3 L | | | | | | | | | | | | |
| V | | | | | | | | | | | | |
| 2 R | | | | | | | | | | | | |
| 3 R | | | | | | | | | | | | |
| 6 R | | | | | | | | | | | | |
| 9 R | | | | | | | | | | | | |
| 12 R | | | | | | | | | | | | |
| 1 D : 6 L | | | | | | | | | | | | |
| 6 L ↔ 6 R | | | | | | | | | | | | |
| 1½ D : 90 L ↔ 1 L | | | | | | | | | | | | |
| 9 L | | | | | | | | | | | | |
| 3 L ↔ 1 L | | | | | | | | | | | | |
| 1 R ↔ 3 R | | | | | | | | | | | | |
| 2 R | | | | | | | | | | | | |
| 2 R ↔ 4 R | | | | | | | | | | | | |
| 3 R ↔ 9 R | | | | | | | | | | | | |
| 9 R | | | | | | | | | | | | |
| 2 D : 15 L | | | | | | | | | | | | |
| 9 L | | | | | | | | | | | | |
| 6 L ↔ 6 R | | | | | | | | | | | | |
| V | | | | | | | | | | | | |
| 9 R | | | | | | | | | | | | |
| 15 R | | | | | | | | | | | | |
| 2½ D : 90 L ↔ 90 R | | | | | | | | 500 | 200 | | | |
| 3 D : 15 L ↔ 15 R | | | | | | | | | | | | |
| 12 L | | | | | | | | | | | | |
| V | | | | | | | | | | | | |
| 12 R | | | | | | | | | | | | |
| 4 D : V | | | | | | | | | | | | |
| 4 R | | | | | | | | | | | | |
| 5 D : 90 L ↔ 90 R | | | | | | | | 125 | 50 | | | |
| 30 L | | | | 75 | 30 | | | | | | | |
| 20 L | 25 | 30 | 35 | 500 | 200 | 60 | 20 | | | 250 | 0.4 | |
| 10 L | 75 | 88 | 100 | 750 | 300 | 150 | 50 | | | 250 | 0.8 | |
| 5 L | 125 | 150 | 175 | 1125 | 450 | | | | | 250 | 1.4 | |
| V | 175 | 205 | 235 | 1125 | 450 | 450 | 150 | | | 250 | 2.8 | |
| 5 R | 125 | 150 | 175 | 1125 | 450 | | | | | 250 | 1.4 | |
| 10 R | 75 | 88 | 100 | 750 | 300 | 150 | 50 | | | 250 | 0.8 | |
| 20 R | 25 | 30 | 35 | 500 | 200 | 60 | 20 | | | 250 | 0.4 | |
| 30 R | | | | 75 | 30 | | | | | | | |
| 10 D : 45 L | | | | | | | | | | | | 0.62 |
| 10 L | 25 | 30 | 35 | | | | | | | 250 | 0.8 | |
| 5 L | | | | 100 | 40 | 60 | 20 | | | | | |
| V | 60 | 75 | 90 | 100 | 40 | 150 | 50 | | | 250 | 0.8 | 0.62 |
| 5 R | | | | 100 | 40 | 60 | 20 | | | | | |
| 10 R | 25 | 30 | 35 | | | | | | | 250 | 0.8 | |
| 45 R | | | | | | | | | | | | 0.62 |
| OVERALL MAXIMUM | | | | | | | | | | | | |
| SOURCE OF STANDARDS | SAE J575d | SAE J588e | SAE J588e | SAE J887 | SAE J887 | SAE J595b | SAE J595b | SAE J845 | SAE J845 | SAE J222 | | SAE J592c |

†When a parking lamp is optically combined with a turn signal, and the parking lamp is connected to be operated with the headlamps, the turn signal must not be less than *three* times the candlepower of the parking lamp at any test point on or above the horizon, except that at H-V, H-5L, H-5R, and 5U-V, the turn signal must not be less than *five* times the candlepower of the parking lamp. Also note that the standards for a one-section turn signal are equivalent to the former "Class A" standards incorporated into SAE J575d. That SAE Standard has been amended since issuance of the FMVSS 108 which established the current manufacturing requirements The two- and three-section photometric turn signal standards reflect this change in J575d and this transfer to J588e of the turn signal photometric standards.

††If 5¾ inch headlamps are used to meet the headlamp requirements (as discussed in the text of this literature review), the combined maximum candlepower of the Type 1 lamp and the upper beam of the Type 2 lamp must not exceed 37,500 candlepower at the ½D-V point for either side.

†††SAE Standard J581, covering Supplementary Driving Lamps, has been withdrawn from (not printed in) the 1972 and subsequent editions of the SAE Handbook.

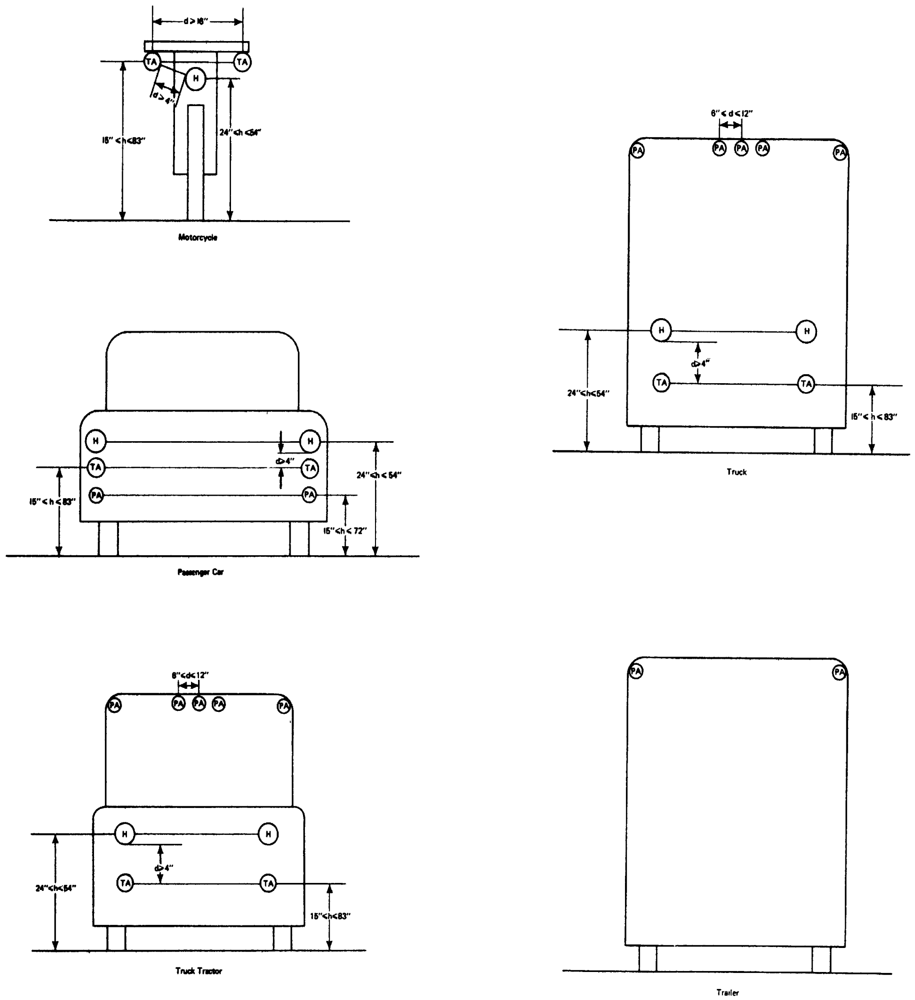



Figure 1.1. Lamps visible on the front of vehicles (see Table 1.2 for an explanation of symbols).

3. Number (minimum):
4. Size (Minimum):
5. Color
6. Location (spacing):
7. Other (general comments):

Source is FMVSS 108 (or SAE Standards referenced therein) unless otherwise specifically attributed.

Additional performance or use requirements or restrictions imposed by any state, if at variance with common usage or other nationally recognized criteria, are also cited.

Headlamps (SAE Standards J579a and J580a, and SAE Recommended Practice J584a).

Intent. Headlamps are intended primarily to illuminate the road surface ahead of the vehicle. The upper beam is a clear-road beam intended to illuminate the road surface well ahead of the vehicle. The lower beam is intended to be low enough on the left to avoid glare in the eyes of oncoming drivers, and is supposed to be used in congested areas and on highways when meeting or closely following other vehicles. A secondary intention of the headlamps is to serve as a means of signaling. Specifically, flashing headlamps are sometimes used on emergency vehicles. Also, the flashing of headlamps in certain codes is used as a form of communication between drivers of large commercial vehicles.

Method of Activation. The headlamp system is manually operated. Beam changing within the system is accomplished by manual or semi-automatic switching, as prescribed in SAE Standards J564b and J565b.

Number - Size: Automobiles, Trucks and Buses. Two 5 3/4" type 1 and two 5 3/4" type 2 headlamps; or two 7" type 2 headlamps.

Number - Size: Motorcycles. One 5 3/4" type 1 and one 5 3/4" type 2 headlamps; or one 7" type 2 headlamp; or one of the type specified in Table 1.4. (Note: SAE Standard 584, the version included within FMVSS 108, permits single-beam headlamps on motor-driven cycles. The revised Standard J584b deletes reference to [and the acceptability of] single-beam equipment for motor-driven cycles. Motorcycle dual-beam and motor-driven cycle dual- or single-beam headlamps have no size requirements. The revised Standard J584b also recognizes for classes [A, B, C, D] of motorcycles, see J213.)

Color. White.

Location - Automobiles, Trucks and Buses. Type 2 headlamps must be mounted at the same height, one on each side of the vertical centerline, as far apart as practicable. Type 1 headlamps, when required in addition to type 2 headlamps, must be mounted at the same height as each other, but need not be mounted at the same height as the two type 2 headlamps, one on each side of the vertical centerline. The type 2 headlamps must be mounted at least as far apart as the type 1 headlamps, where both types are used, to meet the above criteria. The mounting height, measured from the middle of the headlamp bulb, must be not less than 24" nor more than 54" above the level road surface on which the vehicle stands.

Location - Motorcycles. If only one is used, it must be on the vertical centerline. If more than one are used to meet the above requirements, they must be symmetrically disposed about the vertical centerline.

Other. In most states, the Vehicle Codes require that when two vehicles approach at night, they each must have switched from their upper to their lower headlamp beams when their vehicles are at 500 feet. In the remaining states, this requirement varies only in the distance by which this beam change must have been accomplished.

The FHWA and some states require that the headlamps be

TABLE 1.4. Photometric Performance Standards or Recommended Values of Lamps Intended to Show Primarily to the Front of Motorcycles.

| Coordinates | ROAD ILLUMINATION LAMPS | | | | | | | | | | | | | | | | | | | | SIGNAL LAMPS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HEADLAMP(S) | | | | | | | | | | | | | | | | | | | | FRONT TURN SIGNAL LAMPS | EMERGENCY VEHICLE FLASHING LAMPS | | 360° REVOLVING BEACON LAMPS | |
| | 7 Inch Type 2 | | | | 5¾ Inch Type 1 | | 5¾ Inch Type 2 | | | | Motorcycle | | | | Motor-Driven Cycle Dual Beam | | | | Motor-Driven Cycle | | | | | | |
| | Upper Beam White | | Lower Beam White | | Upper Beam White | | Upper Beam White | | Lower Beam White | | Upper Beam White | | Lower Beam White | | Upper Beam White | | Lower Beam White | | Single Beam White | | Yellow | Yellow | Red | Yellow | Red |
| Vert Horiz | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Min | Min | Min | Min | Min |
| 90 U ↔ 10 U: 90 L ↔ 90 R | | | 125 | | | | | | 125 | | | | | | | | | | | | | | | | |
| 10 U: 10 L | | | | | | | | | | | | | | | | | | | | | 15 | | | | |
| 5 L | | | | | | | | | | | | | | | | | | | | | | 60 | 20 | | |
| V | | | | | | | | | | | | | | | | | | | | | 30 | 150 | 50 | | |
| 5 R | | | | | | | | | | | | | | | | | | | | | | 60 | 20 | | |
| 10 R | | | | | | | | | | | | | | | | | | | | | 15 | | | | |
| 5 U: 90 L ↔ 90 R | | | | | | | | | | | | | | | | | | | | | | | | 125 | 50 |
| 5 U: 20 L | | | | | | | | | | | | | | | | | | | | | 15 | 60 | 20 | | |
| 10 L | | | | | | | | | | | | | | | | | | | | | 40 | 150 | 50 | | |
| 5 L | | | | | | | | | | | | | | | | | | | | | 60 | 300 | 100 | | |
| V | | | | | | | | | | | | | | | | | | | | | 90 | 450 | 150 | | |
| 5 R | | | | | | | | | | | | | | | | | | | | | 60 | 300 | 100 | | |
| 10 R | | | | | | | | | | | | | | | | | | | | | 40 | 150 | 50 | | |
| 20 R | | | | | | | | | | | | | | | | | | | | | 15 | 60 | 20 | | |
| 3 U: 3 L | | 500 | | | | 450 | | 300 | | | | | | | | | | | | | | | | | |
| 3 R | | 500 | | | | 450 | | 300 | | | | | | | | | | | | | | | | | |
| 2½ U: 90 L ↔ 90 R | | | | | | | | | | | | | | | | | | | | | | | | 500 | 200 |
| 2 U: 3 L | | 1000 | | | | 750 | | 750 | | | | | | | | | | | | | | | | | |
| 3 R | | 1000 | | | | 750 | | 750 | | | | | | | | | | | | | | | | | |
| 1½ U: 1 R ↔ 90 R | | | 1000 | | | | | | 1000 | | | | 1000 | | | | 1000 | | | | | | | | |
| 1 U: 90 L ↔ 1 L | | | 500 | | | | | | 500 | | | | 500 | | | | 500 | | | | | | | | |
| 4 L | | | | | | | | | | | | | | | | | | | 400 | | | | | | |
| 3 L | | 2000 | | | | 3000 | | 2000 | | | | | | | | | | | | | | | | | |
| V | | | | | | | | | | | | | | | | | | | 1000 | 200 | | | | | |
| 3 R | | 2000 | | | | 3000 | | 2000 | | | | | | | | | | | | | | | | | |
| ½ U: 90 L ↔ 1 L | | | 800 | | | | | | 800 | | | | 800 | | | | 800 | | | | | | | | |
| 1 R ↔ 3 R | | | 2000 | | | | | | 2000 | | | | 2000 | | | | 2000 | | | | | | | | |
| H: 20 L | | | | | | | | | | | | | | | | | | | | | 20 | 90 | 30 | | |
| 10 L | | | | | | | | | | | | | | | | | | | | | 45 | 225 | 75 | | |
| 5 L | | | | | | | | | | | | | | | | | | | | | 120 | 600 | 200 | | |
| V | | | | | | | | | | | | 10000 | | | | 2000 | | | | 2000 | 120 | 900 | 300 | | |
| 5 R | | | | | | | | | | | | | | | | | | | | | 120 | 600 | 200 | | |
| 10 R | | | | | | | | | | | | | | | | | | | | | 45 | 225 | 75 | | |
| 20 R | | | | | | | | | | | | | | | | | | | | | 20 | 90 | 30 | | |
| ½ D: 90 L ↔ 1 L | | | 2000 | | | | | | 2000 | | | | 2000 | | | | 2000 | | | | | | | | |
| 12 L | | 750 | | | | 750 | | 750 | | | | | | | | | | | | | | | | | |
| 9 L | | 1500 | | | | 2000 | | 1000 | | | | | | | | | | | | | | | | | |
| 6 L | | 3250 | | | | 3000 | | 2000 | | | | 1000 | | | | 750 | | | | 750 | | | | | |
| 3 L | | 10000 | | | | 12000 | | 3000 | | | | 4000 | | | | 3000 | | | | 3000 | | | | | |
| V | | 20000 | | | * | 18000 | * | 7000 | | | | 20000 | | | | 5000 | | | | 5000 | | | | | |
| 1 R ↔ 90 R | | | | | | | | | | | | | 10000[++] / 15000 | | | | 10000[++] / 15000 | | | | | | | | |
| 2 R | | | 15000 | 6000 | | | | | 15000 | 6000 | | | | | | | | | | | | | | | |
| 3 R | | 10000 | | | | 12000 | | 3000 | | | | 4000 | | | | 3000 | | | | 3000 | | | | | |
| 6 R | | 3250 | | | | 3000 | | 2000 | | | | 1000 | | | | 750 | | | | 750 | | | | | |
| 9 R | | 1500 | | | | 2000 | | 1000 | | | | | | | | | | | | | | | | | |
| 12 R | | 750 | | | | 750 | | 750 | | | | | | | | | | | | | | | | | |
| 1 D: 6 L | | | | 1000 | | | | | | 1000 | | | | | | | | | | | | | | | |
| V | | | | | | | | | | | | 15000 | | | | 5000 | | | | 5000 | | | | | |
| 1½ D: 9 L | | | | 1000 | | | | | | 1000 | | | | | | | | | | | | | | | |
| 2 R | | | | 15000 | | | | | | 15000 | | | | | | | | | | | | | | | |
| 9 R | | | | 1000 | | | | | | 1000 | | | | | | | | | | | | | | | |
| 2 D: 15 L | | | | 700 | | | | | | 700 | | | | | | | | | | | | | | | |
| 9 L | | 1500 | | | | 1250 | | 750 | | | | | | | | | | | | | | | | | |
| 6 L | | | | | | | | | | | | | | 750 | | | | 500 | | | | | | | |
| 3 L | | | | | | | | | | | | | | 2000 | | | | 1500 | | | | | | | |
| V | | 5000 | | | | 3000 | | 2000 | | | | 5000 | | | | 3000 | | | | 3000 | | | | | |
| 3 R | | | | | | | | | | | | | | 3000 | | | | 2000 | | | | | | | |
| 6 R | | | | | | | | | | | | | | 750 | | | | 500 | | | | | | | |
| 9 R | | 1500 | | | | 1250 | | 750 | | | | | | | | | | | | | | | | | |
| 15 R | | | | 700 | | | | | | 700 | | | | | | | | | | | | | | | |
| 2½ D: 90 L ↔ 90 R | | | | | | | | | | | | | | | | | | | | | | | | 500 | 200 |
| 3 D: 12 L | | 750 | | | | 600 | | 400 | | | | | | | | | | | | | | | | | |
| 6 L | | | | | | | | | | | | 750 | | | | 500 | | | | 500 | | | | | |
| V | | 2500 | | | | 1500 | | 1000 | | | | 2500 | | | | 1000 | | | | 1000 | | | | | |
| 6 R | | | | | | | | | | | | 750 | | | | 500 | | | | 500 | | | | | |
| 12 R | | 750 | | | | 600 | | 400 | | | | | | | | | | | | | | | | | |
| 4 D: V | 5000 | | | | 2500 | | 2500 | | | | 5000 | | | | 5000 | | | | 5000 | | | | | | |
| 4 R | | | 12500 | | | | | | 12500 | | | | 12500 | | | | 12500 | | | | | | | | |
| 5 D: 90 L ↔ 90 R | | | | | | | | | | | | | | | | | | | | | | | | 125 | 50 |
| 5 D: 20 L | | | | | | | | | | | | | | | | | | | | | 15 | 60 | 20 | | |
| 10 L | | | | | | | | | | | | | | | | | | | | | 40 | 150 | 50 | | |
| 5 L | | | | | | | | | | | | | | | | | | | | | 60 | | | | |
| V | | | | | | | | | | | | | | | | | | | | | 90 | 450 | 150 | | |
| 5 R | | | | | | | | | | | | | | | | | | | | | 60 | | | | |
| 10 R | | | | | | | | | | | | | | | | | | | | | 40 | 150 | 50 | | |
| 20 R | | | | | | | | | | | | | | | | | | | | | 15 | 60 | 20 | | |
| 10 D: 10 L | | | | | | | | | | | | | | | | | | | | | 15 | | | | |
| 5 L | | | | | | | | | | | | | | | | | | | | | | 60 | 20 | | |
| V | | | | | | | | | | | | | | | | | | | | | 30 | 150 | 50 | | |
| 5 R | | | | | | | | | | | | | | | | | | | | | | 60 | 20 | | |
| 10 R | | | | | | | | | | | | | | | | | | | | | 15 | | | | |
| OVERALL MAXIMUM | 37500 | | | | | | | | | | 75000 | | | | 75000[+++] | | | | | | | | | | |
| SOURCE OF STANDARDS | | | SAE J579a | | | | | | | | | SAE J584 | | | | SAE J584a | | | SAE J584 | | SAE J575d[++++] | SAE J595b | | SAE J845 | |

[+] If 5¾ - inch headlamps are used to meet the headlamp requirement (as discussed in the text of this literature review), the combined maximum candlepower of the Type 1 lamp and the upper beam of the Type 2 lamp must not exceed 37,500 candlepower at the ½ D-V point for either lamp.

[++] SAE Recommended Practice J584, as it appeared in the 1970 edition of the SAE Handbook and from which the FMVSS 108 requirements are derived, was amended by SAE J584a to raise the recommended maximum candlepower for the lower beams of motor cycle and motor driven cycle dual beam headlamps to 15,000 from the previous level of 10,000 candlepower

[+++] SAE Recommended Practice J584 did not include an overall maximum candlepower level for the upper beam of the dual beam headlamps for motor-driven cycles. However, SAE J584b does now include such a recommended maximum.

[++++] These provisions of SAE Standard J575d have since been made into a separate Recommended Practice, J131.

switched on the lower beam at night when following another vehicle within a certain distance.

When the upper beam is on, a lighted pilot lamp with a minimum area equivalent to that of a 3/16" diameter circle must be plainly visible to drivers of all heights under normal driving conditions when headlamps are required. The color of this pilot lamp need not be red, however (Cf. SAE Standards J564a and J564b with FMVSS 108 S4.5.2.).

The beam or beams from headlamps must meet the photometric specifications shown in Tables 1.3 and 1.4 except that a tolerance of ±1/4° in location of the test point measurement is allowed for each of the points.

NCUTLO recommends (and some states require) that whenever a motor vehicle equipped with headlamps is also equipped with any auxiliary lamps, spot lamps, or any other lamps on the front thereof projecting a beam of greater intensity than 300 candelas, not more than a total of four of any such lamps on the front may be lighted at any one time when upon a highway. Some states instead specify the maximum number of lamps permitted on the front of a vehicle.

Supplementary Driving Lamps (former SAE Standard J581).

Intent. Driving lamps are intended to supplement the upper beam from headlamps (other than sealed beams), recommended SAE Standard J581, which has since been withdrawn. They are not intended for use alone or with the "traffic" or lower headlamp beam(s).

Method of Activation. SAE recommended that the supplementary driving lamp should be turned off when approaching or closely following other cars, and that the switching should be so arranged that when the supplementary driving lamp switch closed, the lamp will be lighted only when the upper beam from the regular headlamps is in use.

Number. NCUTLO recommends that no more than two be used on a vehicle.

Size. No recommendations exist.

Color. SAE recommended white.

Location. NCUTLO recommends they be located on the vehicle's front at a height of not less than 16 inches nor more than 42 inches above the level road surface on which the vehicle stands.

Other. SAE recommended the photometric specifications shown in Table 1.3 when the driving lamp is aimed to center the maximum intensity on the photometric axis, except that when the maximum exceeds 25,000 candelas, the 25,000 candelas point directly above the maximum intensity should be aimed at the photometric axis. The maximum anywhere not lower than ID should be not greater than 50,000 candelas. An aiming tolerance of ±1/4° should be allowed for manufacturing variances. An additional tolerance of ±20% should be allowed for 12-volt filaments.

Supplementary Passing Lamps (SAE Standard J582).

Intent. Passing lamps are intended to supplement the lower beam of the headlamps, including sealed beam headlamps.

Method of Activation. SAE suggests manual or semi-automatic operation. The unit should be turned off when traveling winding roads and in congested areas in cities. It should be wired so that it can be turned on or off only with the lower beam of the regular headlamps.

Number. NCUTLO recommends that no more than two be used on a vehicle.

Size. No recommendations exist.

Color. SAE recommends white.

Location. NCUTLO recommends they be located on the vehicle's front at a height of not less than 24 inches nor more than 42 inches above the roadway surface.

Other. SAE recommends that for greatest visibility, with reasonable limitation of glare to approaching drivers, the left edge of the stray light immediately to the left of the high intensity zone should be aimed at the vertical line through the lamp center, at 25 feet. The top of the high intensity zone should be aimed at the level of the passing lamp center at 25 feet, car unloaded. If means are provided to permit turning the passing lamp on or off conveniently, when the lower beam is on, without removing the hands from the steering wheel, an aim 3 inches higher than that recommended above is desirable. An aiming tolerance of ±1/4° should be allowed on individual test points. An additional tolerance of ±20% should be allowed for 12-volt filaments.

Fog Lamps (SAE Standard J583c).

Intent. Fog lamps are intended to supplement or replace lower beam headlamps in providing road illumination under conditions of rain, snow, dust, or fog.

Method of Activation. No recommendations exist.

Number. NCUTLO recommends that not more than two be used on a vehicle.

Size. No recommendations exist.

Color. SAE recommends white or yellow.

Location. NCUTLO recommends that the lamps should be located not lower than 12 inches nor more than 30 inches above the road surface. Also, the lamps should be so aimed that when the vehicle is not loaded, none of the high-intensity portion of the light to the left of the center of the vehicle shall, at a distance of 25 feet ahead, project higher than a level of 4 inches below the level of the center of the lamp from which it comes.

Other. The HUF summary of fog lamp provisions in the various State Vehicle Codes states: "Considerable variations in phraseology is found in the several state regulations. Several of the states make the distinction between auxiliary driving lamps, passing lamps, and fog lamps provided by the Uniform Code. The majority, however, specify the number of lamps permitted, the location of such lamps and the manner of use. Such lamps in many jurisdictions are to be used only in case of adverse weather or under conditions causing headlight illumination to be ineffective. Some states make specific provisions for fog lights, others have provisions which specify auxiliary lighting equipment. It appears that reference to lamps located 12 to 30 inches above the highway are fog lights, and those 16 inches to 42 inches are auxiliary lamps." SAE Standard J583c differentiates between symmetrical beams and assymetrical beams insofar as the aiming instructions for the photometer tests are concerned. A tolerance of ±1/4° should be allowed for any test point. An additional tolerance of ±20% should be allowed for out-of-focus tests on nonsealed beam units.

Front Turn Signal Lamps (SAE Standards J588d, J588e, and J575d, and SAE Recommended Practice J131a).

Intent. Front turn signal lamps indicate the intent to change direction by flashing the lamp on the side toward which the turn will be made.

Method of Activation. The signal must be able to be activated and cancelled manually, and may in addition be automatically cancellable (see SAE Standard J589a).

Number. Two on all vehicles, excluding trailers.

Size. Those multipurpose passenger vehicles, trucks, and buses of 80 or more inches overall width must be equipped with front turn signal lamps which have an effective projected luminous area of not less than 12.0 square inches. All passenger cars, motorcycles (except as noted above), and also those multipurpose passenger vehicles, trucks, and buses of less than 80 inches overall width, must be equipped with front turn signal lamps which have an effective projected luminous area of not less than 3.5 square inches.

If multiple compartment or multiple lamp arrangements are used to meet the photometric requirements of a front turn signal lamp on passenger cars or motorcycles, or on those multipurpose passenger vehicles, trucks, and buses of less than 80 inches overall width, the effective projected luminous area of each compartment or lamp must be not less than 3.5 square inches. FMVSS 108, probably through oversight, does not currently extend this requirement to multipurpose passenger vehicles, trucks, and buses of 80 or more inches overall width. SAE does not recommend such for these latter classes of vehicles.

Color. Amber. However, all states permit white. Some do not require a specific color, other than to prohibit the use of red or blue.

Location. The front turn signal lamps must be mounted at or near the front of the vehicle, at the same height but not lower than 15 inches nor higher than 83 inches (as measured to their optical axes) from the level road surface on which the vehicle stands, and as far apart from each other as practicable.

When used on motorcycles, the lamps must have a horizontal separation distance of not less than 16 inches, and must have an edge-to-edge separation distance from the headlamp(s) of not less than 4 inches. On other vehicles required to have front turn signal lamps, the optical axis must be at least 4 inches from the inside diameter of the retaining ring of the headlamp unit providing the lower beam on that side of the vehicle.

SAE recommends that the optical axes of the front turn signal lamps should also be at least 4 inches from the lighted edge of any other lamps, such as fog lamps or passing lamps, which are used to supplement or replace the lower headlamp beam, unless the ratio of the projected light outputs between the front turn signal lamp and such other lamps is at least 5:1 at H-V, H-5L, H-5R, and 5U-V, and in addition is at least 3:1 at all other test points above the horizon from 20L to 20R.

Other. The minimum photometric requirements for single compartment yellow turn signal lamps have been grouped into "zones," comprised of the cumulative minimum values of the test points in each of the seven zones designated [37 F.R. 21328]. Furthermore, increased group photometric requirements for multiple compartment yellow turn signal lamps, identical to the SAE recommendations in J588e, are being adopted effective September 1, 1974. No previous multiple compartment photometric requirements for yellow turn signal lamps (Class A or Class B) were formally specified. (Informally, the specifications of J588e have been suggested by the NHTSA.)

When a parking lamp is optically combined with the front turn signal lamp, the ratio of the projected light outputs between the front turn signal lamp and the parking lamp must be at least 5:1 at H-V, H-5L, H-5R, and 5U-V, and in addition must be at least 3:1 at all other test points on or above the horizon.

SAE recommends that, if multiple compartment or multiple lamp arrangements are used for front turn signals on vehicles less than 80 inches in overall width, and the distance between optical axes does not exceed 22 inches for two-compartment or two-lamp arrangements on such vehicles, and does not exceed 16 inches for three-compartment or three-lamp arrangements on such vehicles, then the combination of the compartment or lamp arrangements should be used to meet the photometric requirements for the corresponding number of lighted sections (see Table 1.3). Furthermore, if the parking lamp and the turn signal lamp functions are optically combined, the ratio of the projected light outputs should be computed with all compartments or lamps lighted. However, if the distance between optical axes exceeds the above dimensions, each compartment or lamp should comply individually with the photometric requirements for one lighted section, and should individually have an effective projected luminous area of not less than 3.5 square inches. In this latter instance, if the parking lamp and turn signal lamp functions are optically combined, the ratio of their projected lighted outputs should be computed only for those compartments or lamps where the two functions are actually optically combined, not for the whole array.

SAE further recommends that for vehicles of 80 or more inches in overall width, a maximum of two compartments or lamps per side may be mounted closer together than 22 inches provided that each compartment or lamp meets the single compartment photometric requirements and has an effective projected luminous area of not less than 12 square inches. Although not specifically stated, this recommendation presumably also permits two or more lamps or compartments on each side with optical axes 22 or more inches from each other, but only so long as each lamp or compartment individually meets the photometric requirements for a single lighted section, and has an effective projected luminous area of not less than 12 square inches apiece.

The flashing signal light output from a double-faced turn signal lamp must not be obliterated when subjected to external light rays from either in front or behind.

Additional requirements exist about not obscuring the visibility of the front turn signal lamps by other parts or sections of the vehicle.

The various states require that when activated, the front turn signal lamps be visible at certain distances in normal sunlight, but not be glaring. The minimum distances vary with vehicle type (width, commercial application, etc.), but in all cases where specified, range between 100 and 500 feet.

NCUTLO recommends (and FHWA requires) that turn signals not be flashed on one side only [left, or right] to indicate a parked or disabled vehicle. FHWA further requires that no turn signal lamp be combined with any headlamp or other lighting device or combination of lighting devices capable of producing a greater intensity of light than the turn signal when the latter is activated.

By reference to SAE J588d within FMVSS 108, the following is required: if any turn signal lamp is not readily visible to the driver, there shall be an illuminated indicator to give him a clear and unmistakable indication that the turn signal system is turned "on." Except on truck tractor-trailer combinations using variable load flashers, failure of one or more turn signal lamps to operate should be indicated by a "steady on," "steady off" or by a significant change in the flashing rate of the illuminated indicator. The illuminated indicator shall consist of one or more bright lights flashing at the same frequency as the signal lamps, and shall be plainly visible to drivers of all heights when seated in normal position in the driver's seat, while driving in bright sunlight. The illuminated indicator may be supplemented by an audible signal. If the illuminated indicator is located inside the vehicle, for example in the instrument cluster, it should emit a green color and have a minimum area equivalent to a 3/16 inch diameter circle. If the illuminated indicators are located on the outside of the vehicle, for example on the front fenders, they should emit a yellow color and have a minimum area of 0.1 square inch.

Front Traffic Hazard Warning Lamps (SAE Standards J588d, J588e, J575d, and J910a, and SAE Recommended Practice J945).

Intent. Front traffic hazard warning lamps indicate the presence of a vehicular hazard by flashing the front left and right turn signal lamps.

Method of Activation. Activation must be independent of the setting of the ignition switch. If requiring the operation of more than one switch, they must be able to be actuated simultaneously with a single driver action.

Number. Two, at least one on either side of the front of the vehicle, except none are required on trailers (or semi-trailers) or on motorcycles (or motor-driven cycles).

Size. No requirements exist apart from those previously outlined for front turn signal lamps.

Color. No requirements exist apart from those previously outlined for front turn signal lamps.

Location. No requirements exist apart from those previously outlined for front turn signal lamps.

Other. In addition to the comments made about front turn signal lamps, the following points should be made:

1. For vehicles equipped with left- and right-hand turn signal pilot indicator lamps, both pilots must flash simultaneously while the hazard warning system is activated.

2. In vehicles equipped with a single turn signal pilot indicator lamp, a separate hazard warning pilot indicator lamp must flash (and the turn signal pilot indicator lamp may flash) when the hazard warning system is activated.

3. If a separate hazard pilot indicator lamp is used, it must be red in color and must have an area equivalent to an 0.5 inch diameter circle or greater.

4. The operating motion of the hazard warning signal switch must be different from the actuating motion of the turn signal switch.

Some states specify that the hazard warning lamps may be used only when the vehicle is not in motion, or when it is being brought to a stop. Some make specific requirements for rural mail delivery vehicles, and then in some cases the lamps are allowed or required to flash alternately instead of simultaneously. Otherwise, most states require the front hazard warning lamps flash simultaneously when activated. Some states specify that the lamps for rural mail delivery vehicles must be hood mounted, and/or may emit a red color to the front.

All states permit white to be used for front hazard warning lamps. Some make no restrictions on the colors, while some prohibit red, blue, and/or green.

One state permits the use of hazard warning sign lamps only at night.

Many states have a minimum distance at which these lamps must be visible at night, ranging from 100 to 1500 feet. Some specify instead that the minimum distance of 100 feet be the criterion in bright sunlight.

Front School Bus Loading and Unloading Lamps (SAE Standard J887).

Intent. School bus loading and unloading lamps identify a vehicle as a school bus and inform other drivers that such vehicle is stopped on the road ahead to take on or to discharge school children. (In most states, traffic approaching a loading or unloading school bus from either in front or behind must come to a complete halt until the loading or unloading process is completed.)

Method of Activation. These lamps must be controlled by a manually actuated switch. Where System B (as described below) is used, the signal system must be wired so that the yellow signal lamps are activated only by manual or foot operation, and if activated, are automatically deactivated and the red signal lamps automatically activated when the bus entrance door is opened.

Number and Color. System A - two red lamps; system B - two red lamps, and two yellow lamps.

Size. The effective projected luminous area must be not less than 19 square inches.

Location. System A - they must be mounted as high as possible above the front windshield and at the same height, and as far apart as possible, but in no case less than 40 inches from each other, measured edge to edge. System B - the red lamps are mounted in the same location as in System A above. The yellow lamps are mounted immediately inboard, towards the vertical centerline of the bus, from each of the red lamps and at the same height as each other and the red lamps.

Other. The lamps must flash alternately at a rate between 60 to 120 cycles per minute. The "on" period of the flasher must be long enough to permit the bulb filament to come to full brightness. There must be a visible or audible means of giving a clear and unmistakable indication to the driver when the signal lamps are turned on. Further requirements exist as to not permitting any part of the vehicle to obstruct the visibility of the lamps within certain angles of view.

SAE recommends that the area of the vehicle immediately surrounding the signal lamp be painted black. This recommendation is specifically exempt in FMVSS 108 from the Federal requirements.

When System B is used, the yellow lamps must be at least two and one half times brighter than the specifications in SAE Standard J887 for red signal lamps.

The aiming pads on the lens face mentioned in SAE Standard J887 are also exempt in FMVSS 108.

The various states probably specify whether System A or System B may be used within their jurisdictions. No summary of lamp requirements or prohibitions, nor of conditions or prohibitions of use in the various states is readily available for this review.

Flashing Warning Lamps for Authorized Emergency, Maintenance, and Service Vehicles (SAE Standard J595b).

Intent. The lamps covered in this section are for use on authorized emergency, maintenance, and service vehicles.

Method of Activation. No specifications or recommendations exist.

Number. SAE recommends that there be two on the vehicle front.

Size. SAE recommends each lamp have an area of not less than 12 square inches.

Color. SAE recommends the color be yellow or red.

Location. SAE recommends that the lamps be mounted as high as practicable, and as far apart as practicable, but in no case should the lateral spacing be less than three feet. The location of the front lamps should be such that they can be clearly distinguished when the headlamps are lighted on lower beam.

Other. SAE recommends that these warning lamps should flash at 60-120 cpm. The "on" period of the flasher should be between 30% and 75%. (In comparison with turn signal hazard warning signal flasher requirements, SAE Standards J590c and J945 respectively, the time period and phase recommendations of SAE Standard J595b, covering these emergency lamps, encompasses the entire area within the rectangle, not merely the unshaded area.) There should be a visible or audible means of giving a clear and unmistakable indication to the driver when the warning lamps are turned "on" and functioning normally. To improve the effectiveness of the signal, SAE recommends that, where practicable, the area of the vehicle immediately surrounding the signal be painted black.

The various states set specific standards as to what color of flashing warning lamps (other than hazard flashing lamps utilizing the turn signal lamps) may be used on various types and authorizations of vehicles. The circumstances of permissible use are also covered. No summary of uses in the various states is readily available for this review.

Three-Hundred and Sixty Degree Revolving Beacon Lamp (SAE Recommended Practice J845).

Intent. The lamps are intended for use on authorized emergency vehicles, and emit light 360° through the horizontal plane passing through the lamp.

Method of Activation. SAE recommends that such beacon lamps be provided with an illuminated switch or pilot indicator to give the driver a clear and unmistakable indication that the beacon lamp is turned on.

Number. No recommendations exist.

Size. SAE recommends that the specific style or model of beacon lamp be chosen with reference to its performance characteristics and the requirements needed for the specific application. Otherwise, SAE recommends that the beacon lamp have an effective projected luminous area of not less than 16 square inches.

Color. SAE recommends that beacon lamps be yellow or red when used in highway emergency service missions. The various states establish permissible colors for beacon lamps in their respective Vehicle Codes. The use of blue, green, and white has also been observed.

Location. The beacon lamps should be mounted to provide 360° visibility at all times.

Other. SAE recommends that the device project a beam of light having a vertical spread of at least 10°, extending a minimum of 5° above and below the horizontal axis of the light source. The flash rate observed from a fixed position should be 60-120 cpm. When the flash rate is produced by a current interruption, the "on" period should be long enough to permit the bulb to come to full brightness.

No summary of the performance requirements, or of the use permissions or prohibitions in the various states is available for this review.

Parking Lamps (SAE Standard J222).

Intent. Whether separate or in combination with other lamps, parking lamps are intended to show to the front of the vehicle and to mark the vehicle when parked, or to show the dimension of the front of the vehicle if one or more of its headlamps are not properly functioning.

Method of Activation. The lamps must be able to be activated manually, and must be lighted automatically upon the activation of the headlamp system in a steady-burning state.

Number. Two on all vehicles, excluding motorcycles, trailers, and those multipurpose passenger vehicles, trucks, and buses of 80 or more inches overall width.

Size. No recommendations exist.

Color. White or yellow.

Location. One on each side of the vertical centerline, at the same height and as far apart as practicable. The mounting height must be not less than 15 inches nor more than 72 inches from the level roadway on which the vehicle stands.

Other. The intensity requirements are shown in Table 1.2.

The minimum photometric requirements for parking lamps have been grouped into "zones," comprised of the cumulative minimum values of the test points in each of the seven zones designated [37 F.R. 21328].

In addition, if the parking lamp is optically combined with the turn signal lamp, and the parking lamp is connected to be operated with the headlamps, their relative intensities must meet or exceed certain proportions, as discussed previously in the section on front turn signal lamps.

NCUTLO recommends and most states require that, when the vehicle is parked, the headlamps must also be "depressed or dimmed." Presumably this means the headlamps should either be turned off altogether, or if left on, should not be on high beam. The states themselves mostly refer to "dimmed," rather than "depressed."

Front Clearance Lamps (SAE Standard J592c and J592e).

Intent. The front clearance lamps show to the front and are intended to indicate overall width of the vehicle.

Method of Activation. No specifications exist. Usually the front clearance lamps are manually activated, sometimes as an integral part of the headlamp and/or parking/taillamp circuitry.

Number. Two front clearance lamps are required on those multipurpose passenger vehicles, trucks, trailers, and buses of 80 or more inches overall width.

Size. No recommendations exist.

Color. Yellow.

Location. One must be located on either side of the vertical centerline, at the same height, as near the top as practicable, to indicate overall width of the vehicle. On a truck tractor, front clearance lamps mounted on the cab may be located to indicate width of the cab, rather than the overall width of the vehicle.

Other. No clearance lamp may be combined optically with any identification lamp. Boat trailers need not be equipped with clearance lamps at the front and rear provided that a yellow (to front) and red (to rear) clearance lamp is located at or near the mid-point on each side of the trailer so as to indicate its extreme width when viewed from the front or rear. In a small number of states, other required or permitted types of clearance lamp systems are found: only one lamp instead of two on the front, green and white as optional colors to yellow, a 60-inch height limitation, etc.

SAE Standard J592c is incorporated by reference into FMVSS 108. This standard has since been revised to remove the following test points for front clearance lamps: H-30L and R, H-20L and R, and H-10L and R.

Front Identification Lamps (SAE Standard J592c and J592e).

Intent. Identification lamps are to identify vehicles that are over a certain width.

Method of Activation. No specification exists. Usually these are activated in the same manner as clearance and side-marker lamps.

Number. Three front identification lamps are required on those multipurpose passenger vehicles, trucks, and buses of

80 or more inches overall width. They are not required on trailers, regardless of width, in the FMVSS 108 manufacturing standards. However, some of those few states which require front identification lamps on any vehicles at all extend that requirement to include trailers, or semi-trailers, or both. FHWA requires front identification lamps on both trailers and semi-trailers also.

Size. No specifications exist.

Color. Yellow. Two of the states requiring front identification lamps also permit white.

Location. They must be mounted on the rear as close to the top of the vehicle as practicable, all at the same height, as close as practicable to the vertical centerline, with lamp centers spaced not less than 6 inches nor more than 12 inches apart.

Other. FHWA requires front identification lamps on all truck tractors, but permits those whose cab is not more than 42 inches wide to have just a single identification lamp, at the center of the cab.

SAE Standard J592c is incorporated by reference into FMVSS 108. This standard has since been revised to remove the following test points for front identification lamps: H-30L and R, H-20L and R, and H-10L and R.

Other Lamps Visible to the Front of Vehicles. A small number of other types of forward-facing lamps can also be identified, although no standards or recommendations exist for their use. Included in this group are the following:

1. Hood ornament lamps
2. Grill decoration lamps
3. Running lamps
4. Forward-facing brake signal lamps
5. Reflex reflectors (including reflectorized license plates)

FMVSS 108 states that "no additional lamp, reflective device, or other motor vehicle equipment shall be installed that impairs the effectiveness of lighting equipment required by this standard." Further, "In addition, no part of the vehicle shall prevent the device from meeting the photometric output at any test point specified in any applicable SAE Standard or Recommended Practice. However, if motor vehicle equipment (e.g., mirrors, snowplows, wrecker booms, backhoes, and winches) prevents compliance with this paragraph by any required lamp or reflective device, an auxiliary lamp or device meeting the requirements of this paragraph shall be provided."

As discussed later in this review, the definition of "impairs the effectiveness" needs additional consideration, especially concerning "veiling effects" of additional lighting equipment, etc.

LAMPS VISIBLE ON THE SIDES OF VEHICLES. Figure 1.2 shows the location of lamps visible on the sides of vehicles, and Table 1.5 shows their required or recommended photometric levels. Those requirements referenced within FMVSS 108 are printed in standard type; those recommended in the 1973 SAE Handbook but not included in FMVSS 108 are printed in italics.

Cornering Lamps (SAE J852b).

Intent. Cornering lamps are intended to supplement the headlamps by providing additional illumination in the direction of the turn.

Method of Activation. SAE recommends that cornering lamps be turned on by the turn signal switch or by another suitable means and that they should turn off when the turn signal lamps are turned off. If the cornering lamps are not turned off automatically, a visible or audible warning should be provided to indicate to the driver that the lamps are on. Cornering lamps are primarily intended to be used during times that the headlamps are required.

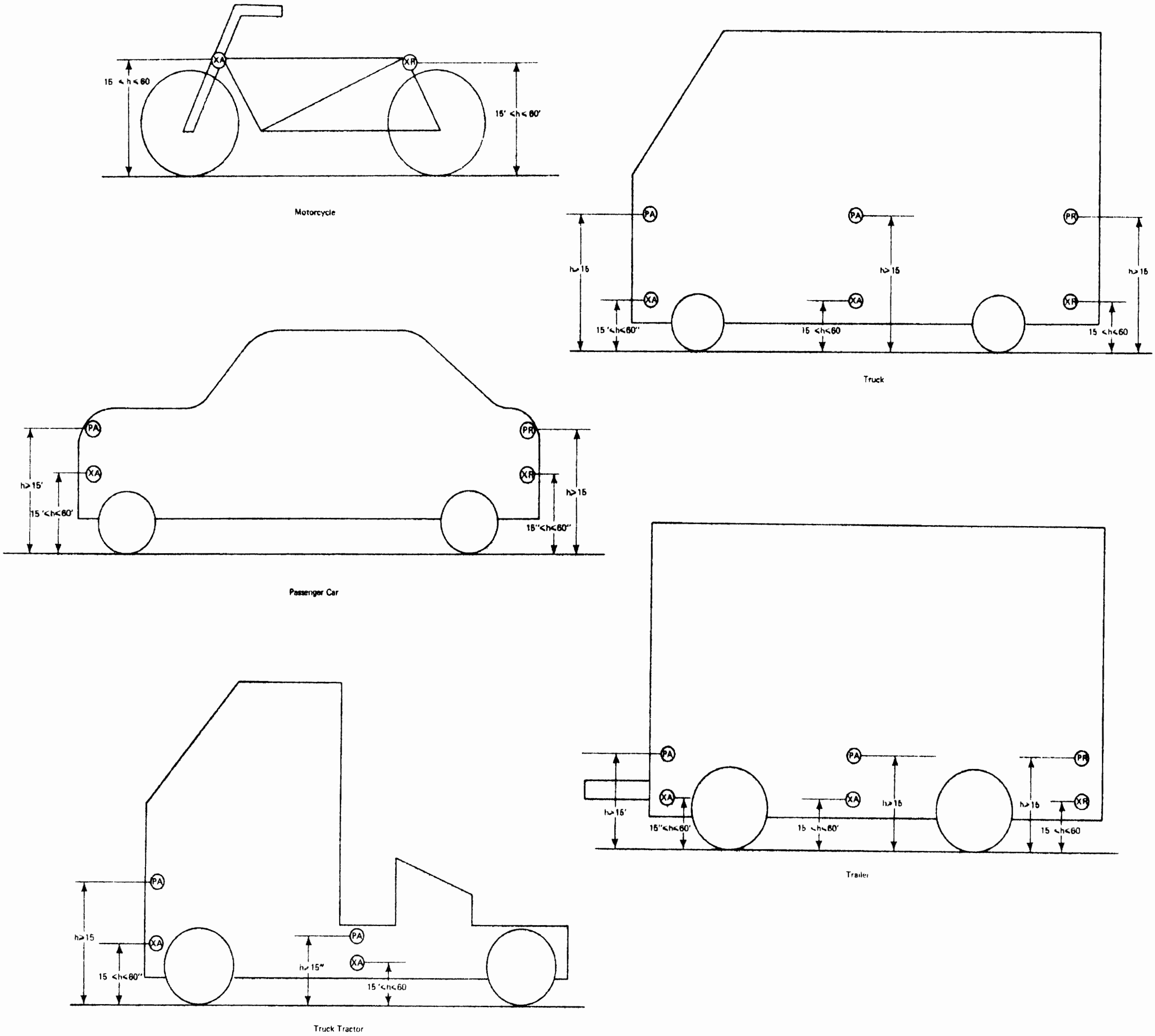



Figure 1.2. Lamps visible on the sides of vehicles (see Table 1.2 for an explanation of symbols).

Note: Intermediate side marker lamps and reflectors are not required on vehicles less than 30 feet in overal length.

TABLE 1.5. Photometric Performance Standards or Recommended Values of Lamps Intended to Show Primarily to the Sides of Motor Vehicles.

| | | ROAD ILLUMINATION LAMPS | | SIGNAL LAMPS | | | DEMARCATION LAMPS | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Coordinates | | Cornering Lamps | | Side Turn Signal Lamps | Beacon Lamps | | Side Marker Lamps | | Coordinates | |
| | | White or Yellow | | Yellow | Yellow | Red | Yellow | Red | | |
| Vert | Horiz | Max | Min | Min | Min | Min | Min | Min | Vert | Horiz |
| 15 U: | V | | | 20 | | | | | 15 U: | V |
| 10 U: | 45 F | | | | | | 0.62 | 0.25 | 10 U: | 45 F |
| | V | | | | | | 0.62 | 0.25 | | V |
| | 30 B | | | 20 | | | | | | 30 B |
| | 45 B | | | | | | 0.62 | 0.25 | | 45 B |
| 90 U ↕ 8 U : | 90 F ↔ 90 B | 125 | | | | | | | 90 U ↕ 8 U : | 90 F ↔ 90 B |
| 5 U : | 90 F ↔ 90 B | | | | 125 | 50 | | | 5 U : | 90 F ↔ 90 B |
| 5 U: | 70 B | | | 30 | | | | | 5 U: | 70 B |
| | 85 B | | | 40 | | | | | | 85 B |
| 4 U: | 90 F ↔ 90 B | 200 | | | | | | | 4 U: | 90 F ↔ 90 B |
| 2½U : | 90 F ↔ 90 B | | | | 500 | 200 | | | 2½U : | 90 F ↔ 90 B |
| 2 U: | 90 F ↔ 90 B | 300 | | | | | | | 2 U: | 90 F ↔ 90 B |
| 1 U: | 90 F ↔ 90 B | 400 | | | | | | | 1 U: | 90 F ↔ 90 B |
| H : | 90 F ↔ 90 B | 500 | | | | | | | H : | 90 F ↔ 90 B |
| | 45 F | | | | | | 0.62 | 0.25 | | 45 F |
| | 30 F | | | | | | 0.62 | 0.25 | | 30 F |
| | 20 F | | | | | | 0.62 | 0.25 | | 20 F |
| | 10 F | | | | | | 0.62 | 0.25 | | 10 F |
| | V | | | 30 | | | 0.62 | 0.25 | | V |
| | 10 B | | | | | | 0.62 | 0.25 | | 10 B |
| | 20 B | | | | | | 0.62 | 0.25 | | 20 B |
| | 30 B | | | 30 | | | 0.62 | 0.25 | | 30 B |
| | 45 B | | | | | | 0.62 | 0.25 | | 45 B |
| | 70 B | | | 30 | | | | | | 70 B |
| | 85 B | | | 50 | | | | | | 85 B |
| 2½D: | 90 F ↔ 90 B | | | | 500 | 200 | | | 2½D: | 90 F ↔ 90 B |
| | 60 F | | 300 | | | | | | | 60 F |
| | 45 F | | 500 | | | | | | | 45 F |
| | 30 F | | 300 | | | | | | | 30 F |
| 5 D: | 90 F ↔ 90 B | | | | 125 | 50 | | | 5 D: | 90 F ↔ 90 B |
| | 70 B | | | 30 | | | | | | 70 B |
| | 85 B | | | 40 | | | | | | 85 B |
| 10 D: | 45 F | | | | | | 0.62 | 0.25 | 10 D: | 45 F |
| | V | | | | | | 0.62 | 0.25 | | V |
| | 30 B | | | 20 | | | | | | 30 B |
| | 45 B | | | | | | 0.62 | 0.25 | | 45 B |
| 15 D· | V | | | 20 | | | | | 15 D: | V |
| OVERALL MAXIMUM | | | | 300 | | | | | OVERALL MAXIMUM | |
| SOURCE OF STANDARDS | | SAE J852b | | SAE J914 | SAE J845 | | SAE J592c | | SOURCE OF STANDARDS | |

† The V axis for the above photometric values is *perpendicular* to the vehicle's longitudinal axis. The "F" and "B" coordinates are towards the "Front" and "Back" of the vehicle respectively. The "F" and "B" coordinates were used instead of the original "L" and "R" to avoid the confusion between left and right sides of the vehicle. The original standards for Side Turn Signal Lamps and Cornering Lamps were given in coordinates having a V axis *parallel* to the vehicle's longitudinal axis, facing forward and rearward respectively; these coordinates have been translated into the above Table.

Number. SAE recommends that two be used, one each on the left and right sides of the vehicle.

Size. No recommendations exist.

Color. SAE recommends white or yellow.

Location. No recommendations exist.

Other. SAE recommends that cornering lamps be steady-burning when activated.

Side Turn Signal Lamps (SAE Recommended Practice J914).

Intent. A side turn signal lamp is a lamp mounted on the side of a vehicle which flashes in unison with the front and rear turn signal lamps to indicate the intention of the vehicle to change direction toward the side on which the signal lamp is flashing.

Method of Activation. SAE recommends that the front and rear turn signals flash in phase.

Number. SAE recommends that two be used one on each side of the vehicle. SAE Recommended Practice J914 applies to side turn signal lamps intended for use on trucks and buses over 80 inches in width.

Size. No recommendations exist.

Color. SAE recommends yellow.

Location. SAE recommends the side turn signal lamps be located on the vehicle's sides at a height not less than 36 inches nor more than 72 inches from the road surface.

Other. SAE recommends that there be an illuminated indicator, which could be the same as the regular turning signal indicator. Except on towed vehicle combinations using variable-load flashers, the failure of a side turn signal to operate should be indicated by a "steady on" or "steady off" of the illuminated indicator.

Three-Hundred and Sixty Degree Revolving Beacon Lamp (SAE Recommended Practice J845).

Intent. The lamps are intended for use on authorized emergency vehicles, and emit light 360° through the horizontal plane passing through the lamp.

Method of Activation. SAE recommends that such beacon lamps be provided with an illuminated switch or pilot indicator to give the driver a clear and unmistakable indication that the beacon lamp is turned on.

Number. No recommendations exist.

Size. SAE recommends that the specific style or model of beacon lamp be chosen with reference to its performance characteristics and the requirements needed for the specific application. Otherwise, SAE recommends that the beacon lamp have an effective projected luminous area of not less than 16 square inches.

Color. SAE recommends that beacon lamps be amber or red when used in highway emergency service missions. The various states establish permissible colors for beacon lamps in their respective Vehicle Codes. The use of blue, green, and white has been observed.

Location. The beacon lamps should be mounted to provide 360° visibility at all times.

Other. SAE recommends a beam having a vertical spread of at least 10°, extending a minimum of 5° above and below the horizontal axis of the light source. The flash rate should be 60-120 cpm. When the flash rate is produced by a current interruption (vs. rotation or complete rotation of the lamp), the "on" period should be long enough to permit the bulb to come to full brightness.

No summary of the performance requirements, or of the use permissions or prohibitions in the various states is available for this review.

Front Side Marker Lamps (SAE Standards J592c and J592e).

Intent. Side marker lamps are intended to show the overall length of a vehicle when viewed from the side.

Method of Activation. On all passenger cars, and on those multipurpose passenger vehicles, trucks, and buses of less than 80 inches overall width, the side marker lamps must be activated with the parking lamps and the headlamps.

Number. Two, one on each side, except that none are required on motorcycles.

Size. No recommendations exist.

Color. Yellow.

Location. Front side marker lamps must be located as far to the front of the vehicle as practicable, exclusive of the tongue on trailers and semi-trailers, and must be mounted not less than 15 inches from the road surface.

Other. The means may be provided to flash side marker lamps for signaling purposes. The required inboard photometric standards for front side marker lamps for all vehicles less than 80 inches in overall width can be met at a single inboard horizontal angle, on the line formed by the intersection of two vertical planes, one at a distance of 15 feet from the vehicle and parallel to its longitudinal axis, and a second perpendicular to the longitudinal axis and located midway between the front and rear side marker lamps.

Some states permit white as well as yellow. Most states require front side marker lamps only on those buses, trucks, and trailers in excess of 80 inches in width, and/or 30 feet in length, or over a certain weight.

SAE Standard J592c is incorporated by reference into FMVSS 108. This standard has since been revised to remove the following test points for front side marker lamps: H-30L and R, H-20L and R, and H-10L and R.

Intermediate Side Marker Lamps (SAE Standards J592c and J592e).

Intent. Intermediate side marker lamps indicate a vehicle greater than a certain length.

Method of Activation. On all passenger cars and motorcycles, and on those multipurpose passenger vehicles, trucks, and buses of less than 80 inches overall width, the side marker lamps must be activated with the parking lamps and the headlamps.

Number. All vehicles of 30 or more feet in overall length must have two, one on each side. (Note: Figure 1.2 shows intermediate side marker lamps only on trucks, tractors, and trailers, since no conventional motorcycles or passenger cars are as long as 30 feet.)

Size. No recommendations exist.

Color. Yellow.

Location. The intermediate side marker lamp must be located at or near the midpoint between the front and rear side marker lamps, and must be mounted not less than 15 inches from the road surface.

Other. The means may be provided to flash side marker lamps for signaling purposes. The special inboard photometric standard mentioned for front and rear side marker lamps cannot be held to apply, since all test points for the intermediate side marker lamp are outboard, irrespective of the 80-inch width.

Some states require intermediate side marker lamps on vehicles manufactured prior to the time of the date of effect of the Federal manufacturing requirement. Some permit red in place of or in addition to yellow. Some variation exists as to the type of vehicle required to have intermediate side marker lamps, most states not requiring any vehicles to have them.

SAE Standard J592c is incorporated by reference into FMVSS 108. This standard has since been revised to remove the following test points for intermediate side marker lamps: H-30L and R, H-20L and R, and H-10L and R.

Rear Side Marker Lamps (SAE Standards J592c and J592e).

Intent. Side marker lamps are intended to show the overall length of a vehicle.

Method of Activation. On all passenger cars and motorcycles, and on those multipurpose passenger vehicles, trucks, and buses of less than 80 inches overall width, the side marker lamps must be activated with the parking lamps and the headlamps.

Number. All vehicles must have two, one on each side, except that none are required on motorcycles.

Size. No recommendations exist.

Color. Red.

Location. The rear side marker lamps must be located as far to the rear of the vehicle as practicable, and must be mounted not less than 15 inches from the road surface.

Other. The means may be provided to flash side marker lamps for signaling purposes. The required inboard photometric standards for rear side marker lamps for all vehicles less than 80 inches in overall width can be met at a single inboard horizontal angle, on the line formed by the intersection of two vertical planes, one at a distance of 15 feet from the vehicle and parallel to its longitudinal axis, and a second perpendicular to the longitudinal axis and located midway between the front and side rear marker lamps.

Most states require rear side marker lamps only on those buses, trucks, and trailers in excess of 80 inches in width, and/or 30 feet in length, or over a certain weight.

SAE Standard J592c is incorporated by reference into FMVSS 108. This standard has since been revised to remove the following test points for rear side marker lamps: H-30L and R, H-20L and R, and H-10L and R.

Front Side Reflex Reflectors (SAE Standards J594d and J594e).

Intent. Reflex reflectors are intended to indicate the presence of a vehicle to an approaching driver by reflecting back to him light from his own approaching vehicle.

Method of Activation. None required.

Number. There must be two, one on each side.

Size. No recommendations exist.

Color. Yellow.

Location. The reflector must be mounted as far to the front as possible, exclusive of the tongue on trailers and semi-trailers, and must be mounted not less than 15 inches nor more than 60 inches from the road surface.

Other. Some states require front side reflex reflectors only on certain classes of vehicles, determined by width, length, or weight. Most states require them on all new motor vehicles. Most jurisdictions specify a minimum mounting height of 20 to 24 inches, although some go as low as 15 inches.

Intermediate Side Reflex Reflectors (SAE Standards J594d and J594e).

Intent. Reflex reflectors are intended to indicate the presence of a vehicle to an approaching driver by reflecting back to him light from his own vehicle.

Method of Activation. None required.

Number. There must be two, one on each side, except none are required on motorcycles, nor are any required on any vehicle less than 30 feet in overall length, irrespective of width. (This assumes that FMVSS 108 use of "side intermediate marker device" includes reflex reflectors.)

Size. No recommendations exist.

Color. Yellow.

Location. The intermediate side reflex reflector must be located on the side, at or near the midpoint between the front and rear side reflex reflectors, mounted not less than 15 inches nor more than 60 inches from the road surface.

Other. Less than a half-dozen states currently require intermediate side reflex reflectors, and then primarily as a replacement for (rather than in addition to) front and rear side reflex reflectors. FHWA requires this device only on trailers and semi-trailers of 80 or more inches overall width and 30 or more feet in overall length. All other jurisdictions specify a minimum mounting height of 20 to 24 inches.

Rear Side Reflex Reflectors (SAE Standards J594d and J594e).

Intent. Reflex reflectors are intended to indicate the presence of a vehicle to an approaching driver by reflecting back to him light from his own approaching vehicle.

Method of Activation. None required.

Number. There must be two, one on each side (left and right), except that none are required on truck tractors.

Size. No recommendations exist.

Color. Red.

Location. The device must be located on the side of the vehicle, as far to the rear as practicable, and mounted not less than 15 nor more than 60 inches from the road surface.

Other. Most jurisdictions specify a minimum mounting height of 20 to 24 inches, although some allow as low as 15 inches. Some states require rear side reflex reflectors only on certain classes of vehicles, distinguished by width, length, or weight. Most states require them on all new vehicles. Many require them (or, more properly, fail to exclude them from the requirements) on truck tractors.

External Turn Signal Indicator Lamps (SAE Standards J588d and J588e).

Intent. To the extent that an externally-mounted turn signal indicator lamp is visible to other drivers, it conveys information in much the same way as does a side-mounted turn signal.

Method of Activation. These serve as pilot lamps for the turn signal system, and flash at the same frequency when the left, right, or hazard warning signal lamps are activated.

Number. SAE recommends that when used, there be two, one on each side of the vehicle.

Size. SAE recommends that they have a minimum area of 0.1 square inches.

Color. Yellow.

Location. SAE suggests that they could be on the front fenders. Since their nominal intent is to inform the driver that the respective turn signals are flashing, they need to be readily visible to the driver.

Other. Although these lamps are so small that they constitute a rather insignificant part of the turn signal lighting system, experience indicates they can be seen rather readily at night, although primarily by drivers in vehicles approaching from the rear rather than from the side. Since no photometric standards have been developed for these indicator lamps, they have not been included on either Table 1.5 or Table 1.6.

Other Lamps on the Side of Vehicles. A small number of other types of side-facing lamps can also be identified. Included within this group are the following: (1) side-facing stop signal lamps; (2) side-facing emergency warning lamps; and (3) reflectorized side trimming.

LAMPS VISIBLE ON THE REAR OF VEHICLES. Figure 1.3 shows the location of lamps mounted on the rear of vehicles, and Table 1.6 shows the photometric levels. Those standards referenced within FMVSS 108 are printed in standard type; those recommended in the 1973 SAE Handbook but not included within FMVSS 108 are printed in italics.

Backup Lamps (SAE Standards J593c and J593d).

Intent. Backup lamps are intended to illuminate the road to the rear of the vehicle, and to provide a warning signal to pedestrians and other drivers when the vehicle is backing up or is about to back up.

Method of Activation. The backup lamp must be illuminated when the ignition switch is energized and reverse gear is engaged, and must not be illuminated when the vehicle is in forward motion.

Number. One, except that more than one may be used to meet the photometric requirements. No backup lamp is required on motorcycles or trailers. Some states limit the number of backup lamps to two.

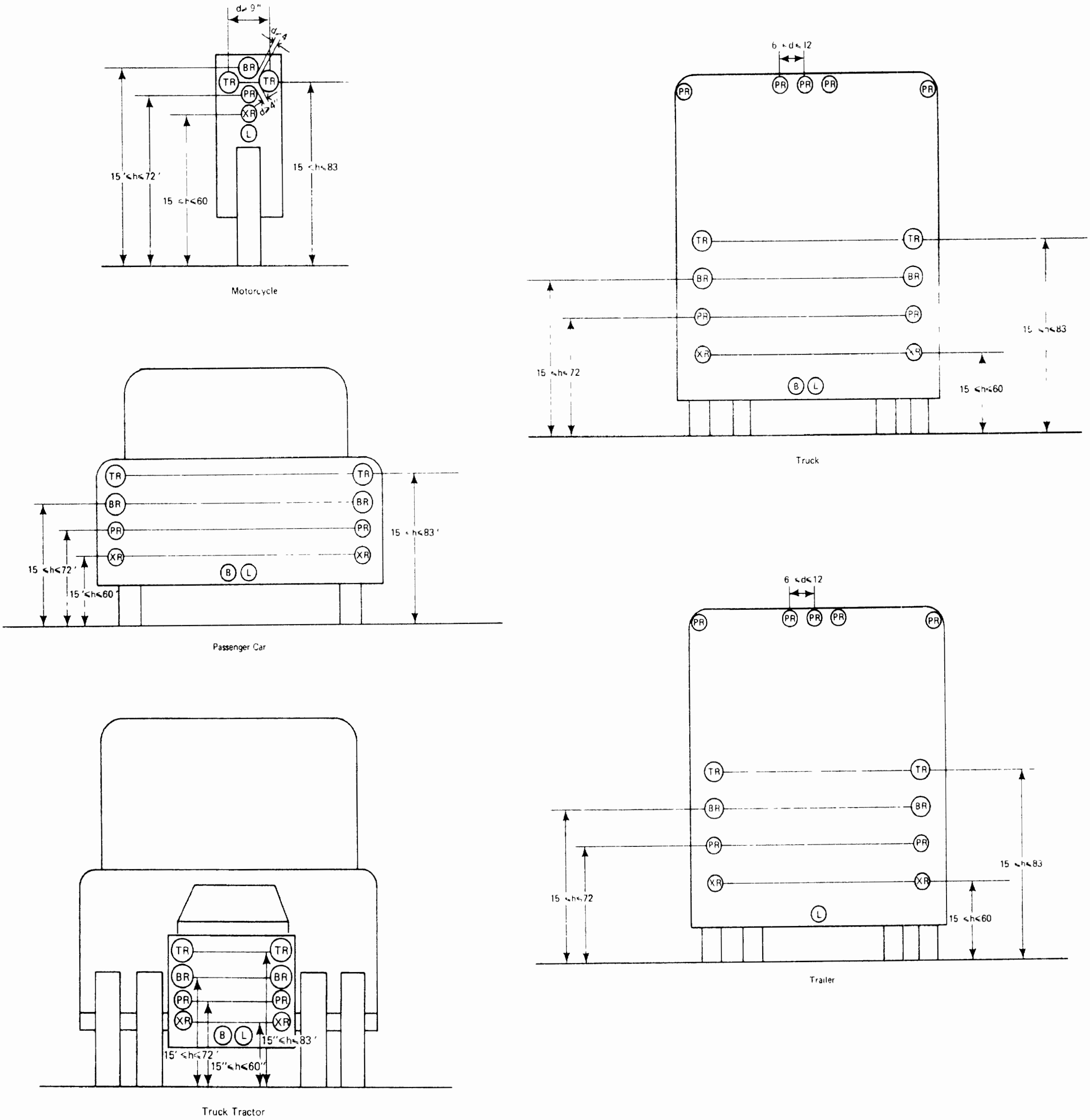



Figure 1.3. Lamps visible on the rear of vehicles (see Table 1.2 for an explanation of symbols).

TABLE 1.6. Photometric Performance Standards or Recommended Values of Lamps Intended to Show Primarily to the Rear of Motor Vehicles.

| | ROAD ILLUMINATION LAMPS | | SIGNAL LAMPS | | | | | | | | | | | | SIGNAL LAMPS (CONT.) | | | | | | | | DEMARCATION LAMPS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BACK-UP LAMPS | | REAR TURN SIGNAL LAMPS | | | | | | | STOP SIGNAL LAMPS | | | SIDE TURN SIGNAL LAMPS | | SUPPLEMENTAL HIGH MOUNTED STOP AND TURN SIGNAL LAMPS | | SCHOOL BUS LOADING & UNLOADING LAMPS | | EMERGENCY VEHICLE FLASHING LAMPS | | 360° REVOLVING BEACON LAMPS | | REAR PRESENCE | | | CLEARANCE & ID. LAMPS | |
| | | | On Motor Cycles and Motor-Driven Cycles | On All Other Vehicles Number of Sections | | | | | | Number of Sections | | | | | | | | | | | | | Number of Sections | | | | |
| | | | | One | | Two | | Three | | One | Two | Three | Left Side | Right* Side | | | | | | | | | One | Two | Three | | |
| Coordinates Vert Horiz | White Max | White Min | Yellow Min | Yellow Min | Red Min | Yellow Min | Red Min | Yellow Min | Red Min | Red Min | Red Min | Red Min | Yellow Min | Yellow Min | Yellow Min | Red Min | Yellow Min | Red Min | Yellow Min | Red Min | Yellow Min | Red Min | Red Min | Red Min | Red Min | Red Min | Coordinates Vert Horiz |
| 10 U: 60 L | | | | | | | | | | | | | | 20 | | | | | | | | | | | | | 10 U: 60 L |
| 45 L | | | | | | | | | | | | | | | | | | | | | | | | | | 0.25 | 45 L |
| 10 L | | 10 | 15 | 25 | 10 | 30 | 12 | 35 | 15 | 10 | 12 | 15 | | | 7 | 5 | | | | | | | 0.3 | 0.5 | 0.7 | | 10 L |
| 5 L | | | | | | | | | | | | | | | | | | | 60 | 20 | | | | | | | 5 L |
| V | | 15 | 30 | 60 | 25 | 75 | 30 | 90 | 35 | 25 | 30 | 35 | | | 15 | 10 | | | 150 | 50 | | | 0.5 | 1.0 | 1.5 | 0.25 | V |
| 5 R | | | | | | | | | | | | | | | | | | | 60 | 20 | | | | | | | 5 R |
| 10 R | | 10 | 15 | 25 | 10 | 30 | 12 | 35 | 15 | 10 | 12 | 15 | | | 7 | 5 | | | | | | | 0.3 | 0.5 | 0.7 | | 10 R |
| 45 R | | | | | | | | | | | | | | | | | | | | | | | | | | 0.25 | 45 R |
| 60 R | | | | | | | | | | | | | 80 | | | | | | | | | | | | | | 60 R |
| 5 U: 90 L ↔ 90 R | | | | | | | | | | | | | | | | | | | | | 125 | 60 | | | | | 5 U: 90 L ↔ 90 R |
| 5 U: 45 L | | 15 | | | | | | | | | | | | | | | | | | | | | | | | | 5 U: 45 L |
| 20 L | | | 15 | 25 | 10 | 30 | 12 | 35 | 15 | 10 | 12 | 15 | | 30 | | | 375 | 150 | 60 | 20 | | | 0.3 | 0.5 | 0.7 | | 20 L |
| 10 L | | 20 | 40 | 75 | 30 | 88 | 35 | 100 | 40 | 30 | 35 | 40 | | | 15 | 10 | 750 | 300 | 150 | 50 | | | 0.8 | 1.3 | 2.0 | | 10 L |
| 5 L | | | 60 | 125 | 50 | 150 | 60 | 175 | 70 | 50 | 60 | 70 | | 40 | 22 | 15 | 750 | 300 | 300 | 100 | | | 1.3 | 2.0 | 3.0 | | 5 L |
| V | | 25 | 90 | 175 | 70 | 205 | 82 | 235 | 95 | 70 | 82 | 95 | | | 22 | 15 | 750 | 300 | 450 | 150 | | | 1.8 | 3.0 | 4.5 | | V |
| 5 R | | | 60 | 125 | 50 | 150 | 60 | 175 | 70 | 50 | 60 | 70 | 40 | | 22 | 15 | 750 | 300 | 300 | 100 | | | 1.3 | 2.0 | 3.0 | | 5 R |
| 10 R | | 20 | 40 | 75 | 30 | 88 | 35 | 100 | 40 | 30 | 35 | 40 | | | 15 | 10 | 750 | 300 | 150 | 50 | | | 0.8 | 1.3 | 2.0 | | 10 R |
| 20 R | | | 15 | 25 | 10 | 30 | 12 | 35 | 15 | 10 | 12 | 15 | 30 | | | | 375 | 150 | 60 | 20 | | | 0.3 | 0.5 | 0.7 | | 20 R |
| 45 R | | 15 | | | | | | | | | | | | | | | | | | | | | | | | | 45 R |
| 2½ U: 90 L ↔ 90 R | | | | | | | | | | | | | | | | | | | | | 600 | 200 | | | | | 2½ U: 90 L ↔ 90 R |
| 90 U ↕ H: 90 L ↔ 90 R | 300 | | | | | | | | | | | | | | | | | | | | | | | | | | 90 U ↕ H: 90 L ↔ 90 R |
| 10 U ↕ H: 90 L ↔ 90 R | | | | | | | | | | | | | | | | | | | | | | | 15** | 20** | 25** | | 10 U ↕ H: 90 L ↔ 90 R |
| H 60 L | | | | | | | | | | | | | | | | | | | | | | | | | | | H: 60 L |
| 45 L | | 15 | | | | | | | | | | | | 30 | | | | | | | | | | | | 0.25 | 45 L |
| 30 L | | 25 | | | | | | | | | | | | | | | 75 | 30 | | | | | | | | 0.25 | 30 L |
| 20 L | | | 20 | 35 | 15 | 45 | 18 | 50 | 20 | 15 | 18 | 20 | | 30 | | | 450 | 180 | 90 | 30 | | | 0.4 | 0.7 | 1.0 | 0.25 | 20 L |
| 10 L | | 50 | 45 | 100 | 40 | 120 | 47 | 140 | 55 | 40 | 47 | 55 | | | 15 | 10 | 1000 | 400 | 225 | 75 | | | [illegible] | 1.3 | 2.0 | 0.25 | 10 L |
| 5 L | | | 120 | 200 | 80 | 240 | 95 | 275 | 110 | 80 | 95 | 110 | | 60 | 22 | 15 | 1250 | 500 | 600 | 200 | | | 2.[illegible] | 3.5 | 5.0 | | 5 L |
| V | | 80 | 120 | 200 | 80 | 240 | 95 | 275 | 110 | 80 | 95 | 110 | | | 22 | 15 | 1500 | 600 | 900 | 300 | | | 2.0 | 3.5 | 5.0 | 0.25 | V |
| 5 R | | | 120 | 200 | 80 | 240 | 95 | 275 | 110 | 80 | 95 | 110 | 50 | | 22 | 15 | 1250 | 500 | 600 | 200 | | | 2.0 | 3.5 | 5.0 | | 5 R |
| 10 R | | 50 | 45 | 100 | 40 | 120 | 47 | 140 | 55 | 40 | 47 | 55 | | | 15 | 10 | 1000 | 400 | 225 | 75 | | | 0.8 | 1.3 | 2.0 | 0.25 | 10 R |
| 20 R | | | 20 | 35 | 15 | 45 | 18 | 50 | 20 | 15 | 18 | 20 | 30 | | | | 450 | 180 | 90 | 30 | | | 0.4 | 0.7 | 1.0 | 0.25 | 20 R |
| 30 R | | 25 | | | | | | | | | | | | | | | 75 | 30 | | | | | | | | 0.25 | 30 R |
| 45 R | | 15 | | | | | | | | | | | | | | | | | | | | | | | | 0.25 | 45 R |
| 60 R | | | | | | | | | | | | | 30 | | | | | | | | | | | | | | 60 R |
| 2½ D: 90 L ↔ 90 R | | | | | | | | | | | | | | | | | | | | | 500 | 200 | | | | | 2½ D: 90 L ↔ 90 R |
| 5 D: 90 L ↔ 90 R | | | | | | | | | | | | | | | | | | | | | 125 | 60 | | | | | 5 D: 90 L ↔ 90 R |
| 45 L | | 15 | | | | | | | | | | | | | | | | | | | | | | | | | 45 L |
| 30 L | | 25 | | | | | | | | | | | | | | | 75 | 30 | | | | | | | | | 30 L |
| 20 L | | | 15 | 25 | 10 | 30 | 12 | 35 | 15 | 10 | 12 | 15 | | 30 | | | 500 | 200 | 60 | 20 | | | 0.3 | 0.5 | 0.7 | | 20 L |
| 10 L | | 50 | 40 | 75 | 30 | 88 | 35 | 100 | 40 | 30 | 35 | 40 | | | 15 | 10 | 750 | 300 | 150 | 50 | | | 0.8 | 1.3 | 2.0 | | 10 L |
| 5 L | | | 60 | 125 | 50 | 150 | 60 | 175 | 70 | 50 | 60 | 70 | | 40 | 22 | 15 | 1125 | 450 | | | | | 1.3 | 2.0 | 3.0 | | 5 L |
| V | | 80 | 90 | 175 | 70 | 205 | 82 | 235 | 95 | 70 | 82 | 95 | | | 22 | 15 | 1125 | 450 | 450 | 150 | | | 1.8 | 3.0 | 4.5 | | V |
| 5 R | | | 60 | 125 | 50 | 150 | 60 | 175 | 70 | 50 | 60 | 70 | 40 | | 22 | 15 | 1125 | 450 | | | | | 1.3 | 2.0 | 3.0 | | 5 R |
| 10 R | | 50 | 40 | 75 | 30 | 88 | 35 | 100 | 40 | 30 | 35 | 40 | | | 15 | 10 | 750 | 300 | 150 | 50 | | | 0.8 | 1.3 | 2.0 | | 10 R |
| 20 R | | | 15 | 25 | 10 | 30 | 12 | 35 | 15 | 10 | 12 | 15 | 30 | | | | 500 | 200 | 60 | 20 | | | 0.3 | 0.5 | 0.7 | | 20 R |
| 30 R | | 25 | | | | | | | | | | | | | | | 75 | 30 | | | | | | | | | 30 R |
| 45 R | | 15 | | | | | | | | | | | | | | | | | | | | | | | | | 45 R |
| 10 D 60 L | | | | | | | | | | | | | | 20 | | | | | | | | | | | | | 10 D: 60 L |
| 45 L | | | | | | | | | | | | | | | | | | | | | | | | | | 0.25 | 45 L |
| 10 L | | | 15 | 25 | 10 | 30 | 12 | 35 | 15 | 10 | 12 | 15 | | | | | | | | | | | 0.3 | 0.5 | 0.7 | | 10 L |
| 5 L | | | | | | | | | | | | | | | | | 100 | 40 | 60 | 20 | | | | | | | 5 L |
| V | | | 30 | 60 | 25 | 75 | 30 | 90 | 35 | 25 | 30 | 35 | | | | | 100 | 40 | 150 | 50 | | | 0.5 | 1.0 | 1.5 | 0.25 | V |
| 5 R | | | | | | | | | | | | | | | | | 100 | 40 | 60 | 20 | | | | | | | 5 R |
| 10 R | | | 15 | 25 | 10 | 30 | 12 | 35 | 15 | 10 | 12 | 15 | | | | | | | | | | | 0.3 | 0.5 | 0.7 | | 10 R |
| 45 R | | | | | | | | | | | | | | | | | | | | | | | | | | 0.25 | 45 R |
| 60 R | | | | | | | | | | | | | 20 | | | | | | | | | | | | | | 60 R |
| OVERALL MAXIMUM | | | 900 / 750 | 900† / 750 | 300 | 900 | 36 | 1050 | 420 | 300 | 360 | 420 | 300 | 300 | 90 | 60 | | | | | | | | | | 15 | OVERALL MAXIMUM |
| SOURCE OF STANDARDS | SAE†† J593c | | SAE J575d, SAE J131 | SAE J575d | | SAE J588e | | | | SAE J575d | | SAE J586c | SAE J914 | | SAE J186 | | SAE J887 | | SAE J595b | | SAE J845 | | SAE J575d | | | SAE J592c | SOURCE OF STANDARDS |

†Although the controlling standard (SAE J575d) establishes the 900 CP photometric maximum, the subsequent revision of the turn signal lamp standard (SAE J588e) recommends the lower 750 CP value

††SAE Standard J593c notes the following: when only one back-up lamp is used on the vehicle, it shall be tested to twice the candlepower requirements. When two unsymmetrical lamps are used, they shall be tested individually and the values added to determine that the combined units meet twice the candlepower requirements. SAE Standard J593c has been revised (J593d) to amend this last sentence to read as follows when two lamps of the same or symmetrically opposite design are used, the reading along the vertical axis and the averages of the readings for the same angles left and right of vertical for one lamp shall be used to determine compliance with the requirement. If two lamps of differing designs are used, they shall be tested individually and the values added to determine that the combined units meet twice the candlepower requirements.

*Side turn signal lamps are included in this Table because their primary light output (as indicated by the minimum candlepower recommendations) is towards the rear. The left and right side turn signal lamp photometric requirements have been separated on this Table to prevent confusion about the need to maintain similar minimum CP values at all intermediary reference points

**Applies only at the lines from H up to 10U.

Size. No recommendations exist.

Color. Backup lamps must be white, except that a backup lamp may project incidental red, yellow, or white light through reflectors or lenses that are adjacent, close to, or a part of the lamp assembly.

Location. The backup lamps must be mounted on the rear of the vehicle in such a manner that the center of the lens of at least one lamp is visible from any eye point elevation from at least 6 feet to 2 feet above the horizontal plane on which the vehicle is standing; and from any position in the area, rearward of a vertical plane perpendicular to the longitudinal axis of the vehicle, 3 feet to the rear of the vehicle and extending 3 feet beyond each side of the vehicle.

One state requires that the white light illuminating the highway from a backup lamp not extended backward to any distance beyond 75 feet. It permits the backup lamp(s) also to be on, controlled by a lighting system which activates the lights for a temporary period of time after the ignition is turned off.

Rear Turn Signal Lamps (SAE Standards J588d, J588e, and J575d, and SAE Recommended Practice J131).

Intent. Rear turn signal lamps indicate the intent to change direction by flashing the lamp on the side toward which the turn will be made.

Method of Activation. The signal must be able to be activated and cancelled manually, and may in addition be automatically cancellable (see SAE Standard 589a).

Number. Two on all vehicles.

Size. Those multipurpose passenger vehicles, trucks, trailers, and buses of 80 or more inches overall width must be equipped with rear turn signal lamps which have an effective projected luminous area of not less than 12.0 square inches. All passenger cars, motorcycles (except as noted above), and also those multipurpose passenger vehicles, trucks, trailers, and buses of less than 80 inches overall width must be equipped with rear turn signal lamps which have an effective projected luminous area of not less than 3.5 square inches. (SAE now recommends an 8.0 square inch minimum instead of 3.5, for this last group of vehicles.)

If multiple-compartment or multiple-lamp arrangements are used to meet the photometric requirements of a rear turn signal lamp on passenger cars and motorcycles, or on those multipurpose passenger vehicles, trucks, trailers and buses of less than 80 inches overall width, the effective projected luminous area of each compartment or lamp must be not less than 3.5 square inches. There is no comparable requirement for multiple compartment or multiple lamp arrays on those multipurpose passenger vehicles, trucks, trailers, and buses of 80 or more inches overall width. SAE does not recommend such for these latter classes of vehicles.

Color. Rear turn signal lamps must be yellow or red in color. Some State Vehicle Codes permit red only (which presumably makes the operation of certain foreign cars with yellow rear turn signal lamps illegal in those states). Others do not specify any color. SAE now recommends that only yellow be used for motorcycle and motor-driven cycle rear turn signal lamps.

Location. The rear turn signal lamps must be mounted on the rear of the vehicle (or, when used on motorcycles, at or near the rear), at the same height but not lower than 15 inches nor higher than 83 inches (as measured to their optical axes, from the level road surface on which the vehicle stands, and as far apart as practicable.

When used on motorcycles, the lamps must have a horizontal separation distance (center to center) of not less than 9 inches, and must have an edge-to-edge separation distance from the brake signal lamps and the rear presence lamps of not less than 4 inches.

Other. The minimum photometric requirements for single compartment red and yellow turn signal lamps have been grouped into "zones," comprised of the cumulative minimum values of the test points in each of the seven zones designated [37 F.R. 21328]. Furthermore, increased group photometric requirements for multiple compartment red and yellow turn signal lamps, identical to the SAE recommendations in J588e, are being adopted effective September 1, 1974. No previous multiple compartment photometric requirements for red and yellow turn signal lamps (Class A or Class B) were formally specified. (Informally, the specifications of J588e have been suggested by the NHTSA.) When a rear presence lamp is combined optically with the rear turn signal lamp, the ratio of the rear presence lamp must be at least 5:1 at H-V, H-5L, and 5U-V, and in addition must be at least 3:1 at all other test points on or above the horizon.

SAE recommends that, if multiple compartment or multiple lamp arrangements are used for rear turn signal lamps on vehicles less than 80 inches in overall width, and the distance between optical axes does not exceed 22 inches for two-compartment or two-lamp arrangements, and does not exceed 16 inches for three-compartment or three-lamp arrangements, then the combination of the compartment or lamp arrangements should be used to meet the photometric requirements for the corresponding number of lighted sections (see Table 1.6). Furthermore, if the rear presence lamp and the turn signal lamp functions are optically combined, the ratio of light outputs should be computed with all compartments or lamps lighted. However, if the distance between optical axes exceeds the above dimensions, each compartment or lamp should comply individually with the photometric requirements for one lighted section, and should individually have an effective projected luminous area of not less than 3.5 square inches, and further should have a total effective projected luminous area (for all lamps or compartments on that side) of not less than 8.0 square inches. In this latter instance, if the rear presence lamp and the turn signal lamp functions are optically combined, the ratio of their projected light outputs should be computed only for those compartments or lamps where the two functions are actually optically combined, not for the whole array.

SAE also recommends that for vehicles of 80 or more inches in overall width, a maximum of two compartments or lamps per side may be mounted closer together than 22 inches provided that each compartment or lamp meets the single-compartment photometric requirements and has an effective projected luminous area of not less than 12 square inches apiece. Although not specifically stated, this recommendation presumably also permits two or more lamps or compartments on each side with optical axes 22 or more inches from each other, but only so long as each lamp or compartment individually meets the photometric requirements for a single lighted section and has an effective projected luminous area of not less than 12 square inches apiece.

A truck tractor need not be equipped with rear turn signal lamps if the front turn signal lamps are so constructed (double-faced) and so located that the photometric requirements shown in Table 1.6 are met to the rear (as well as the requirements shown in Table 1.3 are met to the front) as follows: the light output from directly to the rear and to the left for the left lamp, and from directly to the rear and to the right for the right lamp, must be the same as the stated photometric requirements for a single-compartment lamp, except that at the H-V test point, the minimum candela level for red is 60 (instead of 80), and for yellow is 180 (instead of 200). The intent of these reduced minimums is to permit the manufacturers to provide glare protection for the driver. (The above standards assume the double-faced turn signal is a single-compartment lamp. No such reductions are provided for two- or three-compartment lamp arrangements.)

The flashing signal light output from a double-faced turn signal lamp, such as the one permitted by the previous paragraph, must not be obliterated when subject to external light rays from either in front or behind, at any and all angles.

Additional requirements exist about not obscurring the rear turn signal lamps by any part of the vehicle within certain angles.

The rear turn signal lamp function (left and right) can be presented by the same lamps which also present the brake signal lamp function, but only if such lamps meet the photometric requirements for both functions and are red in color. In such a lighting system, the circuitry must be such that when the turn signal function has been activated, the brake signal function cannot be turned on in the lamp which is serving as the appropriate rear turn signal lamp.

SAE now recommends that if the rear turn signal is yellow in color, and if the red brake signal lamp is turned off on the signaling side, the minimum values may be 0.7 times the values shown in Table 1.6.

The various states require that when activated, rear turn signal lamps be visible at certain distances in normal sunlight, but must not be glaring at night. These minimum distances vary with vehicle type (width, commercial application, etc.), but in all cases where specified are between 100 and 500 feet.

In some states, the requirement of rear turn signal lamps (especially on older vehicles) is determined by the length or width of the vehicle, or the distance from the steering column to a forward extension of any load.

NCUTLO recommends (and FHWA requires) that turn signals not be used for "courtesy" or "do pass" signals to other vehicles approaching from the rear, and that turn signal lamps not be flashed on one side only to indicate a parked or disabled vehicle in lieu of operation of the hazard warning system. FHWA further requires that no turn signal lamp be combined with any lighting device or combination of lighting devices capable of producing a greater intensity of light than the turn signal when the latter is activated.

Some states permit mechanically activated or operated signals, instead of the now conventional electrical flashing signal lamps.

Rear Traffic Hazard Warning Lamps (SAE Standards J588d), J588e, J575d, and J901a, and SAE Recommended Practice J945).

Intent. Rear traffic hazard warning lamps indicate the presence of a vehicular hazard by flashing the left and right turn signal lamps.

Method of Activation. Activation must be independent of the setting of the ignition switch. If requiring the operation of more than one switch, they must be able to be actuated simultaneously with a single driver action.

Number. Two, at least one on either side of the rear of the vehicle, except that none are required on motorcycles.

Size. No requirements exist apart from those previously outlined for rear turn signal lamps.

Color. No Federal requirements exist apart from those previously outlined for rear turn signal lamps. Two states permit only red, while many do not specify any color.

Location. No requirements exist apart from those previously outlined for rear turn signal lamps.

Other. In addition to the comments made about rear turn signal lamps are the following points:

1. For vehicles equipped with left- and right-hand turn signal pilot indicator lamps, both pilots must flash simultaneously while the hazard warning system is activated.

2. In vehicles equipped with a single turn signal pilot indicator lamp, a separate hazard warning pilot indicator lamp must flash (and the turn signal pilot indicator lamp may flash) when the hazard warning system is activated.

3. If a separate hazard pilot indicator lamp is used, it must be red in color and must have an area equivalent to an 0.5 inch diameter circle or greater.

4. The operating motion of the hazard warning signal switch must be different from the actuating motion of the turn signal switch.

Some states specify that the hazard warning lamps may be used only when the vehicle is not in motion, or when it is being brought to a stop. Some make specific requirements for rural mail delivery vehicles, and then in some cases the lamps are allowed or required to flash alternately instead of simultaneously. Otherwise, most states require that rear hazard warning lamps flash simultaneously when activated. Some states specify that the lamps for rural mail delivery vehicles must be roof-mounted.

Two states specifically permit the use of stop signal lamps instead of rear turn signal lamps for the hazard flashing system. Another permits the use of the hazard warning system only at night.

In many states the minimum distance at which these lamps must be visible is 100 to 1500 feet. Some specify instead that the minimum distance of 100 feet be the criterion in bright sunlight.

<u>Stop Signal Lamp</u> (SAE Standards J586b, J586c, and J575d).

<u>Intent</u>. Stop signal lamps project a steady light rear-

ward from a vehicle, or a train of vehicles, to indicate the intention of the driver to stop or to diminish speed.

Method of Activation. The stop signal lamps on all vehicles must be activated upon application of the service brakes.

Number. All vehicles must have two, except that motorcycles need only one. Some State Vehicle Codes require a minimum of one on certain other types of vehicles (converter dollies towed singly, truck tractors, trailers, etc.).

Size. Stop signal lamps must have an effective projected luminous area of not less than 3.5 square inches.

SAE currently recommends that stop signal lamps have an effective projected luminous area of not less than 8 square inches for vehicles less than 80 inches in overall width, and not less than 12 square inches for vehicles of 80 or more inches in overall width.

FMVSS 108 requires that if multiple compartment or multiple lamp arrangements are used on passenger cars, motorcycles, or on those multipurpose passenger vehicles, trucks, trailers, and buses of less than 80 inches overall width, the effective projected luminous area of each compartment or lamp must be not less than 3.5 square inches.

SAE further recommends that the total combined areas of the lamps or compartments used to meet the photometric requirements for each of the two stop signal lamps be not less than 8 square inches for passenger cars, motorcycles, and those multipurpose passenger vehicles, trucks, trailers, and buses of less than 80 inches overall width; and not less than 12 square inches for those multipurpose passenger vehicles, trucks, trailers, and buses of 80 or more inches overall width.

Most states currently specify, instead of size, that the minimum distance at which the stop signal lamp must be visible when illuminated is 100 to 500 feet.

Color. Red.

Some states do not specify the color of stop signal lamps, while one now requires red specifically on trucks, buses, and all new vehicles.

Location. The stop signal lamps must be located on the rear, one on either side of the vertical centerline and as far apart as possible, and at the same height but not less than 15 inches nor more than 72 inches from the level road surface on which the vehicle stands. On motorcycles, the stop signal lamp must be mounted on the vertical centerline within the same height restrictions, except that if two are used, they must be symmetrically disposed about the vertical centerline.

Other. The minimum photometric requirements for single compartment stop signal lamps have been grouped into "zones," comprised of the cumulative minimum values of the test points in each of the seven zones specified. [37 F.R. 21328] Furthermore, increased group photometric requirements for multiple compartment stop signal lamps, identical to the SAE recommendations in J586c, are being adopted effective September 1, 1974. No previous multiple compartment photometric requirements for the current stop signal lamps ("Class A") were formally specified. (Informally, the specifications of J586c have been suggested by the NHTSA.) When a rear presence lamp is optically combined with the stop signal lamp, the ratio of the projected light outputs of the stop signal lamp and the rear presence lamp must be at least 5:1 at H-V, H-5L, H-5R, and 5U-V, and in addition must be at least 3:1 at all other test points on or above the horizon.

SAE recommends that, if multiple compartment or multiple lamp arrangements are used for stop signal lamps on vehicles less than 80 inches overall width, and the distance between optical axes does not exceed 22 inches for two-compartment or two-lamp arrangements, and does not exceed 16 inches for three-compartment or three-lamp arrangements should be used to meet the photometric requirements for the corresponding number of lighted sections (see Table 1.6). Furthermore, if the rear presence lamp and the stop signal lamp functions are optically combined, the ratio of light outputs should be computed with all compartments or lamp lighted. However, if the distance between the optical axes exceeds the above dimensions, each compartment or lamp should comply individually with the photometric requirements for one lighted section, and should individually have an effective projected luminous area of not less than 3.5 square inches, and further should have a total effective projected luminous area (for all lamps or compartments on that side) of not less than 8.0 square inches. In this latter instance, if the rear presence lamp and stop signal lamp functions are optically combined, the ratio of their projected light outputs should be computed only for those compartments or lamps where the two functions are actually optically combined, not for the whole array.

SAE also recommends that for vehicles of 80 or more inches in overall width, a maximum of two compartments or lamps per side may be mounted closer together than 22 inches provided that each compartment or lamp meets the single-compartment photometric requirements and has an effective projected luminous area of not less than 12 square inches. Although not specifically stated, this recommendation presumably also permits two or more lamps or compartments on each side with optical axes 22 or more inches from each other, but only so long as each lamp or compartment individually meets the photometric requirements for a single lighted section and has an effective projected luminous area of not less than 12 square inches apiece.

Supplemental High-Mounted Stop and Turn Signal Lamps (SAE Recommended Practice J186).

Intent. These signal lamps are intended to supplement the information contained in the vehicle's standard stop signal and/or turn signal lamps, and to provide a signal visible through the daylight openings of intervening vehicles to operators of following vehicles.

Method of Activation. The stop signal lamp function is activated in the same manner as the conventional stop signal lamp. The turn signal lamp function is activated in the same manner as the conventional turn signal lamp.

Number. Although no specific SAE recommendation exists, presumably at least one lamp on each side would be used to convey the turn signal function, possibly in combination with the stop signal function; and/or one high-mounted lamp, perhaps two (one on each side) would convey the stop signal function.

Size. No recommendations exist.

Color. SAE recommends that the light from the supplemental stop and/or turn signal lamps should comply with the same color requirements as the original stop and/or turn signal lamps. This means that yellow would not be permitted as a stop signal lamp.

Location. SAE recommends that the lamps be mounted higher than the conventional stop or turn signal lamps, and possibly forward of the rear-mounted rear presence lamp and stop and turn signal lamps.

Other. SAE suggests the supplemental stop and turn signals may be provided by separate lamps, or combined in a single lamp (one on each side). The signal function should be the same as the standard lamp: The stop signal is given by a steady light upon application of the service brakes; the turn signal is given by a flashing light on the side towards which the turn is anticipated or being executed. The phase relationship between supplemental high-mounted turn signals and the standard turn signal should be the same, i.e., not alternating. A rear presence lamp function should not be combined in the supplemental stop and/or turn signal lamps.

Rear School Bus Loading and Unloading Lamps (SAE Standard J887).

Intent. School bus loading and unloading lamps identify a vehicle as a school bus and inform other drivers that such vehicle is stopped on the road ahead to take on or to discharge school children. (In most states, traffic approaching a loading or unloading school bus from either the front or behind must come to a complete halt until the loading or unloading process is completed.)

Method of Activation. These lamps must be controlled by a manually actuated switch. Where System B (as described below) is used, the signal system must be wired so that the yellow signal lamps are activated only by manual operation and are automatically deactivated and the red signal lamps automatically activated when the bus entrance door is opened.

Number and Color. System A - two red lamps; System B - two red lamps, and two yellow lamps.

Location. System A: They must be mounted as high as possible on the rear of the vehicle, but so that the lower edge of the lens is not lower than the top line of the side window openings, at the same height, and as far apart as possible, but in no case less than 40 inches from each other (measured from lamp edge to lamp edge).

System B: The red lamps are mounted in the same location as in System A above. The yellow lamps are mounted immediately inboard (towards the vertical centerline of the bus) from each of the red lamps, and at the same height as each other and the red lamps.

Other. The lamps must flash alternately at a rate between and including 60 to 120 cycles per minute. The "on" period of the flasher must be long enough to permit the bulb filament to come to full brightness. There must be a visible or audible means of giving a clear and unmistakable indication to the driver when the signal lamps are turned on. Further requirements exist as to not permitting any part of the vehicle to obstruct the visibility of the lamps within certain angles of view.

SAE recommends that the area of the vehicle immediately surrounding the signal lamp be painted black. This recommendation is specifically exempted in FMVSS 108 from the Federal manufacturing requirements.

When System B is used, the yellow lamps must be at least two and one-half times brighter than the specification in SAE Standard J887 for red signal lamps.

The aiming pads on the lens face mentioned in SAE Standard J887 are also specifically exempted in FMVSS 108 from the Federal manufacturing requirements.

The various states probably specify whether System A or System B may, must, or may not be used within their jurisdictions. No summary of lamp requirements or prohibitions, nor of conditions or prohibitions of use in the various states, is readily available for this review.

<u>Rear Flashing Warning Lamps for Authorized Emergency, Maintenance, and Service Vehicles</u> (SAE Standard J595b).

<u>Intent</u>. The lamps covered in this section are for use on authorized emergency, maintenance, and service vehicles.

<u>Method of Activation</u>. No specifications or recommendations exist.

<u>Number</u>. SAE recommends that two be used on the rear of the vehicle.

<u>Size</u>. SAE recommends they have an area of not less than 12 square inches.

<u>Color</u>. SAE recommends the color be yellow or red.

Location. SAE recommends that the lamps be mounted as high and as far apart as practicable, but in no case should the lateral spacing be less than 3 feet.

Other. SAE recommends that these warning lamps flash at 60 - 120 cpm. The "on" period of the flasher should be between 30 and 75%. There should be a visible or audible means of giving a clear and unmistakable indication to the driver when the warning lamps are turned "on" and functioning normally. To improve the effectiveness of the signal, it is recommended that, where practicable, the area of the vehicle immediately surrounding the signal be painted black.

The various states set specific standards as to what color of flashing warning lamps (other than hazard flashing lamps utilizing the turn signal lamps) may be used on various types and authorizations of vehicles. The circumstances of permissible or impermissible use are also covered.

Three-Hundred and Sixty Degree Revolving Beacon Lamp (SAE Recommended Practice J845).

See section on Revolving Beacon Lamps for Front-Mounted Lamps.

Rear Presence Lamps (SAE Standards 585d, 585c, and J575d).

Intent. Whether separate or in combination with other lamps, rear presence lamps are intended to designate the rear of a vehicle.

Method of Activation. The rear presence lamps on any vehicle must be activated when the headlamps are activated in a steady-burning state. In addition, on passenger cars, motorcycles, and those multipurpose passenger vehicles, trucks, trailers, and buses of less than 80 inches overall width, the rear presence lamps must be activated when the parking lamps are activated.

Number. All vehicles must have two, except motorcycles need only one. Most states also permit vehicles with only one rear presence lamp and manufactured before a certain date to operate on their public highways.

Size. No minimum size requirements for rear presence lamps are directly specified. However, an indirectly specified size requirement has existed and is currently binding, as construed by the following (SAE Standard J585c):

> "Signals from lamps on both sides of the vehicle shall be visible through a horizontal angle from 45 degrees to the left to 45 degrees to the right. Where more than one lamp or optical area is lighted on each side of the car, only one such area on each side need comply. To be considered visible, the lamp must provide an unobstructed projected illuminated area of outer lens surface, excluding reflex, at least 2 square inches in extent, measured at 45 degrees to the longitudinal axis of the vehicle."

Color. Red.

Location. On motorcycles: The rear presence lamp must be mounted on the vertical centerline at a height of not less than 15 inches nor greater than 72 inches from the level road surface on which the vehicle stands. If two are used, the height requirement still applies, but the lamps must be symmetrically disposed about the vertical centerline. In addition, certain requirements exist about the mounting distance (edge-to-edge separation) between rear presence lamps and rear turn signal lamps, as discussed previously.

On all other vehicles: The rear presence lamps must be mounted at the same height, but not less than 15 inches nor more than 72 inches from the level road surface on which the vehicle stands, one on either side of the vertical centerline and as far apart as practicable.

Other. The minimum photometric requirements for single and multiple compartment rear presence lamps have been grouped into "zones," comprised of the cumulative minimum values of the test points in each of the seven zones specified [37 F.R. 21328]. Rear presence lamps may not be optically combined with clearance lamps. If rear presence lamps are optically combined with turn signal or stop signal lamps, their relative intensities must meet or exceed certain proportions, as previously discussed in the sections on those lamps.

SAE recommends that, if multiple compartment or multiple lamp arrangements are used for rear presence lamps on vehicles less than 80 inches overall width, and this distance between optical axes does not exceed 22 inches for two-compartment or two-lamp arrangements, and does not exceed 16 inches for three-compartment or three-lamp arrangements, then the combination of the compartment or lamp arrangements should be used to meet the photometric requirements for the corresponding number of lighted sections (see Table 1.6). However, if the distance between optical axes exceeds the above dimensions, each compartment or lamp should comply individually with the photometric requirements for one lighted section. The determination of the ratios of light output when the rear presence lamp is combined with a rear turn signal lamp or a stop signal lamp is also affected, as discussed in the previous sections covering those lamps specifically.

SAE further recommends that for vehicles of 80 or more inches overall width, a maximum of two compartments or lamps per side may be mounted closer together than 22 inches, provided that each compartment or lamp meets the single-compartment photometric requirements. Although not specifically stated, this recommendation presumably also permits two or more lamps or compartments on each side with optical axes 22 or more inches from each other, but only so long as each lamp or compartment individually meets the photometric requirements for a single lighted section.

NCUTLO recommends that the rear presence lamps should be so wired that when any auxiliary driving lamps are lighted, the rear presence lamps will also be activated.

Almost all states require that rear presence lamps be visible at a distance of 500 feet at night, rather than to specify photometric or size requirements. Some states permit vehicles other than the rearmost in a tandem train not to have their rear presence lamps illuminated, so long as the rearmost vehicle is equipped with properly functioning rear presence lamps. At least one state does specify the minimum size for rear presence lamps, while some others specify that rear presence lamps be mounted within a certain distance from the rearmost part or extension of the vehicle. One state permits reflex reflectors in lieu of rear presence lamps on trailers below a certain weight.

Rear Clearance Lamps (SAE Standards J592c and J592e).

Intent. The rear clearance lamps show to the rear of a vehicle and are mounted and intended to indicate overall width of the vehicle.

Method of Activation. No specifications exist.

Number. Two rear clearance lamps are required on those multipurpose passenger vehicles, trucks (except truck tractors), trailers, and buses of 80 or more inches in overall width.

Size. No recommendations exist.

Color. Red.

Location. One must be located on either side of the vertical centerline, at the same height, as near the stop as practicable, to indicate overall width of the vehicle.

Other. No clearance lamp may be combined optically with any identification lamp or any rear presence lamp. Boat trailers need not be equipped with both front and rear clearance lamps, provided a yellow (to front) and red (to rear) clearance lamp is located at or near the midpoint on each side of the trailer so as to indicate its extreme width. When the rear identification lamps are mounted at the extreme height of a vehicle, rear clearance lamps need not meet the requirement that they be located as close as practicable to the top of the vehicle.

Some states do not exempt truck tractors. Others require clearance lamps on vehicles over a certain length as well, regardless of width. Some states specify the width as 84 inches, instead of 80 inches.

SAE Standard J592c is incorporated by reference into FMVSS 108. This standard has since been revised to remove the following test points for rear clearance lamps: H-30L & R, H-20L & R, and H-10L & R.

Rear Identification Lamps (SAE Standards J592c and J592e).

Intent. Identification lamps are to identify certain types of vehicles (namely, those over a certain width).

Method of Activation. No specifications exist.

Number. Three identification lamps are required on those multipurpose passenger vehicles, trucks, and buses of 80 or more inches overall width, except none are required on truck tractors regardless of width.

Size. No specifications exist.

Color. Red.

Location. They must be mounted on the rear as close to the top of the vehicle as practicable, all at the same height, as close as practicable to the vertical centerline with lamp centers spaced not less than 6 inches nor more than 12 inches apart.

Other. Two states also require rear identification lamps on truck tractors.

SAE Standard J592c is incorporated by reference into FMVSS 108. This standard has since been revised to remove the following test points for rear identification lamps: H-30L & R, H-20L & R, and H-10L & R.

License Plate Lamps (SAE Standard J587d).

Intent. A license plate lamp illuminates the license plate on the rear of a vehicle. To the extent that such light is reflected backward towards the driver of a following vehicle, this lamp also serves as an indirect rear presence lamp.

Method of Activation. On all passenger cars and motorcycles, and on those multipurpose passenger vehicles, trucks, trailers, and buses of less than 80 inches overall width, the license plate lamp must be illuminated when the parking lamps are activated and when the headlamps are activated in a steady-burning state.

Number. One, except two may be used to meet the photometric requirements.

Size. No specifications exist for the lamp itself.

Color. White.

Location. The license plate lamp(s) must illuminate the license plate from the sides or from above. NHTSA has proposed a change which would again permit the license plate lamp(s) to illuminate the license plate from below as well, but only if a certain unobstructed space is provided between the lamp and the plate [37 F.R. 22991].

When a single lamp is used to illuminate the license plate, the lamp and the license plate holder must be so positioned that at no point on the plate will the incident light make an angle of less than 8 degrees to the plane of the plate. When two or more lamps are used to illuminate the plate, the minimum 8 degree incident light angle applies only to that portion of the plate which the particular lamp is designed to illuminate.

Other. The photometric test is accomplished by measuring each of several "test stations" on a plate of clean, white blotting paper. The minimum measurement must be 0.75 foot-candles. The ratio of maximum to minimum illumination must not exceed 20:1 for a 6" x 12" plate (used on all vehicles except motorcycles), or 15:1 for a 4" x 7" plate (used for motorcycles).

Although the license plate is not usually associated with vehicle lighting and signaling systems, the license plate lamp (or, more properly, the reflection of its light off the license plate, holder, or surrounding trim or body work) might assist, and possibly even detract from, another driver's ability to detect relative velocity (closure) and change in vehicle orientation. For instance, on those vehicles operating in a nonconforming manner because of the absence (or failure to operate) of one or more tail-lamps, the observation of the illuminated license plate can play a significant part in determining that vehicle's exact position and relative velocity.

A few states require that the license plate lamp(s) be mounted no further to the vehicle's right side than the vertical centerline. Some states require that the license plate lamp(s) be controlled by the head lamp switch on all vehicles, and that the lamp(s) be lighted whenever the headlamps have been activated. Almost all states set specific standards of visibility in terms of the number of feet (minimum) at which the license plate can be read when illuminated by the license plate lamp(s).

Rear Reflex Reflectors.

Intent. Reflex reflectors are intended to indicate the presence of a vehicle to an approaching driver by reflecting back to him light from his own approaching vehicle.

Method of Activation. None required.

Number. Two, except only one is required on motorcycles.

Size. No specifications or recommendations exist. Most states give the visibility requirement in terms of the minimum distance at which they must be seen when illuminated by lawfully adjusted lower or upper headlamp beams (as the individual state may specify).

Color. Red.

Location. One on either side of the vertical centerline, as far apart as practicable, and at the same height but not less than 15 nor more than 60 inches from the road surface. On a truck tractor, the red rear reflex reflectors may be mounted on the back of the cab instead of on the rear of the vehicle, but only if the middle of the reflector is not less than 4 inches above the height of the rear tires.

Other. Most jurisdictions specify a minimum mounting height of between 20 and 24 inches, although some allow it to be as low as 15 inches.

Other Lamps on the Rear of Vehicles. Other lamps not mounted on the rear but which are intended to project primarily in a rearward direction have been discussed previously. They include the following:

1. Side Turn Signal Lamps. These were discussed in the section on side-mounted lamps. Since there are unique and specific photometric recommendations for these lamps, a separate column for this type has been included in Table 6.

2. Double-Faced Turn Signal Lamps. These were discussed in conjunction with rear turn signal lamps in this section. They have the same photometric requirements as conventional rear-mounted turn signals (except for the inboard test points, and except for a requirement concerning obliteration of the signal by external light), and are therefore not given a special category in Table 1.6.

3. External Turn Signal Indicator Lamps. These were discussed in the section on side-mounted lamps. Since no photometric standards have been developed for these indicator lamps, they have not been included in either Table 5 or Table 6.

A small number of other types of rear-facing light sources on vehicles can also be identified. Included within this group are: (1) reflectorized rear trim; and (2) reflectorized license plates.

## OBSERVATIONS ABOUT THE CURRENT STANDARDS

DEVELOPMENT OF THE CURRENT STANDARDS. The history of automotive signaling and marking lamps develops from the requirements of lighting on other forms of transportation, notably from the fields of maritime and railroad transportation. Fisher (1968) notes that lighting devices on the early automobiles were actually equipment borrowed from carriages.

The early carriage lamps sometimes had white or colored jewels emitting light to the sides or rear. As automobiles began developing a shape more distinctive than a horseless carriage, one or two large headlamps with a candle or oil lamp for its light source became commonly used, with a small taillamp, red in color, frequently on the rear. The first SAE recommendation for red taillamps was approved in 1918. The color red was significant, for it probably was derived from the red lantern used on the rear of railroad trains. A red signal of "danger" was appropriate for railroad traffic, because of the relatively slow deceleration rate of trains. Perhaps there was also felt to be a similar danger of rear-end collisions among automobiles. In any case the color of red, already associated with an attention-commanding communication, was adopted and has remained as the convention for taillamps.

This connotation of "danger" contrasts with the current intent of the taillamp, to indicate the presence of a vehicle, but otherwise to do nothing under normal traffic conditions to command attention (other than for detecting closure, or relative velocity). Indeed we might well feel fortunate that another early "aftermarket" product, a green stoplamp, did not similarly catch the attention and enthusiasm of automotive pioneers.

The first SAE recommendations covering stop and turn signal lamps were in the 1927 SAE Handbook.

The development of special lighting equipment for vehicles exceeding certain dimensions is another example of how a convention's original intent has been lost. Fisher (1968) points out that "the advent of large trucks, and buses made clearance markers, sidemarkers, and identification lights necessary," although he does not cite the particular reasons why this was so. Perhaps with the more primitive road system, large vehicles needed to be intercepted before attempting to traverse bridges or narrow lanes which could not accommodate their greater height, width, or weight. Special marking and identifying lamps could have assisted in this interception. In addition, special marking might have been used to identify vehicles engaged in interstate commerce.

SAE first established criteria for clearance, sidemarker, and identification lamps in 1937. The colors were to be white, yellow, or green (except identification lamps were to be only green) to the front, and red to the rear. The lamps were intended to indicate extreme width (clearance lamps), total length (sidemarker lamps), or to "identify a slow moving, large vehicle" (identification lamps).

The 1939 SAE Handbook eliminated white and green as colors permissible for clearance, sidemarker, and identification lamps, and amended the intent of identification lamps "to identify a certain type of vehicle." Exactly what "certain type of vehicle" SAE had in mind is not clear, but exactly the same wording is retained in the current requirements (SAE Standard J592c). However, it can be assumed that the change was made because the vehicles on which the lamps were being mounted were not necessarily "slow moving, [and] large," as the earlier Standard had described. This suggests that the use of clearance, sidemarker, and identification lamps had by that time already become common on certain classes of vehicles.

Only a handful of states actually require identification lamps today. For some reason, however, the FHWA and the ICC do require such lamps for use on commercial interstate vehicles. NCUTLO recommends them on all vehicles over a certain size, regardless of use.

PROBLEMS ENCOUNTERED IN THE CURRENT DESIGNS AND APPLICATIONS.

1. Considerations of Lamp Area and Intensity. The current standards for automotive lighting equipment establish photometric levels with only occasional reference to lamp area. Minimum lamp area is specified directly for the following lighting equipment:

A. Turn signal lamps (3.5 or 12.0 square inches, with SAE recommending an 8.0 square inch minimum instead of 3.5).
B. Brake signal lamps (3.5 or 12.0 square inches, with SAE recommending an 8.0 square inch minimum instead of 3.5).
C. School bus loading lamps (19 square inches).
D. Flashing warning lamps on authorized emergency, maintenance, and service vehicles (12 square inches).
E. Three hundred and sixty degree rotating beacon-type lamps (16 square inches).
F. Headlamps (7 inches in diameter for one type, 5 3/4 inches in diameter for the other; except that motorcycles could have other, smaller types for which no size specifications exist).
G. Externally-mounted turn signal pilot indicator lamps (0.1 square inch).
H. Rear presence lamps (but only in a plane 45° canted relative to the longitudinal axis of the vehicle: 2 square inches).

Perhaps also to be added to this list would be the reflected light off rear-mounted license plates. Two sizes of license plates are recommended, one for motorcycles, another for all other vehicles. No standards for the reflectivity of the license plates themselves exist, however.

The lack of a clearly and directly defined minimum size standard for rear presence lamps is especially noted. Davids (1963) points out that drivers with certain color vision abnormalities could confuse a large, circular rear presence lamp with a headlamp. Array coding, as Allen (1970) mentions, might help alleviate this problem.

Most jurisdictions which establish and enforce their own standards on vehicle operation (i.e., individual states in their State Vehicle Codes, and local governmental units in their ordinances; also, the FHWA and ICC for certain kinds of commercial, interstate transportation) specify operating minimums not in lamp size, but in the minimum distance at which the lamp can be seen under certain atmospheric and ambient conditions. Since this criterion is subject to the interpretation of the observer, and by other factors such as the test conditions under which the observation is carried out, substantial variation could result. Nevertheless, since such a visual test relates directly to the actual performance of such lighting equipment under field-test conditions, this method is not without strong rational defense, lack of standardization notwithstanding.

Even where minimum sizes are specified, no maximum sizes are given. Forbes (1966) points out that many drivers found some brake lamps to be excessively bright at night. Merely an intensity requirement would not accommodate such a problem--since both lamp size and total luminous flux affect discomfort glare.

2. Lack of Inclusion of Certain Types of Vehicles. Motor-driven cycles, motorized bicycles, motorscooters, and ATV's are not mentioned in the FMVSS 108. Most states differentiate among these various subdivisions, using as the criteria engine displacement, horsepower, wheel size, speed potential, passenger carrying capability, etc. The need for licensing of such vehicles and/or their operators, and the legality of operating them on public roads varies from one state or jurisdiction to another. Nevertheless, to the extent that such vehicles interact with the traffic patterns

of the more conventional types (cars, trucks, buses, etc.) the need for lighting equipment standards exists.

Similarly, the recent population explosion of snowmobiles, all-terrain vehicles (ATV's), amphibious vehicles, and other industrial and recreational vehicles creates the need for some kind of uniform lighting equipment standards. These vehicles are, at least occasionally, operated near conventional traffic, even though such operation may be legally restricted or prohibited in many places.

A rather common example of such interaction in some northern states is the point at which snowmobile trails cross over public highways. The lack of side marking devices (lamps, or reflex reflectors) on snowmobiles creates an obvious hazard to their operators, and to other drivers, especially since such crossover points are frequently not well marked on either the road (for the oncoming car) or on the snowmobile trail. Car-snowmobile collisions have become frequent enough that during some months of the year, some areas find a greater proportion of property damage and personal injury accidents from this category than from collisions strictly between the more conventional vehicles.

3. Separate Standards for Certain Commercial Vehicles. Certain commercial vehicles' lighting systems are regulated by the FHWA's Bureau of Motor Carrier Safety [BMCS], in their Motor Carrier Safety Regulations [MCSR; 49 C.F.R. 293 B]. For instance, converter dollies are not covered under the FMVSS 108, but have certain requirements when towed singly by another vehicle but not part of a full trailer.

4. Exclusion of Certain Vehicles from Minimum Compartment or Lamp Size. FMVSS 108, section S4.1.1.7 in effect requires that if multiple compartment or multiple lamp arrays are used for stop or turn signal lamps on passenger cars, each lamp or compartment must have an effective projected luminous area of not less than

3.5 square inches. This standard is also noted in Table 1.6, but only for passenger cars, and those multipurpose passenger vehicles, trucks, and buses of less than 80 inches overall width. There is no comparable requirement for multiple compartment or multiple lamp arrays on those multipurpose passenger vehicles, trucks, and buses of 80 or more inches in overall width.

No justification has been given why these other types of vehicles have been excluded from this requirement.

5. Reference to Class A and Class B Lamp Size and Photometric Standards. Since the former distinctions between Class A and Class B photometric standards are not mentioned in the 1973 SAE Handbook, such reference would best be eliminated altogether from MVSS 108. The size requirements remain, although no compelling reason is known why that justifies retention of the Class A/Class B distinction. The revised SAE standards seem to adapt well to the size distinctions without reference to the "Class" requirements.

6. Rear Turn Signal Lamp Requirements on Truck Tractors. Truck tractors are currently excluded from the requirement that all vehicles (except certain motorcycles) must have rear turn signal lamps, if their front turn signal lamps are so constructed and so located that they can be seen directly to the rear and at the normal outboard angles. The same photometric requirements must be met for the rear light projected from such a mounting as for a regular turn signal lamp, except that the H-V minimum is reduced, and except that no inboard photometric levels need be met.

Therefore, the driver of another vehicle following a truck tractor so equipped might be unable to see a right turn signal, or even a left turn signal if he is following slightly to the right behind the truck tractor. Although the value of such a double-faced turn signal lamp as a side turn signal indicator is obvious (for instance, to another vehicle passing the truck tractor-with-trailer combination if he is forward of the rear signal lamps' position), no clear reason can be seen for not requiring a regular rear turn signal lamp for especially those situations in which the truck tractor is not towing a trailer.

Furthermore, the reduced photometric minimum at the H-V point is to permit the lamp manufacturer to construct a double-faced turn signal lamp which would be less likely to cause glare to the operator of the vehicle on which it is mounted. This reduction in glare can be accomplished by other means (baffles, shields, different mounting locations, etc.). Therefore, this reduced minimum seems to be unnecessary, and has the practical effect of making the turn signal on such a large (and, frequently, slow-moving or slow-responding) vehicle less likely to be seen and rapidly recognized as a turn signal function.

7. <u>Hazard Warning System Can be Incapacitated by Stop Signal</u>. The hazard warning system, unlike the turn signal system, on many vehicles does not override the stop signal function in those lamp housings or arrays where the two are electrically combined. Therefore, when the stop signal switch is activated (by application of the service brakes) and the hazard warning system is already on, all signals (including those in front as well as the rear) on such vehicles cease to flash and remain steadily on.

On certain vehicles the side marker lamps are also flashed when the turn signal function on their respective side is activated. This flashing overrides the normal side marker lamp function, and is accomplished electrically by grounding, rather than mechanically in the turn signal switch. One side of the marker filament, which we will call the "A" side for convenience, is connected to the presence lamp output line from the headlamp switch. The other side of the filament, the "B" side, is connected not to the chassis ground (the conventional wiring method for automotive lighting), but instead to the respective front turn signal line. When the presence lamp function is inactive, the operation of the front turn signal lamp on either side also provides the nominal +12 volts on the "B" side of the side marker lamp, while the "A" side of the side marker lamp, connected to the inactive presence lamp line is actually grounded to the chassis frame through the rear presence lamps and through the parking lamps ( on vehicles less than 80 inches overall width) or clearance and identification lamps (on vehicles of 80 or more inches overall width). Therefore, the side marker lamps flash in phase with the turn signals when the presence lamp function is inactive.

When the presence lamp function is activated, on the other hand, the "A" side of the side marker filaments is provided with +12 volts, while the "B" side is inactive, but actually grounded through the front turn signal lamp on the respective side. When the turn signal system on that side is activated, +12 volts is alternately provided and then removed ("flashed," by means of the vehicle's turn signal flasher). When that +12 volts is being provided from the turn signal flasher, both the "A" and the "B" sides of the respective side marker filaments are provided with the +12 volts, and therefore the voltage across the bulb itself is zero, and the lamp is extinguished. The resulting apparent flashing of the side marker lamps (on vehicles where this wiring system is utilized) when the presence lamp function is on, is therefore exactly out of phase from the regular turn signal function. This may be undesirable, since it may have an effect of rendering the side marker lamp as not appearing to be part of the same system as the other lamps and provide a visual discontinuity which may render it more difficult to identify the vehicle. For example another driver may believe there is more than one vehicle involved.

This same phase relationship, dependent upon the activation or lack of activation of the presence lamp system, also holds true for the hazard warning system. Therefore, on vehicles so wired, when the presence lamp function is on and the hazard warning system is activated, and also when the brake pedal is depressed (thereby activating the stop signal function), the hazard warning flash freezes "off" in the side marker lamps. This leaves such vehicle without any side marker lamps on either side at a time when it is especially important that side marking lamps be illuminated as well as the hazard warning system.

A solution to these problems could be accomplished by requiring that the hazard warning system override the stop signal input to the rear lamps on vehicles that utilize this conventional lighting system. (This would, of course, not be necessary on those vehicles where the stop signal function and the rear turn signal function are not combined into a single lamp.)

8. <u>Width of Beam on School Bus Loading and Unloading Lamps</u>. Present photometric requirements for school bus loading and unloading lamps do not extend beyond 30° from the horizontal line through the lamp axis and parallel with the vehicle's longitudinal axis. In particular, no component normal to the vehicle's longitudinal axis is specified. To the extent that school buses load or unload only on straight sections of road not close to intersections, this lack is unimportant. However, school buses on occasion load or unload (and have their specialized, alternating flashing warning lamps activated) on curved road sections or near intersections where oncoming cross-traffic would have no chance to view the loading lamps from within the ±30° horizontal range.

Some consideration should be given to revising the warning lamp requirements for school bus loading and unloading lamps, to [illegible] the warning lamp requirements (perhaps by requiring warning lamps on the sides as well as on the front and rear) so that the signals will be visible to drivers approaching the bus from a greater angular displacement.

9. <u>Truck-Tractor Clearance Lamps Indicate Cab Width</u>. Clearance lamps on a truck tractor need indicate only the width of the cab, not the overall width of the vehicle itself. Furthermore, since only one identification lamp is required in some states

on those truck cabs (tractors, or single-chassis trucks) less than a certain width, the distinctive feature of the five-lamp array (except on trailers) is further compromised. Since the intent of clearance lamps is to indicate the extreme width of the truck, and to be as high as possible, this suggests the standard permitting cab-mounting of the clearance lamps should be changed to read that they must be mounted at the extreme width, even if this point is not on the cab itself. The requirements for the identification lamps could remain, except that three should be required even on those vehicles whose cabs are less than a certain width. On narrow-cab trucks, the cab usually is situated on the left front side of the chassis. The center lamp of the three identification lamps would not be able to be mounted on the vehicle's centerline in this instance. Perhaps this exception should be specifically allowed in the FMVSS 108.

10. Actuation of Clearance, Side Marker, and Identification Lamps. The wiring requirements of FMVSS 108, paragraph S4.5.7, apply only to passenger cars and other vehicles less than 80 inches overall width. An additional requirement should be made, applicable to those vehicles required to have clearance and identification lamps, that whenever such lamps are on, the taillamps, license plate lamp(s), and side marker lamps must be on. Further, clearance, identification, side marker, license plate, and taillamps should be required to be on whenever the headlamps are on. An additional "momentary off" switch (preferably a push-button type) should be provided which temporarily extinguishes clearance and identification lamps (and, optionally, side marker, license plate, and taillamps) when headlamps are on, for the purposes of signaling. Further, the means should be provided for turning the headlamps off without turning off the clearance, identification, side marker, license plate, and taillamps, also for signaling purposes. This can normally be accomplished with the conventional headlamp switch. The momentary push-button switch for "blinking" the clearance lamps, etc., should be within easy reach of the driver when he is restrain-

ed by any required seat belts, shoulder harnesses, or other restraining devices in place during normal operation of the vehicle.

11. Boat Trailer Exemption from Certain Clearance Lamp Requirements. Boat trailers currently need not have both front and rear clearance lamps, if instead they have one clearance lamp on each side, yellow facing forward and red rearward. Unladen boat trailers and depressed flat-bed trailers (or "lowboys") present a special hazard in that the only mounting surface for clearance and side marker lamps is frequently well below the heights at which drivers expect to see such marking devices. The hazard is especially evident in merging traffic situations, or in lane change maneuvers in which the vehicle towing such a trailer is overtaking another vehicle. Consideration should be given to requiring some type of structure, perhaps collapsible or removable during loading, which would contain auxiliary side marker and/or clearance lamps.

12. Use of Rear Clearance and Identification Lamps. Although FMVSS 108 exempts truck tractors from the requirements to have rear clearance, rear identification, rear side marker lamps, and rear side reflex reflectors, some states still require this equipment.

The absence of this equipment means that when a truck tractor is not towing a trailer, it lacks those indicators that it is an oversize vehicle. Also, if a truck tractor is backing onto a road but is still essentially perpendicular to it and jutting into the traffic lane, there are no side marking devices which other drivers can see, except the rear presence lamps (not visible if the truck is still perpendicular to the direction of traffic), behind the front side marker lamp and reflector, or the intermediate side marker lamp and reflector if the truck is 30 or more feet in overall length.

On the other hand, each vehicle in a tandem series has its own rear marking devices (clearance, identification, side marking, and taillamps). Most states permit such rear marking devices on vehicles ahead of the rearmost vehicle in a tandem series to be extinguished, so long as the rearmost vehicle has all the necessary lamps. However, this is not required, and the result is that a merging driver, as he is being overtaken in the passing lane by such a tandem trailer rig, might mistakenly assume that when the first trailer has cleared (he can see its red clearance, identification, side marker, and rear presence lamps), he is then able to pull into the left lane. (This problem is identical to the problem encountered with unladen boat trailers and "lowboys," except that instead of the side marker lamp being too low to be seen, it may now be too high, since no maximum height requirement for side marker lamps exists.)

This problem could be solved by one or more of several changes. First, a maximum height of front side marker lamps on tandem trailers (or semitrailers) could be set at about four feet. Second, red identification, clearance, side marker, and rear presence lamps on all those vehicles not the last in a tandem series could be required to be extinguished, and preferably replaced with yellow side marker lamps, or left off altogether.

This suggestion merely reinforces the practice of using the color red only on the rear of the last vehicle in a train of vehicles.

Joinable containers could be similarly treated.

13. Mounting Location of Side Marker Lamps. Although front, rear, and when required, intermediate side marker lamps must all be mounted at a height of not less than 15 inches above the level road surface on which the vehicle stands, no requirement is made that they all be mounted at the same height on a given vehicle. The result is that a vehicle's vertical orientation cannot be accurately determined merely from observing the side marker lamps. Since this information is of interest to driver's approaching

from the side (for instance, at a highway intersection), no logical reason is known for not making this requirement.

14. Use of 360° Beacon Lamps, and Other Emergency Vehicle Lamps. No uniformity exists between states, and frequently even within states, concerning the use of emergency vehicle signal lamps. For instance, in some states, blue lamps are permitted only on police vehicle while on emergency business. In some other areas, blue is used to identify press vehicles, snowplows, or other certain special vehicle types.

The need for national standardization is increased by the frequency of interstate travel on our modern highway systems. That a specific type of signal could mean one thing in one area, and yet something else entirely in another, is obviously confusing to the driving public.

## 2. A REVIEW OF DIFFERENCES IN U.S. AND FOREIGN VEHICULAR LIGHTING EQUIPMENT STANDARDS

### OBJECTIVES OF THIS REVIEW

The original intent of this review was to define the areas of congruence and divergence in the lighting equipment standards applicable to vehicles manufactured for sale in the United States, versus the comparable standards applicable to vehicles manufactured for sale in various foreign countries. This review was planned to determine the changes required to convert vehicles prepared for the domestic marked instead for sale abroad.

The initial investigation revealed that the individual automobile companies' foreign sales departments were already fully aware of these basic differences in lighting equipment standards, and that little new information would be uncovered. Therefore, the definitions of divergence are merely summarized in the first part of the review, without an extensive country-by-country breakdown. (Unless otherwise specified, congruence in standards will be assumed. Namely, vehicles equipped to meet the U.S. standards will be assumed to meet or exceed the equipment standards in the other countries.)

As work progressed, another benefit of this comparison in lighting equipment standards came to our attention. Most countries' equipment standards have evolved over a period of time, changing to reflect in part the successes and failures of certain concepts and items of equipment based on local experiences. Therefore, an investigation of the differences between these standards might reveal lighting concepts that should be considered for use in the U.S. This second subject is covered later in this review.

### DETERMINING THE COUNTRIES FOR CONSIDERATION

To prevent extension of this review to cover the standards of every country in the world, some criterion had to be developed to limit its scope. Because the original objective concerned determining the modifications necessary to enable domestic vehicles to be sold abroad, the first criterion considered was based on export data. Namely, to which countries are U.S.-manufactured vehicles most frequently exported?

According to data from the U.S. Department of Commerce (Report FT-410), as reprinted in part by the Motor Vehicle Manufacturers Association, some of the more highly industrialized nations were among the lowest consumers of U.S.-built automobiles. On the other hand, some of the least industrialized nations were among the largest consumers.

This situation may be due to the competitive rivalry existing between the more highly industrialized nations. This rivalry produces both the implicit trade barriers, as well as the more explicit barriers and import quotas. An example of the former might be the slightly tighter restrictions imposed by certain countries on vehicle lighting equipment mounting locations. (From the experience gained in compiling this review, the tighter tolerances of the Italian standards could be explained by this logic.)

Whatever the causes of this unexpected export situation, choosing the countries of consideration by these export data alone would be inappropriate.

A second criterion, based on the various countries' levels of industrialization, was then developed. The rationale for this criterion was that the more industrialized countries are more likely to have developed minimum vehicular lighting equipment standards for themselves, based at least in part on consideration of the effectiveness of the various lighting concepts and configurations used in their countries in the past.

Since this second criterion more closely served the function intended for the second part of this review, namely, dealing with additional concepts worthy of further consideration, it was used as the basic guideline.

Using this criterion, the following resource materials were used in the investigative work done for this review:

1. "Summary of Foreign Regulations; Lighting Equipment," issued by the Technical Regulations Section, Engineering Department, GM-Vauxhall.

2. Various volumes of the "Inter-Europe Vehicle Regulations" subscription collection of the Motor Vehicle Manufacturers Association.

3. The "Agreement Concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval for Motor Vehicle Equipment and Parts," and its Addenda, as established by the Inland Transport Committee of the Economic Commission for Europe of the United Nations. (This reference will hereinafter be referred to as "the ECE Regulations.")

4. The ECE's draft regulations "Uniform Provisions Concerning the Approval of Vehicles with Regard to the Installation of Lighting and Light-Signaling Devices" (hereinafter referred to as "the ECE's recent draft provisions").

5. The "ISO Recommendation R-303, May 1963" of the International Organization for Standardization.

6. Various other printed resources of less importance.

A summary of the relationships between the various international bodies which authored the above regulations is contained in "Lighting, Visibility, and Accidents" (Organization for Economic Cooperation and Development, 1971, pages 23 and 24.)

MULTIPLE STANDARDS: CONFLICTING REQUIREMENTS

Although most industrialized countries have developed their own vehicle lighting equipment standards, many have also become signatories to various international conventions on such equipment. The most widely known and followed of these international manufacturing standards is the set collectively known as the ECE Regulations. This set, including the subsequent addenda to the original agreement, contains the basic guidelines for the design and illumination performance of the various items of lighting equipment, and the conditions of their reciprocal type-acceptance by various countries. (The ECE's recent draft provisions, on the other hand, concern more the installation requirements on particular types of vehicles. The latter are comparable to the Federal Motor Vehicle Safety Standard No. 108, whereas the ECE Regulations are comparable to the individual SAE Standards and Recommended Practices.)

In some instances, direct conflicts exist between the internally and the internationally imposed standards to which the particular country is a signatory. In most such instances, the respective authorities seem willing to accept lighting equipment which meets either the internal or the international standards.

This dual-acceptance is not always followed, however. For instance, although West Germany is a signatory to the ECE Regulation No. 5, covering the design and use of sealed beam headlamps, current West Germany law still prohibits their use on vehicles sold in that country. The rigidity or uniformity of enforcement of this prohibition was not determined. Ironically, West Germany is one of the primary importers of U.S.-built sealed beam headlamps, according to the Department of Commerce data previously cited. (This might be explained, however, by the fact that many vehicles intended for export to and sale in the U.S. are manufactured and assembled in West Germany factories.)

DIFFERENCES IN STANDARDS FOR SPECIFIC LIGHTING EQUIPMENT

The most significant differences between the vehicular lighting equipment standards applicable to vehicles manufactured for sale in the United States and the comparable standards applicable to vehicles manufactured for sale in many of the other primary industrial countries concern the location of and supplement to the front turn signal lamps. Differences of somewhat less significance concern the mounting locations of the various items of lighting equipment, their photometric characteristics (color, beam pattern, intensity), special headlamp controls, and special requirements for larger vehicles. Each of these areas is discussed in greater detail in the next few pages.

A. Supplement to the Front Turn Signal Lamp. In three countries (Denmark, Norway, and Italy) the conventional front and rear turn signal lamps must be supplemented by a side-mounted turn signal lamp on each side of the vehicle. Several other countries require these supplemental turn signal lamps on vehicles greater than 19' 8" (6 m) in length. The location of these lamps is specified in the various countries as being not further rearward than the front third of the vehicle, not further rearward than the front edge of the load-carrying body, or not further rearward than 5' 11" (1.8 m) from the vehicle's leading edge.

In those three countries where these lamps are required on all vehicles exclusive of length, each lamp must project light horizontally rearward to as much as within 5° of the vertical plane passing through the lamp and parallel with the vehicle's longitudinal axis. In one country (Italy), this lamp must also project light continuously forward to the forward projection of that same vertical plane.

In the other countries which require side-mounted turn signal lamps on larger vehicles, these lamps must, in some instances, project light horizontally forward and rearward to 5° inboard. A single lamp designed to meet all of these requirements would have to project light through a horizontal angle of at least 190°.

Side-mounted turn signal lamps must also project light vertically to as much as 30° above and 30° below the horizontal plane passing through their centers.

The exact intent of these side-mounted turn signals (i.e., whether they may serve as a supplement to or a replacement of the front and/or the rear turn signal lamps on the respective side) varies from one country to another. Actually, several different specific types of side-mounted turn signal lamps are identified by some countries (for instance, England's shoulder, side, and flank indicators) and by the ECE Standards. The composite described above is that which would be necessary to meet the requirements for all such lamps which are necessary to supplement the more conventional front and rear turn signal lamps in the countries of consideration.

B. The Color of Projected Light from Certain Marking and Signaling Lamps. In the early 1960's, the U.S. standards were changed to require that front turn signal lamps project yellow instead of white light. The color of projected light from parking lamps was then permitted to be either yellow or white. (The color of light projected from front clearance and identification lamps on vehicles over a certain size had for some time been required to be yellow.) Some foreign countries require that yellow be the color of light projected from the front turn signal lamps, although most other countries permit either white or yellow. However, most countries require that the front presence lamps project white light.

For export to some countries, domestic vehicles need modification which merely replaces the yellow lens of the combination parking lamp/front turn signal lamps with a white one. In other instances, however, this modification requires the addition of separate lamp housings, since a requirement for a white parking lamp and a yellow front turn signal lamp make the two functions incompatible in the same housing.

Some foreign countries require that the color of light projected from the rear turn signal lamp be yellow. Many permit either red or yellow. Many require red (some permit yellow) for the brake signal lamp. Virtually all require red for the rear presence lamp function. On vehicles intended for sale in those countries requiring a yellow rear turn signal lamp, a separate lamp housing solely for the rear turn signal function is therefore required. On many U.S.-built vehicles, this presents no major problem, since they are already equipped with multiple rear lamp housings. Only a change in lens color and socket indexing is required in addition to the modifications in the wiring system. On U.S.-built vehicles with only single rear lamps on each side, however, separate housings need to be installed to provide the yellow rear turn signal.

Most countries permit yellow as well as white for the backup lamp(s), and one country (France) requires yellow instead of white. (France also requires yellow headlamps.)

C. The Location of Lamps and Reflectors on Motor Vehicles. Differences between foreign and U.S. standards for the mounting of lighting equipment are shown in Table 2.1. In general, the mounting locations (or ranges) specified by the various foreign countries are somewhat more restrictive than those permitted by the U.S. standards. Listed in Table 2.1 are those specific requirements where lamps or reflectors installed to meet U.S. standards may fail to meet the comparable foreign standards. (The most restrictive requirements are generally cited, unless otherwise noted.)

D. Special Lighting Equipment Required on Certain Larger Vehicles. Although most countries require some special lighting equipment on large and special-use vehicles, none make as extensive requirements as does the U.S. for clearance, identification, and side marker lamps. In general, these special marking lamps must project a diffused white light if facing to the front or side, and a red (in one country, yellow) light if facing to the

TABLE 2.1. Conflicts Between Foreign and U.S. Lighting Standards for Lamp Mounting Locations (Cont.)

| Lamp | Requirements: Foreign | Requirements: United States |
|---|---|---|
| **Front and Rear Turn Signal Lamps** | | |
| Min height, lower edge | 15.75' ( 400 mm)[1] | |
| lamp center | | 15" ( 381 mm) |
| Max height, upper edge | 59.06" (1500 mm)[2] | |
| lamp center | | 83" (2108 mm) |
| Max inboard, outer edge | 15.75" ( 400 mm)[3] | as far apart from each other as practicable |
| Min separation between turn signals | 23.62" ( 600 mm)[4,5] | (as far apart from each other as practicable) |
| **Side Turn Signal Lamps** | | |
| Min height, lower edge | 19.69" ( 500 mm) | - |
| Max height, upper edge | 59.06" (1500 mm)[6] | - |
| Max inboard, outer edge | 15.75" ( 400 mm)[7,8] | - |
| Min separation between side turn signal lamps | 23.62" ( 600 mm) | - |

[1]Australia (to the lamp center) and the Republic of Ireland (to the lower edge): 16" (406 mm).

[2]Finland: 59.06" (1500 mm) to the lamp center; Australia: 47.24" (1200 mm) to the upper edge.

[3]Finland: 15.75" (400 mm) to the lamp center; Italy: 11.81" (300 mm) to the lamp edge.

[4]Great Britain: 24" (610 mm); Australia: 30" (762 mm) to the lamp center.

[5]Several countries: require that turn signal lamps be no further inboard than any other signal lamps on the same side of the vehicle.

[6]Finland: 59.06" (1500 mm) to the lamp center.

[7]Italy: 11.81" (300 mm) to the outer edge.

[8]For certain large vehicles in some countries, the maximum distance from the side-mounted turn signal lamp's illuminated area to the vehicle's outside edge must be somewhat less.

TABLE 2.1. Conflicts Between Foreign and U.S. Lighting Standards for Lamp Mounting Locations (cont.)

| | | |
|---|---|---|
| Stop Signal Lamps | | |
| Min height, lower edge | 15.75" ( 400 mm)[9] | |
| lamp center | | 15" ( 381 mm) |
| Max height, upper edge | 59.06" (1500 mm)[10] | |
| lamp center | | 72" (1829 mm) |
| Max inboard, outer edge | 15.75" ( 400 mm)[11] | as far apart from each other as practicable |
| Min separation between brakelamps | 23.62" ( 600 mm) | |
| Rear Presence Lamps (Taillamps) | | |
| Min height, lower edge | 15.75" ( 400 mm)[12] | |
| lamp center | | 15" ( 381 mm) |
| Max height, upper edge | 59.06" (1500 mm)[13] | |
| lamp center | | 72" (1829 mm) |
| Max inboard, outside edge | 15.75" ( 400 mm)[14] | as far apart from each other as Practicable |
| Min separation between taillamps | 23.62" ( 600 mm) | |

[9] Israel: 16.1" (409 mm) to lamp center.

[10] Republic of Ireland: 48" (1219 mm) to upper edge; Italy: 47.24" (1200 mm) to upper edge; France: 35.43" (900 mm) to upper edge.

[11] Finland: 15.75" (400 mm) to center of lamp; Italy: 11.81" (300 mm) to outer edge.

[12] Israel: 16.1" (409 mm) to lamp center; Canada: 20" (508 mm) to lamp center.

[13] Austria: 55.12" (1400 mm) to upper edge; Italy: 47.24" (1200 mm) to upper edge; Great Britain: 42" (1067 mm) to upper edge; Australia: 42" (1067 mm) to lamp center; Finland: 39.37" (1000 mm) to lamp center; Republic of Ireland: 36" (914 mm) to upper edge; France: 35.43" (900 mm) to upper edge.

[14] Italy: 11.81" (300 mm).

[Note: The effect of this minimum separation requirement on the use of "bar-type" taillamps is not known for sure.]

TABLE 2.1. Conflicts Between Foreign and U.S. Lighting Standards for Lamp Mounting Locations (cont.)

| | | |
|---|---|---|
| Parking Lamps (also known as "front reserve lamps"; "sidelamps" [G.B., etc.]) | | |
| Min height, lower edge | 15.75" ( 400 mm)[15] | |
| lamp center | | 15" ( 381 mm) |
| Max height, upper edge | 59.06" (1500 mm)[16] | |
| lamp center | | 72" (1829 mm) |
| Max inboard, outer edge | 15.75" ( 400 mm)[17] | as far apart from each other as practicable |
| Min separations between parking lamps | 23.62" ( 600 mm)[18] | |
| Reflectors | | |
| Min height, lower edge | 15.75" ( 400 mm)[19] | 15" ( 381 mm) |
| Max height, upper edge | 35.43" ( 900 mm)[20] | 60" (1524 mm) |
| Max inboard to outer edge | 15.75" ( 400 mm)[21] | as far apart from each other as practicable |
| Min separation between reflectors | 23.62" ( 600 mm) | |

[15]Israel: 16.1" (409 mm) to lamp center.

[16]Finland: 49.21" (1250 mm) to lamp center; Austria and Italy; 47.24" (1200 mm) to upper edge.

[17]Great Britain: 12" (305 mm) to lamp center; Italy: 11.81" (300 mm) to outer edge.

[18]Australia: 42" (1067 mm) between lamp centers.

[19]Canada: 20" (508 mm) to reflector center.

[20]France and Israel: 31.50" (800 mm); West Germany: 27.56" (700 mm) to lower edge.

[21]Finland: 15.75" (400 mm) to reflector center.

[Note: Parking lamp equivalents are required in most countries on larger vehicles, in lieu of our clearance and identification lamps. In such cases, these lamps usually must be located at the outermost edges of these larger vehicles (including trailers), or within 5.9" (150 mm) of the outer edge. The requirements for special lighting on larger vehicles are discussed later in this review.]

TABLE 2.1. Conflicts Between Foreign and U.S. Lighting Standards for Lamp Mounting Locations (concluded.)

| | | |
|---|---|---|
| Backup Lamp(s) | | |
| Min height | 9.84" ( 250 mm) | none specified |
| Max height | 47.24" (1200 mm)[22] | none specified |
| Headlamps | | |
| Min height, lower edge | 23.62" ( 600 mm)[23] | |
| lamp center | | 24" ( 610 mm) |
| Max height, upper edge | 47.24" (1200 mm)[24] | |
| lamp center | | 54" (1372 mm) |
| Max inboard, lamp outside edge | 15.75" ( 400 mm) | as far apart from each other as practicable |
| Min separation between headlamps (presumably, the outermost ones) | 24" ( 610 mm) | |

[22]Italy: 39.37" (1000 mm).

[23]Note: A sealed beam lamp whose center is at 24" (610 mm) would have a lower edge below 23.62" (600 mm).

[24]Norway and Finland (to the lamp center) and Italy (to the lamp upper edge): 43.31" (1100 mm); Denmark and West Germany (to the lower edge): 39.37" (1000 mm).

[Note: Some countries place further restrictions on the mounting locations of quad headlamps. In general the pair on each side must be mounted such that the space in between them is not greater than the width of either headlamp in the same plane, or that the illuminated surfaces should have a total of at least half that of the smallest rectangle which can be circumscribed about the two lamps on each side. However, another requires a minimum separation between headlamp centers of 6.19" (157 mm).]

rear. Vehicles needing such devices are generally distinguished by width [as narrow as 53.3" (2.1 m) and wider], length [as short as 19' 10.2" (6 m) and longer], and/or weight. Two such special lamps are usually required on the front and two on the rear of the vehicles affected. These lamps can sometimes be combined with parking lamps or rear presence lamps if these pre-existent lamps are already within 1.97" (50 mm) of the outer edge of the vehicle. The mounting heights for these special lamps vary, but are generally more restricted, especially in maximum height, than the comparable clearance lamps on U.S.-built vehicles.

Side marker lamps are required in only a few countries. In some of these instances, however, there must be as many side marker lamps on each side as needed to insure the spacing of one at least every 12' (3.66 m).

Front clearance-type lamps are sometimes also required on trailers, especially those over a certain length, whose width exceeds-that of the pulling vehicle by more than 7.87" (200 mm).

E. Photometric Projection of Light Output. In general, lamp photometric projection requirements of the various foreign countries call for a greater beam spread than is specified in the U.S. standards. In Table 2.2 the first figure given is the broadest of the minimum figures for the countries surveyed. The second figure (in parentheses) is the comparable U.S. requirement.

F. Lamp Intensity; Power Requirements and Restrictions. The specific photometric requirements for vehicular lighting equipment were not investigated for each of the countries covered in this review. Instead, Table 2.3 compares the ECE photometric standards with the comparable U.S. ones. These figures are based on the intensities at the H-V photometric axis of the lamp.

The ECE Regulations Nos. 6 and 7 permit rear turn signal lamps and stop signal lamps respectively to be either of the

TABLE 2.2. Generalized Comparison of Foreign and (U.S.) Lamp, Reflector and License Plate Visibility Projections.

| Lamp | Along the V Axis (up and down) | | Along the H Axis (left and right) | |
|---|---|---|---|---|
| Parking lamps | ±15° | (±10°) | outboard 80°<br>inboard 45° | (±20°) |
| Front and rear turn signal lamps | ±30° | (±10°) | outboard 90°<br>inboard 45° | (±45°) |
| Side-mounted turn signal lamps | ±30° | -- | forward 95°<br>rearward 95° | -- |
| Rear presence lamps | ±30° | (±10°) | outboard 90°<br>inboard 45° | (±45°) |
| Stop signal lamps | ±30° | (±10°) | outboard 90°<br>inboard 45° | (±45°) |
| Backup lamps | +10°<br>-30° | (±10°) | ±60°[1] | (±45°) |
| Rear reflectors | ±30° | (±10°) | outboard 80°<br>inboard 45° | (±20°) |
| License plate visibility | +30°<br>- 5° | -- | ±30°[2] | |

[1]For backup lamps, the inboard angle along the H axis needs to be only 30° if two backup lamps are used.

[2]Measured from the respective outside edges of the license plate.

[Note: For rear presence, turn and stop signal lamps, the actual photometric requirements in the U.S. go only to ±20° along the H axis. However, an additional requirement is made that these lamps must be "visible" at the greater angle (although no photometric values are given.]

TABLE 2.3. Comparison of ECE and U.S. Lamp Intensity Standards at H-V.

| Lamp | Limit | ECE | U.S. |
|---|---|---|---|
| Front turn signal lamp | min | 175 cd | 120 cd |
| | max | 700 cd | - - |
| Rear turn signal lamp (yellow, one section, single intensity level) | min | 50 cd | 200 cd |
| | max | 200 cd | 900 cd |
| Stop signal lamp (red, one section, single intensity level) | min | 40 cd | 80 cd |
| | max | 100 cd | 300 cd |
| Rear presence lamp (red, one section) | min | 2 cd | 2 cd |
| | max | 12 cd | 15 cd |
| Parking lamps (white or yellow) | min | 4 cd | 4 cd |
| | max | 60 cd | 125 cd |

single-intensity type (as described above), or of the dual-intensity type. The latter is compared with the U.S. single-intensity standards in Table 2.4 on the next page.

In these sets of figures the problems of photometric compliance can be seen. Specifically, to meet both the U.S. and the ECE requirements, the stop signal should project no less than 80 cd (the U.S. minimum) but no more than 100 cd (the ECE single-intensity maximum). Finch (1968) surveyed the stop signal lamps on U.S. automobiles of model years 1965 through 1967. The summary of these

TABLE 2.4 Comparison of ECE Dual-Intensity Standards with U.S. Standards for Turn and Stop Lamps.

| Lamp | Limit | ECE Daytime | ECE Nightime | U.S. 1 Section | U.S. 2 Sections | U.S. 3 Sections |
|---|---|---|---|---|---|---|
| Rear turn, yellow | min | 175 cd | 40 cd | 200 cd | 240 cd | 275 cd |
| | max | 700 cd | 120 cd | 900 cd | 900 cd | 1050 cd |
| Stop, red (optionally: rear turn on U.S. vehicles) | min | 130 cd | 30 cd | 80 cd | 95 cd | 110 cd |
| | max | 520 cd | 80 cd | 300 cd | 360 cd | 420 cd |

comparisons are stated below:

| Vehicle Model Year | Rear Presence Lamps Mean | Rear Presence Lamps Standard Deviation | Stop/Turn Signal Lamps Mean | Stop/Turn Signal Lamps Standard Deviation |
|---|---|---|---|---|
| 1965 | 10 | ±6.0 | 121 | ±54.0 |
| 1966 | 11.0 | ±6.1 | 151.0 | ±86.5 |
| 1967 | 11.0 | ±8.0 | 136.0 | ±78.0 |

These figures indicate a substantial number of U.S.-built automobiles also have rear presence lamps which exceed the ECE 12 cd maximum.

The ECE standards establish minimum and maximum power levels for presence lamps at 5 and 10 watts respectively. U.S.-built automobiles have typically 7.1 to 8.3 watt bulbs for each presence bulb (including arrays utilizing more than one rear presence lamp on each side).

Many countries require that, if the stop signal lamp and presence lamp functions are combined into a single compartment or lamp, the ratio of intensities must be at least 5:1. The U.S. standards require that the ratio be only at least 3:1, except at least 5:1 at H-V, H-5L, H-5R, and 5U-V.

Great Britain requires that the minimum and maximum power levels for stop signal lamps must be 15 and 36 watts respectively. Another country (Iceland) specifies a maximum of 20 watts for that lamp. U.S.-built automobiles have typically 23 to 26.8 watt bulbs for each rear signal lamp.

One country (France) places a 25 watt maximum on the power of the backup lamp, or 21 watts apiece if two are used. Most countries instead limit the distance at which the main portion of the beam may strike the level roadway behind the vehicle.

G. Lamp Size Requirements. Vehicles manufactured to meet U.S. requirements on lamp size will generally meet and usually far exceed size requirements imposed by other countries. However, no minimum size requirements are specified in the U.S. standards for rear presence lamps, parking lamps, clearance and identification lamps, side marker lamps, or reflectors.

In general, rear presence lamps, parking lamps, clearance lamps, and side marker lamps of at least 3.1 $in^2$ (20 $cm^2$) size, or 6.2 $in^2$ (40 $cm^2$) on larger vehicles and trailers over 5' 11" (1.8 m) wide, will meet these other requirements. Note that clearance and side marker lamps on U.S.-built vehicles are generally much smaller than that.

H. The Color, Size, and Shape of Reflectors. In most European countries, triangular reflectors are mandatory on trailers and prohibited from use on any other types of vehicles.

Many countries also require the use of reflectors on the front of all vehicles (in some countries, only on the front of those over a certain width).

As with forward-facing presence lamps, front and side reflectors are frequently required to be white instead of yellow. Side reflectors are required only in some countries, and then usually only on vehicles greater than a certain length. The requirements for side-mounted reflectors are usually found in the same countries and on the same vehicles that side marker lamps are required. In one country, rear reflectors must be orange instead of red.

The current U.S. standards place no minimum size requirements on "service" reflectors (i.e., those normally affixed to the vehicle and always displayed), other than on the special "Slow Moving Vehicle" (SMV) reflectors. Domestic size and shape requirements do exist, however, for those special reflectors intended to be deployed at the scene of a large vehicle's breakdown.

Many of the countries considered do place minimum size requirements on service reflectors, ranging from as much as 3.1 $in^2$ (20 $cm^2$) for passenger vehicles, up to as much as 6.2 $in^2$ (40 $cm^2$) on larger vehicles. The special triangular trailer reflectors need to be somewhat larger, from 4.9" (150 mm) to 7.9" (200 mm) on each of the three sides (see ECE Regulation No. 3).

I. Color of Panel Indicator or Pilot Lamps. The ECE standards (plus the standards for at least one country) require that a green pilot indicator lamp be illuminated to indicate the functioning of the parking lamps. The ECE standards permit this indicator to be deleted if the instrument panel lighting can be turned on only when the parking lamps are lighted.

The ECE standards also require that blue be used as the color of the high beam headlamp pilot indicator lamp.

## TOPICS SUGGESTED FOR FURTHER INVESTIGATION

From the research for this review other topics have been suggested as being worthy of further investigation. Discussed in order are the following:

A. Signal lamp coding by color and separation of function.

B. Limitations on mounting location.

C. Method of measuring photometric intensity of multiple element arrays.

D. Angles of photometric projection.

E. Ratios of photometric projections.

F. Dual intensity signal lamps.

G. Side turn signal lamps.

H. Other new or modified signal lamps.

I. Special marking for large and special-use vehicles.

J. The use of reflectors on the front of vehicles.

K. The use of reflectors: coding by vehicle type and conditions of use.

A. Signal Lamp Coding by Color and Separation of Function. Signal lamp function coding by color has been advocated by almost all of the recent investigations of vehicular lighting. The use of yellow for the rear turn signal lamp, as distinct from the use of red for brake signal lamp, is almost universally permitted, and in some countries is required on new vehicles.

The primary reasons cited in previous studies for not adopting yellow as the rear turn signal lamp color, in order to distinguish these lamps from red brake signals, were the following:

1) Confusion could result from departing from the more traditional all-red rear lighting configuration.
2) This two-color rear lighting system would require separate lamps for stop and turn signals.

Claims that confusion might result from a departure from the traditional color scheme have been disproved by the apparently wide public acceptance of yellow rear turn signal lamps on recently built vehicles. Most foreign manufacturers, and even some domestic manufacturers (especially those of buses and semi-trailers), are now using this color-coded scheme.

Most recent reviewers of vehicle rear lighting systems, including those urging retention of the all-red scheme, have recommended separating the stop and turn signal functions as an additional coding redundancy. Using yellow for rear turn signal lamps would cause them to be distinct from stop signal lamps by three coding parameters: phasing (steady vs. flash), color, and lamp housing (separation).

Another advantage to distinguishing between rear stop and turn signals by all three coding parameters is that should a system failure eliminate one of those parameters, two still remain. For example, in the conventional fixed-load-flasher system, if one of the turn signal lamp filaments burns out, the electrical current drawn by the remaining turn signal lamps is not sufficient to cause the flasher mechanism to operate normally. An outage of the front turn signal filament, which would cause the flasher to remain in the "on" phase would not be as likely to cause an incorrect signal interpretation if the rear stop and turn signal lamps were color coded, since a yellow lamp would still be on, but not flashing.

A study of the advantages of functional separation and color coding when a vehicle's lighting system has a malfunction failure is contained in a separate report (Mortimer and Domas, 1973).

B. Limitations on Mounting Locations. As the previous tables show, many foreign countries' manufacturing standards require lighting equipment mounting locations which are more restrictive than required in the comparable U.S. standards. For instance, the signaling and marking lamps on the front and rear of U.S. vehicles must generally be mounted "as far apart from each other as practicable" (referring to similar components). This imprecise designation has permitted the mounting of lamps somewhat closer together than the extreme outside portion of the vehicle side. (Example: the front turn signal lamps on some compact- and intermediate-sized cars are mounted substantially inboard from the outside edge.

Therefore, consideration should be given to changing the U.S. standards to require that signaling and marking lamps, and especially parking lamps, rear presence lamps, and front and rear turn signal lamps, be mounted not only as far outboard as possible, but also not greater inboard than a specified distance. For instance, as stated in the ECE's recent draft provisions, "the extreme outer edge of the vehicle and the outer edge of the illuminating surface shall not exceed 400 mm" [15.75"].

Most foreign countries' vehicle lighting equipment standards also require that similar components mounted on the left and on the right sides of the vehicle's front and rear be separated by at least 600 mm (23.62"). The value of requiring a distinct separation between left and right lamps, as compared with presence lamps extending across the rear of the vehicle, for instance, should be further investigated[1]. More specifically, the extent to which the use of a solid bar of light obscures or detracts from signals presented by only a portion of that bar should be determined. If a negative effect is found, then perhaps some minimum separation requirement should be incorporated into the U.S. standards, especially those covering stop and turn signal lamps.

C. Method of Measuring Photometric Intensity of Multiple-Element Arrays. In the U.S. standards, separate photometric requirements are applied to multiple- and single-element (compart-

---

[1]A simulation study (Mortimer, 1970) showed that there was no detrimental effect upon the threshold for detecting a change in the headway distance.

ment) lamps. Consideration should be given to changing these standards to require that in a multiple-element array, the outermost element be capable of meeting the single-element photometric standards at least at the outboard angles. This would insure that if the inside elements are concealed, for instance by a following vehicle, an adequate light would still be projected by the outermost element at these angles.

D. Angles of Photometric Projection. The photometric requirements in the U.S. standards covering marking and signaling lamps generally extend only to ±10° vertically and ±20° horizontally. The added requirement is made that certain lamps must be "visible" at ±45° horizontally, but without photometric values being specified.

1. If lamps are to be visible at certain photometric points, then rear photometric values should be specified, rather than leaving the evaluation of "visible" to such a subjective interpretation.

2. Most foreign countries require light projection to greater angles, for some countries for some lamps to as much as 90° horizontally outboard. A comparison of these requirements was contained in a previous section of this review. Consideration should be given to increasing the projection requirements in the U.S. standards. The projection from presence or marking lamps (parking lamps, rear presence lamps, side marker lamps, and on certain vehicles clearance and identification lamps) should extend (with actual values stipulated) to at least ±45° horizontally, to insure that vehicles are lighted from all horizontal directions. (In the current U.S. standards only side marker, clearance, and identification lamps have actual photometric requirements extending as far as ±45° horizontally.) The requirements for signaling lamps should be determined after consideration of the driving environments and visual angles most frequently

encountered. Signal lamps may need a significant increase in their horizontal outboard projections, and perhaps somewhat less of an increase for the inboard angles.

E. Ratios of Photometric Projections. The current U.S. standards require a minimum 3:1 ratio between the intensities of a signal lamp and a marking lamp at all points on and above the H axis when the two lamp functions are combined in the same lamp or housing. In addition, a minimum ratio of 5:1 is required at certain points (H-V, H-5L, H-5R, and 5U-V). Consideration should be given to whether or not a 3:1 minimum ratio is sufficient to insure detectability of the onset of the signal, or to insure recognition that the signal is on when the onset is not observed.

Many other countries require that this minimum ratio by 5:1, without limiting the application of this measure to the select number of points, described above, in the U.S. standards.

F. Dual Intensity Signal Lamps. Many countries now permit, and some are considering requiring, dual-intensity rear signal lamps. Forbes (1966) developed formulas useful for determining the intensity requirements for red signal lamps as a function of lamp surface area. Mortimer (1970) has proposed specific photometric ranges, based on test data, for red, yellow, and blue-green signal lamps as a function of lamp area and driving environment (night vs. day).

The following table (2.5) compares Mortimer's (1970) recommendations for a lamp of 8.0 square inches (the current SAE recommended minimum for passenger vehicles) with the ECE dual-intensity standards for red and yellow signal lamps. Mortimer's minimum values are about twice the ECE minimum values, but the ranges overlap (although just barely for nighttime red). The maximum values range from not quite twice to more than seven times the ECE maximum values. A study described in section 5 of this report shows

TABLE 2.5. Comparison of ECE Standards and Mortimer's (1970) Recommendations for Dual-Intensity Standards for Yellow[1] and Red Signal Lamps.

| Color of Signal | Time of Use | ECE Standard | | Mortimer Recommendation | |
|---|---|---|---|---|---|
| | | Min | Max | Min | Max |
| Yellow | Day | 175 cd | 700 cd | 350 cd | 5000 cd |
| Yellow | Night | 40 cd | 120 cd | 85 cd | 200 cd |
| Red | Day | 130 cd | 520 cd | 250 cd | 2000 cd |
| Red | Night | 30 cd | 80 cd | 70 cd | 160 cd |

[1]Not flashing.

that the values are also dependent on other coding characteristics of the rear lighting configuration.

G. Side Turn Signal Lamps. Mortimer (1970) and others have recommended the use of side turn signal lamps. This lamp would be comparable to the British "flank indicator," the ECE "category 5" turn signal, or the SAE "side turn signal lamp" (SAE Recommended Practice J914, 1968). The intent of this special turn signal would be to give a warning to other drivers who are alongside or overtaking from the rear. The SAE side turn signal lamp is meant to project primarily rearward, but also as far outward as the vertical plane perpendicular to the vehicle's longitudinal axis and passing through the lamp.

Mortimer found that the current SAE intensity recommendations were close to those desired, based on a series of subjective day, dusk, and nighttime tests at various angular locations, but only if a single-intensity system were used. He recommends that a dual-intensity system, operated in conjunction with a dual-intensity system on the vehicle's other signal lamps, be used instead.

The ECE standards and those of other countries requiring flank indicators on some or all vehicles specify minimum intensities considerably below those in SAE J914. The minimum intensities in these foreign standards are more closely related to the concept of the exterior turn signal indicator lamp, as described in SAE Standard J588e, paragraph 4.5.3 (1970).

H. Other New or Modified Signal Lamps. The wide angles of photometric projection specified for signal lamps in the lighting standards of many foreign countries, as discussed in Section D, suggest another question: Are there other current or new lamp functions which need indication on vehicles beyond their present application?

For instance, should stop signal lamps project to the sides or the front, as well as to the rear. An argument could be made that the function of braking should be indicated on all sides of the vehicle.

The color of a front-mounted stop lamp should not be red to avoid confusion between the front and the rear of vehicles, and since red on the front is almost universally reserved for emergency vehicles. On the other hand, the use of yellow might be confused with the front turn signal lamps unless some other coding parameter were used, such as lamp mounting location. Results of a preliminary study suggested that a forward-facing stop signal deserves further consideration (Post and Mortimer, 1971).

The overall question of signal visibility is also ultimately tied to the problem of drivers' inability to process large amounts of signal information without the possibility of confusion or distraction detracting from those signals which are most important.

I. Special Marking for Large and Special-Use Vehicles. As noted previously, many foreign countries require special marking lamps and reflectors for certain vehicles and trailers. None of these requirements are as extensive as those in the United States for clearance, identification, and side marker lamps, however. The whole question of special marking for large or slow vehicles needs special attention.

Another type of special-use vehicle is the emergency vehicle. Most countries have specific standards concerning special lighting and auditory devices for police, fire, ambulance, and other emergency vehicles. In general, the use of rotating beacon lamps (or their more recent replacements, strobe lamps), alternating flashing lamps, and certain lamp colors is reserved for emergency or highway maintenance vehicles. Other than these general descriptions, very little uniformity or equipment standards for emergency vehicles exists between countries, or even between the various jurisdictions within the same country. Because of the increasing mobility of the driving population, some standardization seems desirable. The specialized types of emergency equipment used in the various foreign countries deserves consideration for use domestically, and vice versa.

J. The Use of Reflectors on the Front of Vehicles. Two foreign countries require white, front reflectors on all vehicles. Many others require white, front reflectors on trailers and semi-trailers. Current U.S. standards do not require reflectors on the front of any vehicles. (A proposal has been made [37 FR. 16002] that reflectors be permitted to be used in lieu of front clearance lamps on certain classes of semi-trailers, however.)

In 1970 the U.S. adopted the requirement of "front reserve lamps," whereby a vehicle's front-side dimensions could be identified during operation at night even if one of its headlamps were not operating. This was accomplished by wiring the parking lamps such that they remained on whenever the rear presence lamps were illuminated (namely, in either the "parking lamp" or the "headlamp" position of the headlamp switch). Before the requirement for the front reserve lighting system was instituted, the alternative use of front reflectors was considered. This alternative was dismissed as being ineffective.

However, this leaves U.S. (and most foreign) vehicles without front marking protection when all of the vehicle's forward lamps are extinguished (for instance, during a complete electrical failure, or while the vehicle is parked). Collision data may suggest that front reflectors are desirable.

K. The Use of Reflectors: Coding by Vehicle Type and Condition of Use. In designing and specifying the use of vehicular signal lamps, the various regulatory authorities have assumed that the electrical system of every vehicle on which the lamps are mounted is in proper working order. For normal vehicle operations, this assumption is probably justified since few vehicles can be operated with massive electrical system failures. This assumption is not justified during the occurrence of a vehicle breakdown, however, or in the case of parked vehicles.

Four-way hazard flashing lamps should be displayed on any vehicle which is suffering a breakdown and whose location presents a hazard to other vehicles. But what options are left to the operator of such a vehicle if the nature of the breakdown is in the electrical system which prevents the operation of such hazard warning lamps?

Traditionally, special warning devices have been used for such occurrences, including auxiliary flags, reflex reflectors, fusees, and lanterns deployed back down the road towards oncoming traffic in the nearest lane. The need for distinguishing these signaling devices should be obvious. Since the use of fusees, and (to a lesser extent) lanterns and flags is not found except in such special circumstances, no unusual concern exists in their use insofar as it attempts to express a distinct and somewhat urgent message.

The following three basic message categories are suggested in which reflex reflector displays are needed:

1. Indication of the Presence of a "Normal" Vehicle in "Normal" Operation. Within this category would be included the side, rear, and if adopted, front reflex reflectors of all vehicles capable of and likely to be maintaining "normal" (i.e., moderate or high) velocities on a highway. These side and rear reflectors also serve to mark the vehicle in case of a minor bulb outage problem with the side marker or rear presence lamps.

2. Indication of the Presence of an "Unusual Vehicle" in "Normal" Operation. Within this category would be included the side and rear reflex reflectors of oversized vehicles and other vehicles probably unable to maintain normal highway speeds. This general concept is already recognized in the "Slow-Moving-Vehicle" (SMV) triangular reflector as used on farm implements and horse-drawn conveyances. Note that in most foreign countries, a reflex reflector of similar equilateral triangular shape is reserved specifically for and required on all trailers (see ECE Regulation No. 3).

3. Indication of the Presence of a Vehicle in a Non-Operational Situation. Within this category would be included vehicles parked on or off the traveled portion of a normal traffic lane.

The need for improved passive, nighttime marking of vehicles was shown in a study of collision data by Mortimer and Post (1972), with special emphasis on reflectorization displays that help drivers to distinguish a parked vehicle from others.

## 3. REVIEW OF EFFECTIVENESS OF SEPARATION OF FUNCTION

A readily apparent problem with the conventional rear lighting system is the difficulty in determining at night if a vehicle ahead is showing a presence or a brake signal. This is because the lamps showing the presence indication and the brake signal are the same, and the signal must be detected on the basis of the increase in intensity which occurs when the brake signal is given. If the driver is looking at the rear lamps of the vehicle ahead when the intensity change takes place he would be expected to detect this difference quite readily. A minimum 5:1 intensity ratio between presence lights and brake lights is required (SAE J575d, 1967) by FMVSS-108. While this intensity ratio would be adequate to allow reliable detection of the stop signal if the driver viewed the signal during the transition from presence to stop intensities, it would be inadequate for an absolute judgment to be made. This tendency to confuse presence lights and brake signals was shown by Rockwell and Banasik (1968).

The time taken to respond to signals given by eight rear lighting systems was measured by Mortimer (1969a). This was one of the first large-scale rear lighting system evaluations of the concepts of functional separation and color coding. In one of these systems the presence lights were given by two lamps and an additional two lamps were used to present stop and turn signals. It was found that this four-lamp, all red, system produced significantly shorter reaction times to the stop signal. This study also showed that color coding, with separation of function, was an additionally effective technique. This study was augmented by a series of dynamic, driving, studies conducted to evaluate rear lighting systems incorporating separation of function and color coding by comparison with the present system. In the first of these studies eight rear lighting systems were again used (Mortimer, 1969b) with a 5:1 intensity ratio obtained by using 7 candelas for presence lights and 35 candelas for signal lights. The findings of this study clearly showed that the response time of a following driver in both urban and rural driving conditions could be reduced by rear lighting display design. Partial separation of function, using all red lights, was effective and improved by complete functional separation of presence, turn, and stop lamps. The systems that included color coding and functional separation provided even better performance. The effectiveness of these systems, compared to the current system, was also indicated by the significantly greater number of signals missed with the current system than the experimental systems. Subjective evaluations made by the drivers showed that they also considered that the systems incorporating functional separation were more effective than the current system. The proportion of missed signals decreased as the extent of the functional separation, from partial functional separation to complete functional separation, was increased.

In a subsequent series of dynamic driving tests the same experimental paradigm was used. The main variation involved the use of different intensity ratios and absolute intensities (Mortimer, 1970). Five of the previously used rear lighting systems were evaluated in this series of tests in one of which signal light intensity was 91 candelas and presence light intensity was 7 candelas, for an intensity ratio of 13:1. In the second study an intensity ratio of 13:1 was again used but the signal light intensity was 35 candelas and the presence light intensity was 2.7 candelas. These tests were conducted in order to compare them with the previous study mentioned (Mortimer, 1969b) to determine the effect of the intensity ratio and the absolute intensity level. The findings from these studies have remained remarkably stable, and are therefore rather impervious to these variables. It was again found that performance of a following driver in response time required to detect a signal was decreased as partial or complete functional separation was introduced. In addition, errors in signal identification were also reduced, though this difference was not statistically significant. A significant reduction in the number of missed signals was found for experimental systems compared to the current system. The subjects again rated the systems using functional separation as significantly more effective than the current system.

These extensive studies have quite clearly and repeatedly shown the value of separating lamps according to their function. The benefits that accrue from such displays were to reduce errors, reduce the number of signals that are missed--potentially a very hazardous condition in close car following, reduce response times to stop and turn signals, and apparently provide drivers with the impression that the experimental systems offered greater effectiveness in displaying the signals.

The reliability of systems using functional separation needs also to be considered in comparison with the current system. Reliability can be degraded in the event that there is a malfunction in the flasher or if a bulb filament is burnt out. In the present system if the flasher is not operating a continuous signal will be given on the turning side. A following driver may confuse this malfunction as representing a stop signal with the filament on the nonturning side burnt out, or he may interpret correctly that a malfunction of the flasher exists. Detection of such a signal will, in any event, be decreased. For systems employing a partial functional separation with four red lamps, the preferred arrangement would be to combine the turn signal with the presence light and to separate out the stop signal in two separate lamps. In such a system a malfunction in the flasher would be indicated as a continuously burning high intensity lamp on the turning side. This could be confused in the same way as for the current system until the brakes are applied when two additional lamps would be lighted. Therefore, the brake signal would not be degraded. In either system, a burned-out filament in the turn lamp would result in no signal being given, but in the system would remain intact whereas brake application in the current system could be misinterpreted as a malfunctioning flasher since only one lamp would be lighted continuously. In the partially separated system, a burned-out filament in one of the two stop lamps would result in a continuous signal being given by the other lamp which could only be confused as a turn signal given on a vehicle with four red lamps in one of which the bulb is malfunctioning and in which the flasher is also malfunctioning. Thus, the probability of a confusion arising in this situation is considerably less than if a two-lamp system is used.

By utilizing complete functional separation most of these problems can possibly be avoided. A flasher malfunction will result in a steady-burning lamp on the rear on the turning side and could be recognized as such by standardization of the relative locations of the turn signal lamps with respect to the presence and stop lamps. By the same token a burned-out stop lamp filament could not be confused with a malfunctioning flasher.

While functional separation can lead to improved signal integrity, as described, the situation can be much improved further by the use of color coding. In the event that amber turn signals, green-blue presence lights and red stop lamps were used all signals could be readily identified, except for a burned-out amber rear turn signal.

The only advantage of the current design could accrue in the detection of the rear turn signal or stop signal if a multiple lamp array is used. In that event a filament failure in one of the bulbs will still provide a signal on that side of the vehicle given by the remaining bulb. Since such a system would not provide the advantages in improving following driver performance it is doubtful that this increase in reliability outweighs the generally improved reliability of a partially functionally separated system compared to one which uses only one bulb on each side of the vehicle, as is common practice. The effects of system malfunctions need to be empirically investigated to determine the responses of drivers, and form part of the work to be carried out in other phases of this project. But, in normal and malfunctioning conditions of operation, functional separation would appear to be a valid and relatively simple technique by which to improve rear lighting system effectiveness.

## 4. ANALYSIS TO DETERMINE THE DISTANCE AT WHICH SIGNALS SHOULD BE IDENTIFIABLE

One of the considerations in determining the effectiveness of the rear lighting system in driving situations is concerned with the distance at which signals given by the system can be identified by a driver approaching the vehicle from the rear. Adequate identification of the signal meaning is important in order to allow the following driver sufficient time to determine his best course of action, such as to pass the vehicle ahead or to slow down in order to avoid a collision.

In order to establish the minimum distance at which the signal status of a vehicle should be identifiable, one must carefully analyze the driving situation. What is desired is a criterion distance which will minimize accident occurrences related to deficiencies in the rear signal system. The simple solution of setting the distance as great as engineering feasibility allows is not desirable. Minimizing costs is one reason. Another is that at close viewing distances signals identifiable at great distances are likely to be too bright to a following driver. Moreover, it is conceivable that there could be some detriment in having a signal visible at very great distances. To a motorist traveling at freeway speeds the sight of a brake signal or emergency flasher on a vehicle ahead contains hazard potential, and is likely, therefore, to elicit vigilant monitoring. That is, the following driver may give a great deal of attention to such a signal at the expense of other relevant stimuli. If the lead car is very far ahead, and does not warrant undivided attention, such vigilance would be undesirable and perhaps dangerous.

Anticipating, then, the tradeoffs probable if too great a distance is arbitrarily set as the minimum for identification of signal status, it is necessary to locate that distance which is just great enough to preclude the occurrence of an accident which might follow because a driver failed to perceive a change of signal status on a lead vehicle. What is required, then, is a "worst case" analysis. Such a case might be represented by a slow-reacting driver of a vehicle equipped with poor brakes and tires, driving at high speed on a down-hill stretch of ice-covered road. How far ahead should the driver be able to see a critical signal (brake lights or emergency flasher) on a stopped vehicle, decide that the situation requires braking, and bring his vehicle to a safe, controlled stop?

Consider the general case in which car C is following another car A in the same lane as C. Assuming that the distance is closing between A and C, and that, at time $T_o$, A is so far ahead that driver C cannot even see vehicle A. Then there will be some later time $T_1$ when driver C first notices A. At time $T_1$ car A becomes like one of driver C's control panel gauges, something to be sensitized to and occasionally glanced at. But the fact that driver C is monitoring car A at time $T_1$ does not necessarily imply that he would react differentially to any of the signals that may be indicated by car A at that instant (e.g., presence, braking, turning, turn plus braking, emergency flasher). There is some later time, $T_2$, at which driver C will begin to react differentially to signals on car A. At $T_2$, and later, the signal system of car A will be periodically monitored by driver C. If a signal status change occurs on car A at time $T_3$, during a period when driver C is glancing in his rearview mirror or monitoring his control panel, he will not notice the change until some later time $T_4$, when he returns his attention to car A. When driver C notices A's changed signal, he is not likely to take immediate action to bring his car to a halt (given that the particular signal might sometimes ultimately lead to such action). The duration of the signal is part of the message.

If the duration of the signal and other visual cues convinces driver C that he is not observing a temporary, slight reduction in A's forward progress, he will probably first remove his foot from the accelerator pedal and check to see if he can change lanes if it should become desirable to attempt to go around A. (It must be kept in mind that this analysis is dealing with the case of cars following at the extreme distance at which signal discriminability is desirable. Such behavior is not expected from a driver following five to ten carlengths behind a fast moving vehicle.) Some time will have to be allotted between $T_4$, when driver C notices A's changed signal status, and $T_5$ when he decides that he must make some response to avoid hitting A. At time $T_5$ driver C still has the option of passing A rather than braking. Between $T_5$, when the requirement to act is identified, and $T_6$ when driver C responds, he will be assessing the relative feasibility of passing or braking. Thus, he is likely to monitor his rearview mirror in order to see if he can pull out to pass, assess the probable slipperiness of the road, etc. At time $T_6$ driver C makes his decision to brake. During the period $T_4$ - $T_6$ driver C may or may not have already removed his foot from the gas pedal, but the deceleration to be expected from a few seconds coasting is small (Mortimer, 1970) and can be ignored in the present analysis.

At time $T_7$, which will be later than $T_6$ by the time needed for the driver to move his foot to the brake pedal, the brakes of car C will be engaged. At $T_8$ car C will have been stopped.

The present analysis assumes that, under the worst conditions, car A is in fact stopped in the road ahead at time $T_4$, when driver C first notices that A's signal state is one that might necessitate evasive action.

What is a reasonable distance over which to allow car C to decelerate to a stop without hitting car A? At high speeds, and on wet roads, the maximum brake force coefficient possible is often below 0.1g, depending on the type of road surface, depth of water cover, and the type and condition of tires (Allbert et al., 1966). However, on level roadway, coasting deceleration averages about 0.1g at vehicle speeds of 70-80 mph. Moreover, since the brake force coefficient increases as speed decreases, while the opposite is true for coasting deceleration (Allbert et al., 1966; Mortimer et al., 1970), it is not necessary to consider deceleration rates less than 0.1g. For example, a vehicle which could achieve a brake force coefficient of only .05g at 70 mph on a wet road could realize 0.2g brake force coefficient at 50 mph, rising to 0.4g at 35 mph (Allbert et al., 1966). In such a case the average deceleration, from 80 to 0 mph, will be very close to 0.15g. It would be a rare instance when a vehicle could not achieve an average deceleration of at least 0.15g.

There are additional reasons for selecting 0.15g as a criterion rate of deceleration. Carpenter (1955) found that, in normal traffic conditions, drivers seldom (<5%) decelerated at greater than 0.30g, and most stops (>50%) were made at 0.10g or lower indicating that levels of deceleration higher than 0.15g are uncomfortable and unusual. It would be desirable, under conditions where high braking coefficients (e.g. 0.7) can be attained, to permit a comfortable level of braking. A level of deceleration such as 0.15g would have the advantage, under such conditions, of being unlikely to cause a critical level of disruption in the traffic flow, possibly resulting in a wave of panic braking along a line of traffic.

It may be argued that few drivers would take advantage of an opportunity to brake their vehicles at 0.15g over so extended a distance as 1450 feet (which is the distance a vehicle would travel in decelerating at 0.15g from 80 to 0 mph). Observation points to the conclusion that drivers generally ascribe a certain cost to the act of decelerating from high speeds, and do so with reluctance. Essentially, the sight of a brake signal on a car ahead invites the following driver to gamble. He can pay the small cost of a gentle braking maneuver while there is still a great distance separating his car from the one ahead, or he can play for double or nothing by not adjusting his velocity on the bet that the car ahead will accelerate and obviate the necessity for any braking at all. It is likely that a great number of rear-end collisions result when a driver misjudges the distance and relative speed with which he has to gamble. However, even if the gambling model better represents actual driver behavior, early signal detection is still desirable in that it gives the following driver more time to judge the point at which he will call his gamble lost, and begin deceleration.

Figures 4.1 and 4.2 represent the road conditions and deceleration maneuvers discussed above. In Figure 4.1 the thick line represents the maximum deceleration attainable as a function of the coefficient of friction between the vehicle tires and a wet road. The broken line represents the actual deceleration that might be used when stopping over the distance represented. The broken line is above the solid line early in the braking maneuver, because the coasting deceleration, largely a function of air resistance, exceeds the maximum obtainable braking coefficient at high vehicle speeds. In Figure 4.2 the black line represents the more usual situation, in which a fairly high coefficient of friction permits greater deceleration. The dotted line represents the braking behavior of a vehicle conforming to the model of comfortable braking. The broken line depicts a more risky response to the situation, in which the following driver does not attempt to stop until it is necessary to use a greater braking deceleration than is comfortable or desirable.

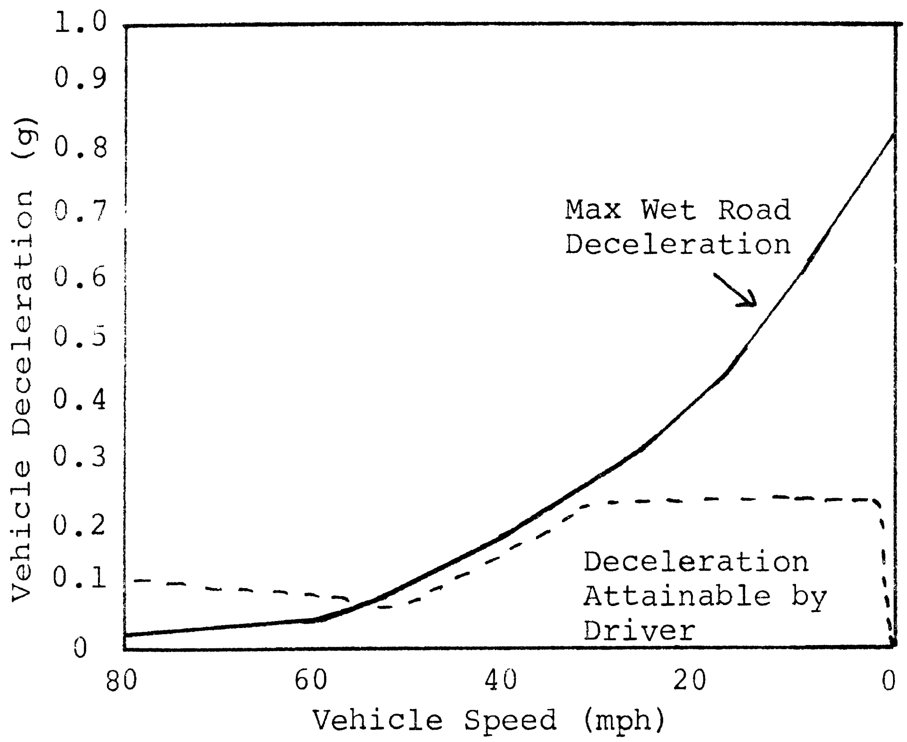



Figure 4.1. Hypothetical examples of maximum possible braking deceleration and that controllable by a typical driver.

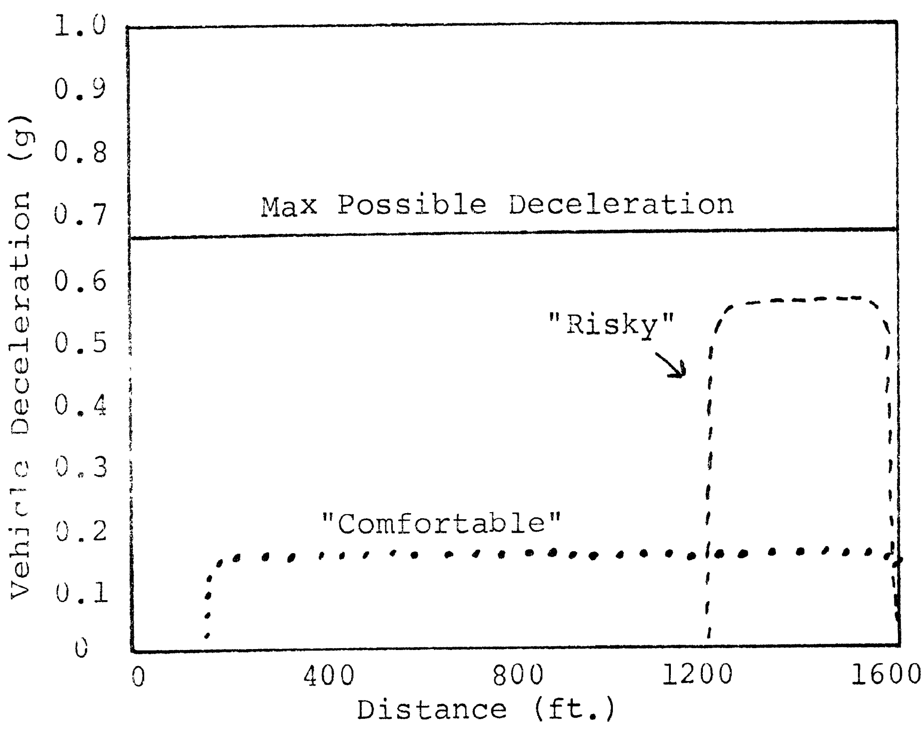



Figure 4.2. Hypothetical comfortable and risky driver braking behavior.

Figure 4.3, represents the entire continuum of time from $T_0$, when car A is too far ahead to be seen by driver C, to $T_8$, when car C is stopped just short of striking A. From the discussion above, $T_3$ is the point at which it is desirable for car A's signal status to be identifiable. At time $T_3$, however, not all drivers will be monitoring the road ahead. Those drivers who do not identify A's signal at time $T_3$ will be those who have shifted their attention to monitor some instrument, to glance at the rearview mirror, or to survey the surrounding scenery. Whatever the behavior, it is unlikely that driver C will long keep his attention from the roadway he is covering at 118 ft/sec. One second will be allowed between $T_3$ and $T_4$. This is reasonable on the basis of measurements of drivers' eye fixations made with the HSRI Eye Marker. They show that eye fixations away from the pavement being traveled rarely exceed one second. Since the median duration of coasting during high speed (56-80 mph) driving was found (Mortimer, 1970) to be just over two seconds, at least two seconds should be allowed between $T_4$ and $T_5$ for driver C to decide that he must take evasive action. Another second must be allotted between $T_5$ and $T_6$, for driver C to glance at his rear-view mirror and to decide if he wants to attempt to pass A rather than begin braking.

The period from $T_6$ to $T_7$ represents the transport time of driver C in removing his foot from the accelerator and applying it to the brake. Normann (1953) found the average reaction time to a braking signal to be 0.73 sec, and that 95 percent of drivers reacted in less than 0.9 sec. In the present analysis, one second will be allowed between $T_6$ and $T_7$.

The total time from $T_3$ to $T_7$ is five seconds. During this time period car C will cover 590 feet at 80 mph. Starting to decelerate at time $T_7$ at a constant 0.15g car C will travel

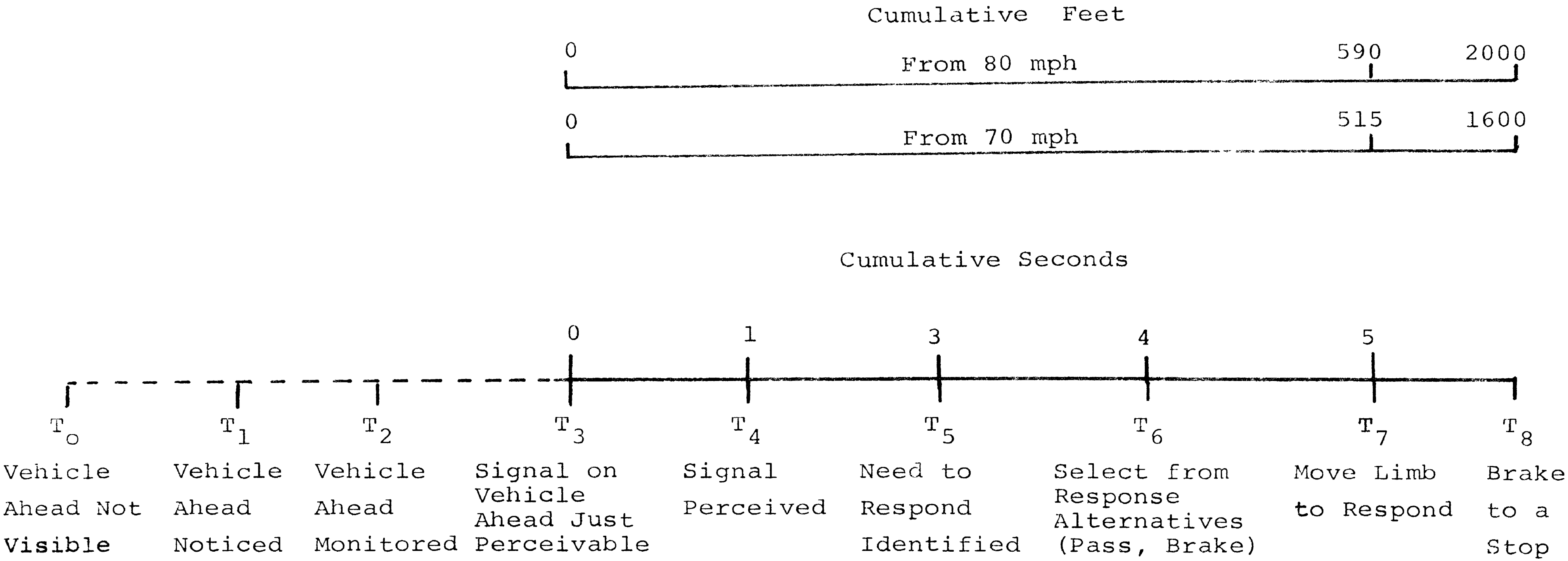



Figure 4.3. Simple driver model to show hypothetical sequence of events used to derive signal identification distance.

another 1450 feet. Thus, a total distance of 2000 feet may not be an unreasonable minimum for signal status identifiability. From an initial speed of 70 mph about 1600 feet would be required.

This analysis indicates that signals should be visible at considerably greater distances than required in State motor vehicle codes--a level of performance that is easily exceeded by lighting equipment on currently manufactured vehicles. More to the point is the need to provide signal identification at distances of 1500-2000 feet.

## 5. THE EFFECT OF SIGNAL INTENSITY, PRESENCE INTENSITY, LIGHTING SYSTEM, VIEWING DISTANCE AND AMBIENT LIGHTING, ON SIGNAL IDENTIFICATION, BRIGHTNESS RATINGS, AND SYSTEM EFFECTIVENESS RATINGS.

The analysis described in Section 4 has shown that signals should become identifiable at fairly large distances in order to provide adequate warning to drivers of a potentially hazardous situation caused by another vehicle in the same roadway lane ahead of them. It was suggested that signals should become identifiable at distances of about 1500-2000 feet. The purpose of this study was to determine the effect of various variables pertaining to lamp performance, as well as the system configuration, upon signal identification.

Most previous tests of lamp intensity requirements have been carried out at distances of less than 500 feet. In considering the lamp intensity it is important to ensure not only that the signal which a lamp presents is clearly visible under day and night conditions, but that it is also not liable to cause discomfort glare. This problem of providing adequate visibility without glare is likely to be heightened when the performance requirements of the lamp are increased for distances of between 1500-2000 feet. Previous tests and analytical work has shown (Forbes, 1966; AMA Lighting Committee Tests, 1958-64; Mortimer, 1970) that an intensity which is adequate for recognition of a signal in the daytime will cause discomfort glare at night. These studies and others previously reviewed (Mortimer, 1970) have all shown the necessity of a dual-intensity system for night and day use, in order to provide a satisfactory solution to this problem.

Apart from the dynamic study conducted by Finch (1968) complete signal systems were not used in these tests. Rather, lamps were used in isolation in order to obtain ratings of lamp effectiveness of one type or another. The study by Finch (1968) was limited in the types of rear lighting systems which he used in that all the lamps were red and that not all kinds of signal modes were evaluated for intensity requirements. For this reason the present study was conducted in order that the effect of realistic variables could be studied to show their effect upon the intensity requirements of lamps when used in complete systems. The major deficiency of the study, in terms of realism, was that it was conducted statically, but in other respects attempted to simulate night and daytime driving situations.

In this study a number of rear lighting systems, such as have been found to be effective in previous static and dynamic tests of driver performance, were used and incorporated separation of function and color coding. The other major system variables that were considered included the intensities of the presence and signal lamps, and the separation distance between lamps in systems using partial or complete functional separation. Three viewing distances were used, of 250 feet, 1000 feet and 20000 feet, in order to span the range recommended by the analysis in Section 4. The day and nighttime ambient illumination levels were simulated by conducting the daytime tests when bright sunshine was present and nighttime tests when conditions replicated those where a vehicle is being followed without opposing traffic and in the presence of glare from the headlights of opposing cars. The measurements taken in this test were objective data of the ability of the observers to identify the signals presented on any given occasion, and subjective ratings of the brightness of those signals and overall ratings of the effectiveness of each system.

METHOD

SUBJECTS. A total of 101 subjects, all with drivers' licenses, were used. Thirty-five subjects observed under daytime conditions, 35 subjects observed under nighttime conditions, and 31 subjects observed in the night + glare conditions. Subjects were randomly assigned to the test conditions. The ages of the subjects were 18 years-65 years. Each subject was tested for color blindness by Dvorine color test charts. Only one deuteranomalous individual was run in these tests, with all other subjects being color-normal.

APPARATUS. A lamp board was constructed on which the test lamps were mounted (Fig. 5.1). Ten lamps were mounted on the board in special housings which could receive colored and neutral density filters. Each housing contained a type 4416, sealed beam lamp selected for this study because of its light output (about 35,000 candelas at about 12.8v), size (4.5 in. dia.), lack of filament shielding, and the light pattern which provided a uniform intensity distribution within about 3° horizontally and 1° 45′ vertically. Each lamp was mounted individually on the board and aimed so that parallel beams from the lamps were obtained. An aiming tube located in the center of the board and mounted perpendicular to it was used to aim the board toward the van containing the observers. The board itself was leveled by means of four legs which could be independently adjusted. The background for the lamps was painted a flat gray, with a reflectance of 0.42.

The test lamps on the board and the controlling circuits were powered from the battery of an automobile running at fast idle. The lamp control panel (Fig. 5.2) had individual potentiometers for each lamp so that voltage could be varied to produce the desired intensity. Digital counters on the potentiometer knobs permitted replication of exact settings, and a voltmeter on the panel allowed monitoring of any lamp voltage or the input voltage. A 5-position rotary switch was used to designate the lamps to be used for a particular lighting system, of the five systems that were used, and a toggle switch was used to designate either near or far spacing between lamps in systems using functional separation. With these two switches set correctly, actuation of the correct signal mode pushbutton turned on the desired lamps operating in the correct signal condition. The pushbuttons allowed presence, left turn, right turn, stop, left turn + stop, and right turn +

Figure 5.1. Lamp board layout and vehicle housing the control panel and operator.

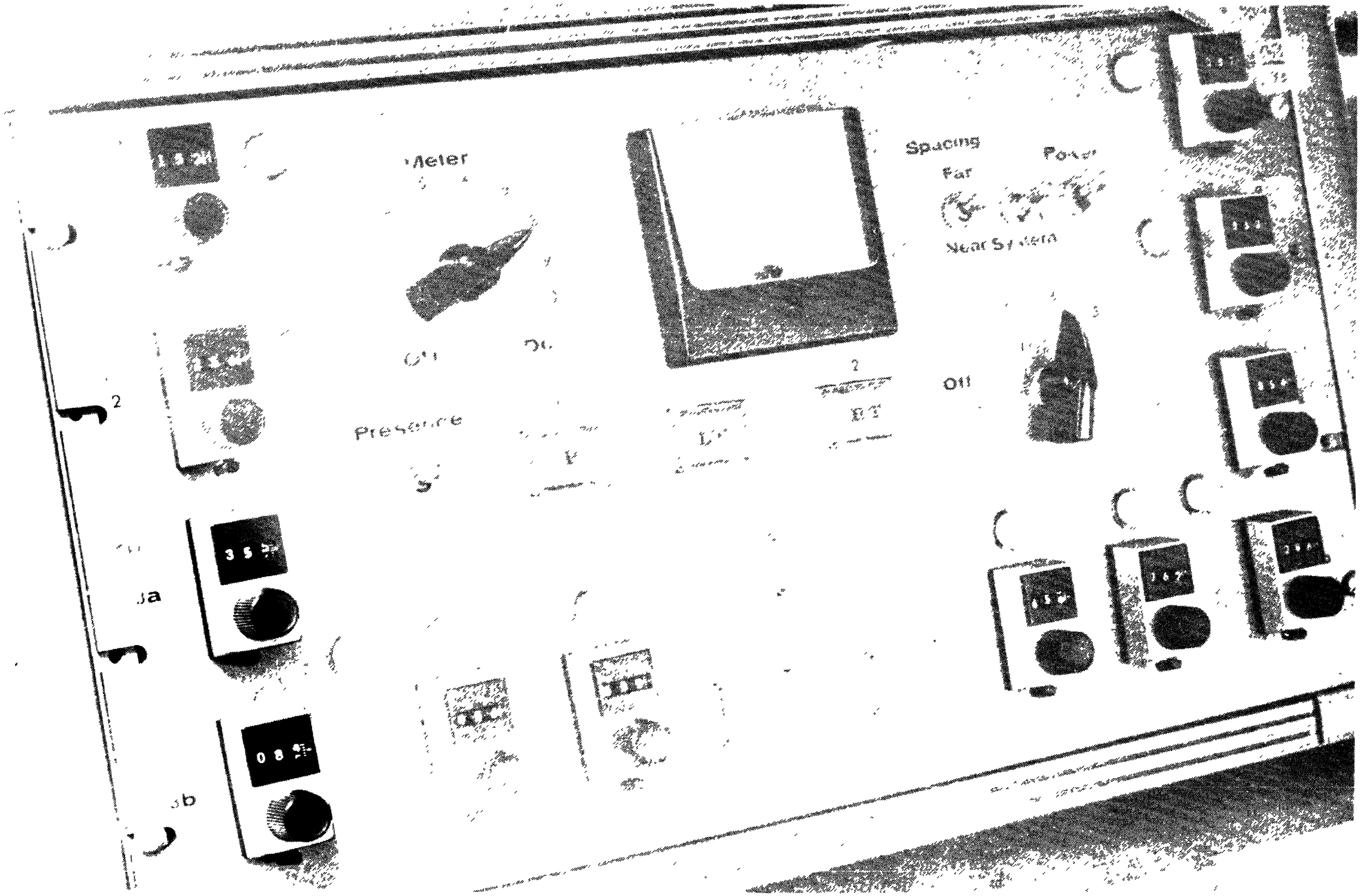



Figure 5.2. The lamp control panel.

stop signals to be given.

A 12-passenger van was modified to house the observers. The front passenger seat was removed and the three bench seats were remounted so that they were in line with the long axis of the vehicle. Thus, the subjects were looking out of the side of the van through the perpendicular side window glass which has a transmission of 91%. This value compares favorably with the transmission of untinted windshields when measured perpendicular to the plane of the glass. Six subjects could be seated in the front row and two or three more subjects in the back row. Each observer had a clipboard which was equipped with an illumination source for the data sheet and a response button. The pushbutton and lamp on each clipboard were wired in series with the lamp on the experimenters control panel located in the van. At the end of a signal presentation a buzzer sounded in the van to alert the subjects to record their responses. Simultaneously the lights on the clipboard and the control panel were illuminated. When a subject pressed the button on his clipboard, the light on the clipboard and the control panel went out indicating to the experimenter that the subject had completed that trial.

A cable was laid over the 2000 foot test distance with intermediate connectors at 250 feet and 1000 feet from the lamp board. This allowed communication with the lamp board operator and also automatically presented a buzzer for a 12-second period at the end of each trial. Figure 5.3 shows the van in which the test subjects were seated.

A dead-end, asphalt-paved road, approximately 2500 feet long and 22 feet wide, was used as a test site. The lamp board was positioned behind a station wagon near one end of the road with the operator and the control panel that he used hidden by the board and located in the rear of the station wagon. Another experimenter was in charge of changing filters for the lamps and calling out the requisite potentiometer settings for the lamp operator. The third experimenter was in the van with the subjects. The lamp board

Figure 5.3. Van housing test subjects.

remained in position at all times with the subject van being moved to the 250, 1000, and 2000 feet distances as needed. The van was in the same lane as the light board. Figure 5.4 shows a view of the setup as seen by the test subjects.

Lamp Photometry. The lamps were photometered using a Spectra Pritchard photometer in order to determine the lamp voltages required to provide 4 and 15 candelas for presence lamps and 80, 185, 525 and 1000 candelas for signal lamps. These voltages were determined for each lamp including the necessary color and neutral density filters. Neutral densities were used in order to maintain lamp voltage as high as possible and similar across all conditions. Surge relays were incorporated in the design so that warm-up time for the lamps was reduced, which was particularly important in presenting turn signals. For turn signals, the flash rate was 1 cps with 60% "on" time. Each signal condition was presented for a period of 6 sec.

PROCEDURE. A block diagram showing the design of the study is shown in Figure 5.5. The independent variables were ordered so as to minimize time-consuming changes in the equipment, thus permitting a greater number of trials to be run in a given time period.

For a given ambient condition (day, night, night + glare) a viewing distance of 250, 1000 or 2000 feet was selected. (Only a sub-set of the subjects were run at 1000 feet in each ambient condition.) A system and lamp separation combination was then chosen at random from those available. Systems 1, 2 and 3 were run during the day; systems 1, 4 and 5 at night; and systems 1 and 5 at night + glare. For the night + glare study a car with low beam headlights on was placed adjacent to the board carrying the test lamps facing the subjects. A signal intensity was then selected at random. Signals were then selected at random from the four

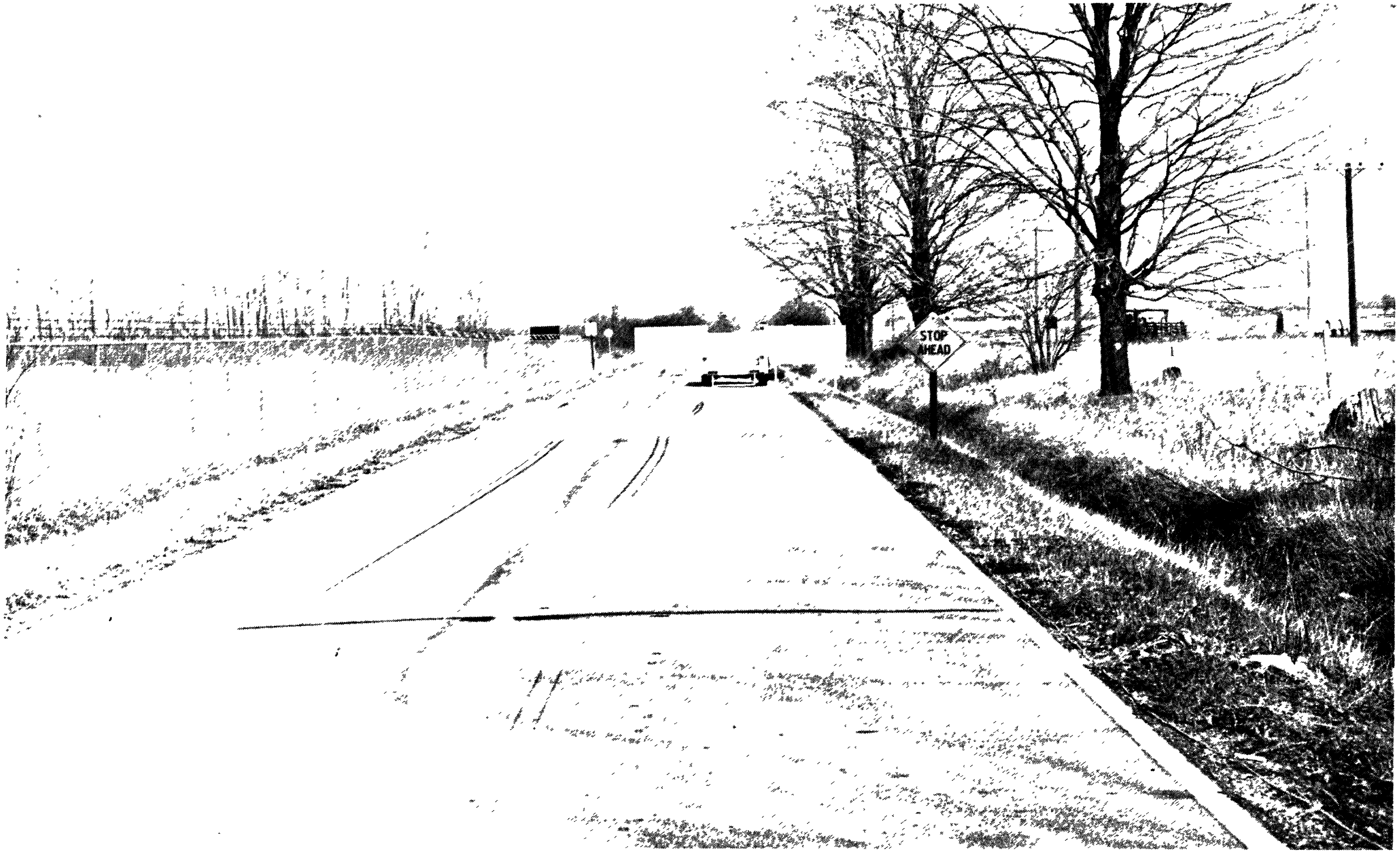



Figure 5.4. View of test lamps from the subjects' van at 250'.

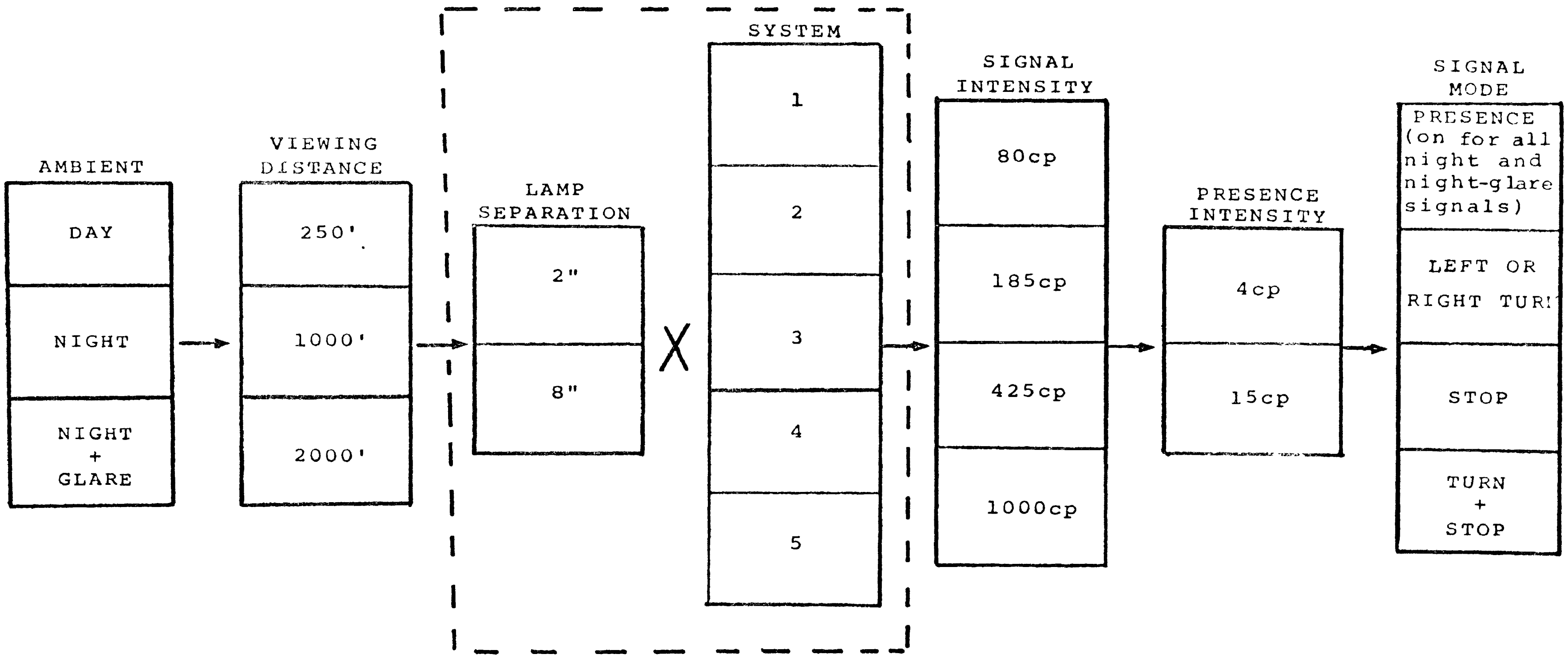



Figure 5.5. The experimental design showing the order in which variables were chosen.

available, except that in the daytime presence lights were never used. Each signal condition was presented for a total period of 6 sec. When all the modes had been exhausted for that intensity of the signal the next presence intensity was used, with the same signal intensity being retained. The signal intensity was then changed and the procedure for selecting presence intensity and mode was repeated. When all four signal intensities were exhausted, another system-lamp separation combination was selected. When all system-lamp separations had been used another one of the three distances was randomly selected and the procedure repeated. Each test condition was given twice during the daytime but once only in the night conditions.

NUMBER OF TRIALS. For most subjects, who had only two viewing distances, there were 240 trials during the day, 320 trials at night and 192 trials for night + glare. For those who viewed also at the 1000 feet distance, the number of trials was 312 for the day, 480 at night and 288 for night + glare. Subjects were given a break whenever the viewing distance was changed, which occurred at intervals of about one hour.

Instructions. After the observers were seated in the van, data sheets and pencils were given to them and the instructions shown in Appendix A were read to the observers. In summary, the subjects' task was to observe the lamp board in the event that a signal appeared. When a buzzer was sounded they were to rate the brightness of each signal that they saw as either too dim, adequate, or too bright. In this way the signals which were seen and the manner in which they were identified as well as the ratings of subjective brightness were obtained. At the conclusion of presentations with a given lighting system the subjects also rated the system for overall effectiveness in presenting signals.

INDEPENDENT VARIABLES. The following independent variables were used in this test:

1. Ambient illumination: day, night, night + glare (the glare was simulated by the low beam headlights of a vehicle positioned at the test lamp board).

2. Viewing distance: 250, 1000, 2000 feet.

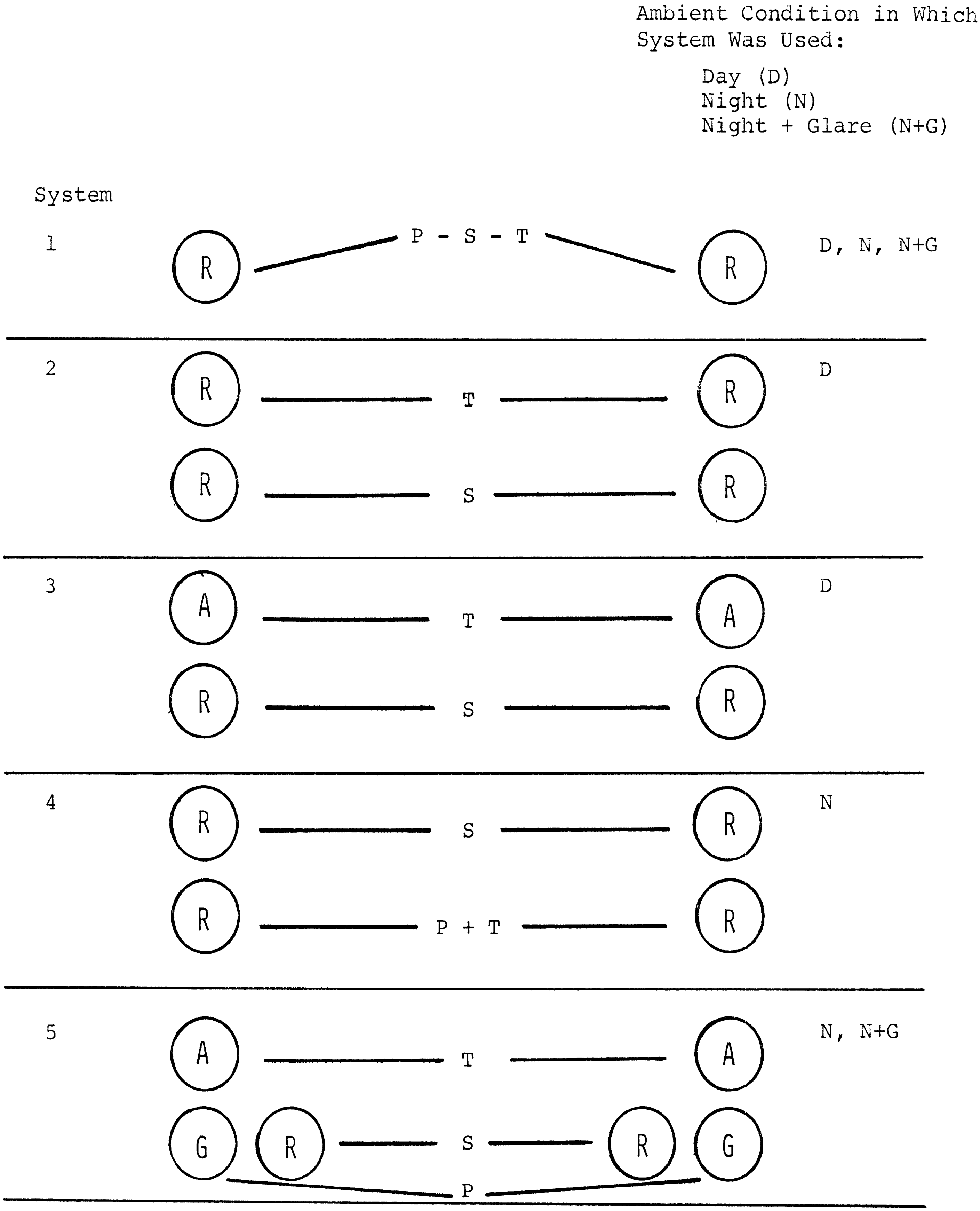
3. Lighting system (see Fig. 5.6).

4. Lamp separation distance: 2 in., 8 in., edge-to-edge (lamp separation applies only to systems using functional separation, i.e. systems 2-5).

5. Signal mode: presence (not used in day tests), left and right turn, stop, left or right turn + stop.

6. Presence lamp intensity: 4, 15 candelas.

7. Signal lamp intensity: 80, 185, 425, 1000 candelas.




P=Presence R=Red
T=Turn A=Amber
S=Stop G=Green-Blue

Figure 5.6. The lighting systems.

RESULTS

The results of this study are shown separately for each of the three dependent variables that were used: percent of signals identified, signal brightness ratings, and overall system effectiveness ratings. The responses which the subjects made on the data sheets were coded and prepared for computer data processing. A special purpose program was written in order to provide the percent of signals identified in each possible category for each actual signal mode that was presented. These outputs allowed the data to be scanned in terms of the correctness of the identification, the errors or confusions that were made, and the brightness ratings assigned to each signal. A separate analysis was carried out on the overall system effectiveness ratings.

An illustration of the computer output of the signal identification and brightness ratings data is shown in Table 5.1. This indicates the total number of responses made by the subjects to each signal mode in terms of their identification of the signal and the brightness ratings in terms of inadequately bright, adequately bright or excessively bright. The numbers in parentheses are the percent of responses made in each of these categories. For example, Table 5.1 shows data for a night condition, 250 feet viewing distance, system 1 using 80 candelas for the signals and 15 candelas for the presence light. The data are based on the responses from 35 subjects. The data show that 79.9% of the subjects identified the signal as a presence light when a presence light was presented; while 14.2% of the responses identified it as a stop signal, 2.8% as a presence + stop, and 2.8% as a presence + turn. Of those subjects who identified the signal as a presence light 2.8% indicated it to be inadequately bright, 59.9% considered it adequately bright and 17.1% reported it as excessively bright. By analogy when a presence + stop signal was

TABLE 5.1. Typical Computer Printout Data Sheet Showing Independent Variables in Top Left Corner. Signal Mode Presented is Shown by Column with I, A, and E Indicating Brightness Ratings. Frequencies are Shown with Percents in Parentheses.

CAR-TRUCK MARKING AND SIGNALING EXPERIMENT DATA

AMBIENT CONDITIONS- NIGHT
DISTANCE- 250 FEET
LAMP SPACING- NEAR
SIGNAL SYSTEM- 1
SIGNAL INTENSITY- 80 CANDLEPOWER
PRESENCE INTENSITY- 15 CANDLEPOWER
N= 35

I - INADEQUATE
A - ADEQUATE
E - EXCESSIVE

SIGNAL MODE

| RESPONSE | PRES I | PRES A | PRES E | PRES + STOP I | PRES + STOP A | PRES + STOP E | PRES + TURN I | PRES + TURN A | PRES + TURN E | PRES + STOP + TURN I | PRES + STOP + TURN A | PRES + STOP + TURN E |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NONE | SUM= 0 (0.0) | | | SUM= 0 (0.0) | | | SUM= 0 (0.0) | | | SUM= 0 (0.0) | | |
| PRES | 1 (2.8) | 21 (59.9) | 6 (17.1) | 0 (0.0) | 7 (19.9) | 4 (11.4) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| | SUM= 28 (79.9) | | | SUM= 11 (31.4) | | | SUM= 0 (0.0) | | | SUM= 0 (0.0) | | |
| STOP | 2 (5.7) | 3 (8.5) | 0 (0.0) | 7 (19.9) | 11 (31.4) | 2 (5.7) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| | SUM= 5 (14.2) | | | SUM= 20 (57.1) | | | SUM= 0 (0.0) | | | SUM= 0 (0.0) | | |
| TURN | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 1 (2.8) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| | SUM= 0 (0.0) | | | SUM= 0 (0.0) | | | SUM= 1 (2.8) | | | SUM= 0 (0.0) | | |
| PRES | 1 (2.8) | 0 (0.0) | 0 (0.0) | 1 (2.8) | 2 (5.7) | 1 (2.8) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| + STOP | 1 (2.8) | 0 (0.0) | 0 (0.0) | 3 (8.5) | 0 (0.0) | 1 (2.8) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| | SUM= 1 (2.8) | | | SUM= 4 (11.4) | | | SUM= 0 (0.0) | | | SUM= 0 (0.0) | | |
| PRES | 0 (0.0) | 1 (2.8) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 2 (5.7) | 20 (57.1) | 4 (11.4) | 0 (0.0) | 15 (42.8) | 3 (8.5) |
| + TURN | 0 (0.0) | 1 (2.8) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 16 (45.7) | 9 (25.7) | 1 (2.8) | 16 (45.7) | 2 (5.7) | 0 (0.0) |
| | SUM= 1 (2.8) | | | SUM= 0 (0.0) | | | SUM= 26 (74.2) | | | SUM= 18 (51.4) | | |
| STOP | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 4 (11.4) | 3 (8.5) | 0 (0.0) | 1 (2.8) | 14 (39.9) | 2 (5.7) |
| + TURN | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 4 (11.4) | 1 (2.8) | 2 (5.7) | 12 (34.2) | 4 (11.4) | 1 (2.8) |
| | SUM= 0 (0.0) | | | SUM= 0 (0.0) | | | SUM= 7 (19.9) | | | SUM= 17 (48.5) | | |
| PRES | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 1 (2.8) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| + STOP | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | [illegible] | 0 (0.0) | 1 (2.8) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| + TURN | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | (2.8) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| | SUM= 0 (0.0) | | | SUM= 0 (0.0) | | | SUM= 1 (2.8) | | | SUM= 0 (0.0) | | |

presented 57.1% of subjects identified it as a stop signal and 11.4% as a presence + stop; when a presence + turn signal was presented 74.2% identified it correctly with the largest number of errors being made by subjects (19.9%) who called the signal a stop + turn.

Further analyses were conducted utilizing these basic data in order to evaluate the effect of the independent variables upon identification of signals, the brightness ratings, and the overall effectiveness ratings. Each of these statistical analyses will be described separately.

SIGNAL SYSTEM IDENTIFICATION. Identification of the signals in day, night, and night + glare conditions, at each of four signal intensities (80, 185, 425 and 1000 candelas), at each of three viewing distances (250, 1000 and 2000 feet) was evaluated by analysis of variance for three modes (stop, turn, stop + turn). For the day condition a four-factor analysis of variance was conducted for each of three system-lamp separations and for each of the modes at each of the signal intensities and at each of the distances. Under the night + glare conditions presence intensity was added to the analysis as a factor.

Separate analyses of variance, not shown here, were conducted in each ambient condition. Where the analysis of variance indicated that there were significant differences ($P \leq .01$) between the factors, Newman-Keuls tests were conducted to test the differences (at the .01 level of significance) between the mean percent of signals correctly identified. The Newman-Keuls procedure is one that can be used to determine if two or more means are significantly different from each other. For a further explanation of this test see Winer, 1962).

Day - Signal Identification. The results of the Newman-Keuls tests on the significant interaction between systems at each distance (Fig. 5.7) are shown in Table 5.2.

The analysis indicates that of the three systems (1, 2, 3) which were used in the daytime tests, no significant differences were found between the systems except at 2000 feet where systems 1 and 2(8") were significantly more effective than system 3. This difference was due to the difficulty in seeing the amber turn signal in system 3 at 2000'.

TABLE 5.2. Newman-Keuls Tests of Signal Identification in the Day Condition Across Distances for Each System.

| Distance (ft) | System(s) | Resulted in Significantly Greater Mean Percentage Identification | Than System(s) |
|---|---|---|---|
| 250 | None | " | |
| 1000 | None | " | |
| 2000 | 1, 2(8")* | " | 3(2"), 3(8") |

*The values in parentheses indicate the inter-lamp separation used with systems 2-5.

A comparison of systems across distances is shown in Table 5.3. The shorter the viewing distance the more effective the results in all cases except systems 1 and 2(8") where 250 feet and 1000 feet were not significantly different because identification did not decrease as much at these distances for these two systems as with the other systems.

TABLE 5.3. Newman-Keuls Tests of Signal Identification in the Day Condition Across Distances for Each System.

| System(s) | Distance (ft) | Resulted in Significantly Greater Mean Percentage Identification | Than Distance (ft) |
|---|---|---|---|
| 1 | 250, 1000 | " | 2000 |
| 2(2") | 250, 1000 | " | 2000 |
| " | 250 | " | 1000 |
| 2(8") | 250, 1000 | " | 2000 |
| 3(2") | 250, 1000 | " | 2000 |
| " | 250 | " | 1000 |
| 3(8") | 250, 1000 | " | 2000 |
| " | 250 | " | 1000 |

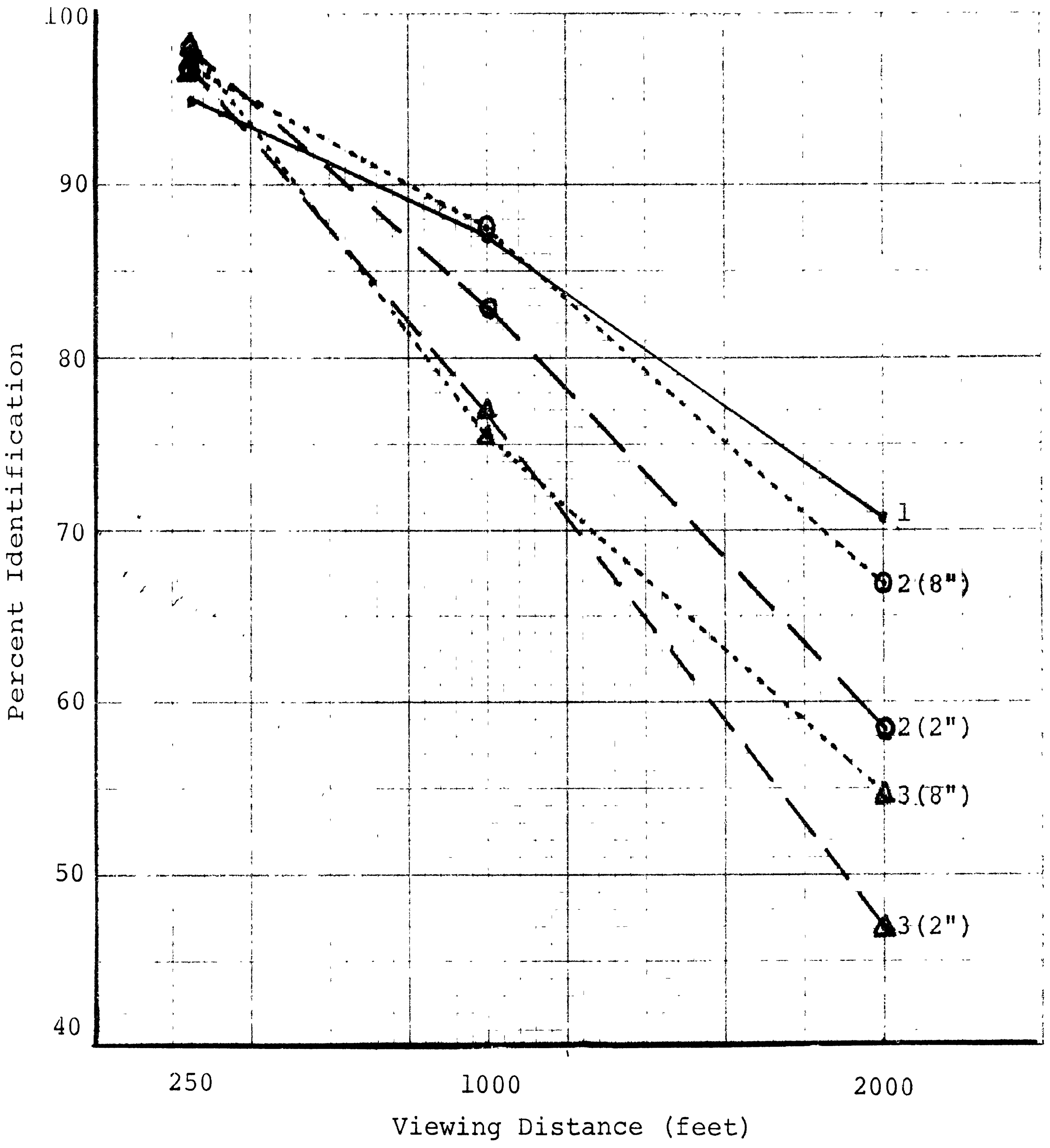



Figure 5.7. Percent identification of day signals as a function of system-separation and viewing distance.

The results of the Newman-Keuls tests on the significant interaction of systems in each mode (Fig. 5.8) are presented in Table 5.4.

TABLE 5.4. Newman-Keuls Tests of Signal Identification in the Day Condition Across Systems for Each Mode.

| Mode | System(s) | Resulted in Significantly Greater Mean Percentage Identification | Than System(s) |
|---|---|---|---|
| Stop | None | " | |
| Turn | None | " | |
| Stop + Turn | 1 | " | 2(2'), 3(2"), 3(8") |
| " | 2(8") | " | 3(2") |

Only for stop + turn was one system more effective than another system. System 1 was better than all but 2(8") which was better than 3(2").

Table 5.5 indicates the results of Newman-Keuls tests for

TABLE 5.5. Newman-Keuls Tests for Signal Identification in the Day Condition Across Modes for Each Distance and Signal Intensity.

| Distance (ft) | Signal Intensity (cd) | Mode | Resulted in Significantly Greater Mean Percentage Identification | Than Mode |
|---|---|---|---|---|
| 250 | All | None | " | |
| 1000 | 425, 1000 | None | " | |
| " | 185 | Stop, Turn | " | Stop + Turn |
| " | 80 | Stop, Turn | " | Stop + Turn |
| " | 80 | Stop | " | Turn |
| 2000 | 425, 1000 | Stop, Turn | " | Stop + Turn |
| " | 185 | Stop, Turn | " | Stop + Turn |
| " | 185 | Stop | " | Turn |
| " | 80 | Stop | " | Turn, Stop + Turn |

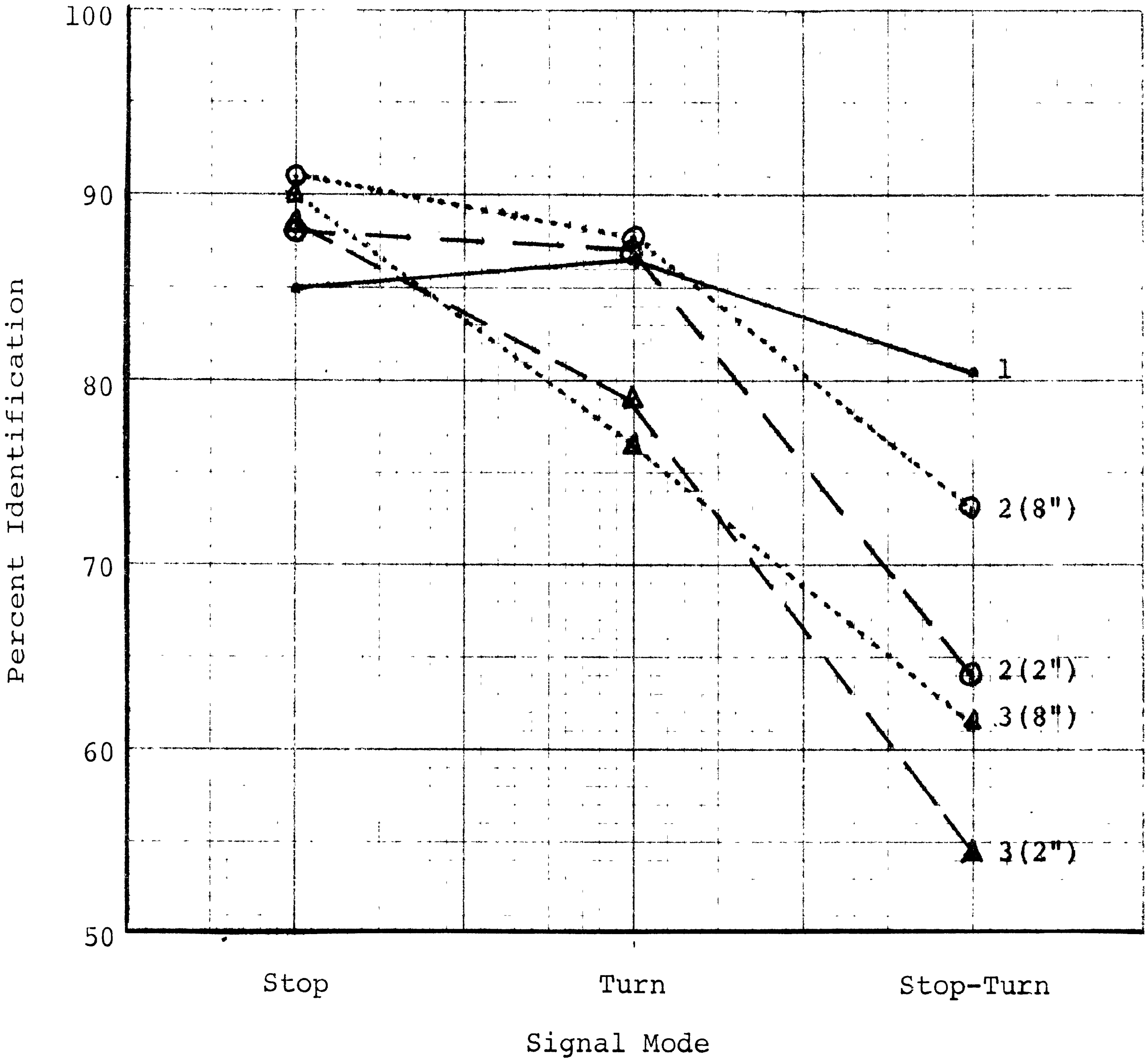



Figure 5.8. Percent identification of day signals as a function of system-separation and mode.

the significant three-factor interaction (Fig. 5.9) of viewing distance and signal intensity across modes. At 250 feet with all signal intensities and at 1000 feet with the higher two intensities, there were no significant differences between modes. At 80 and 185 cd stop and turn were each more identifiable than stop + turn. Furthermore, at 80 cd stop was more effective than turn. At 2000 feet stop and turn were more effective than stop + turn except at 80 cd. Stop was more effective than turn at the lower two intensities.

Day - Signal Identification Summary. Thus, in conditions where the viewing distance was large and multiple signals were presented the merits of systems 1 and 2 (especially with 8 in. separation) became apparent. Amber turn signals must be of greater intensity than red signals. Even with red signals 425 cd was needed in the stop + turn mode. The mean percent correctly identified signals across all the independent variables in the daytime study are shown in Figure 5.10. This four-factor interaction was not significant, but provides an overview of the conditions leading to poor identification. All systems performed well at 250 feet in all modes at 80 cd, but as the distance increased 425 cd was required in the stop and the turn modes, with the amber signal (systems 3(2"), 3(8")) being somewhat poorer except at 1000 cd. Stop + turn mode identification was poor at 1000 feet at less than 425 cd, and remained poor at up to 1000 cd at 2000 feet with systems using the amber turn signal.

Night - Presence Mode Only Signal Identification. Results in this section are based on identification of the presence signal when presented by itself, not with other signals. Mean percent correct identification was 95.0 at 250 feet, 95.9 at 1000 feet, and 92.0 at 2000 feet.

Newman-Keuls tests conducted on the interaction of system-separation and presence intensity (Fig. 5.11) are shown in

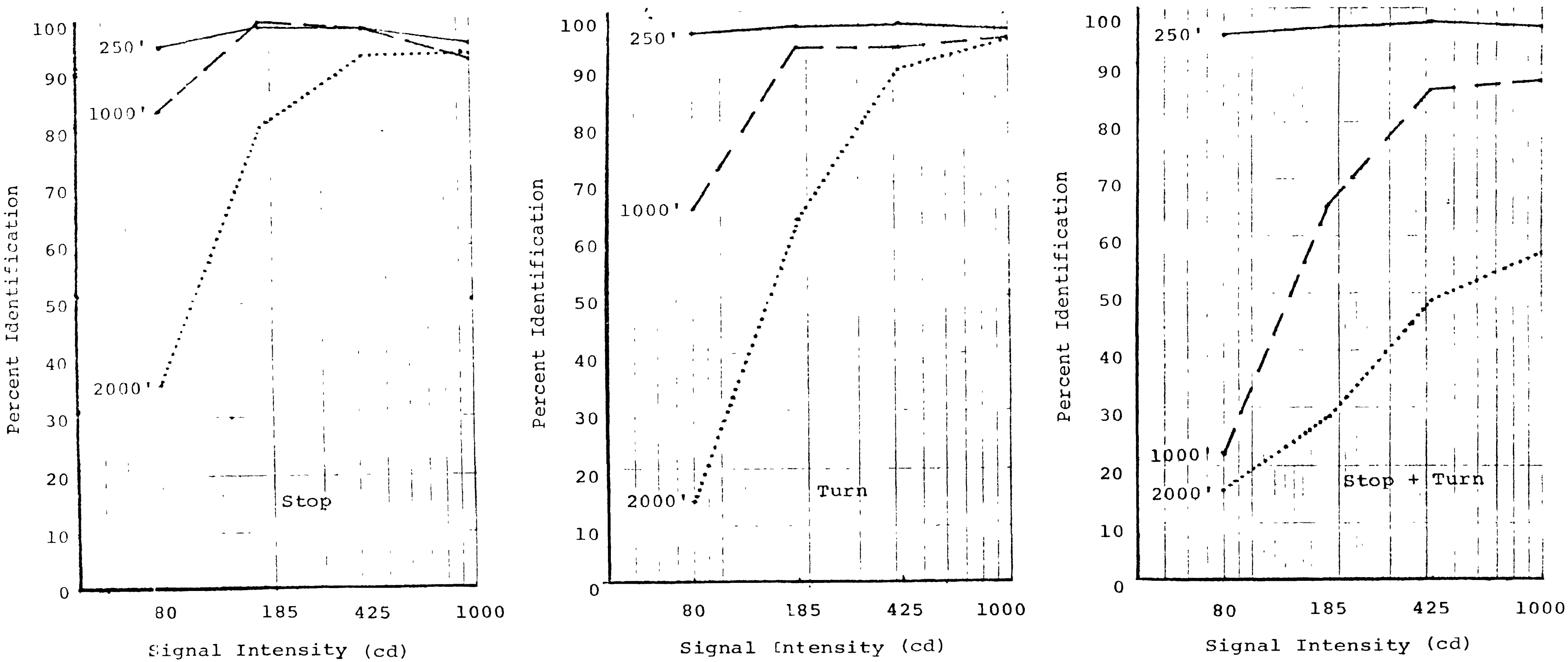



Figure 5.9. Signal identification of day signals (stop, turn, and stop + turn) as a function of signal intensity, distance, and modes.

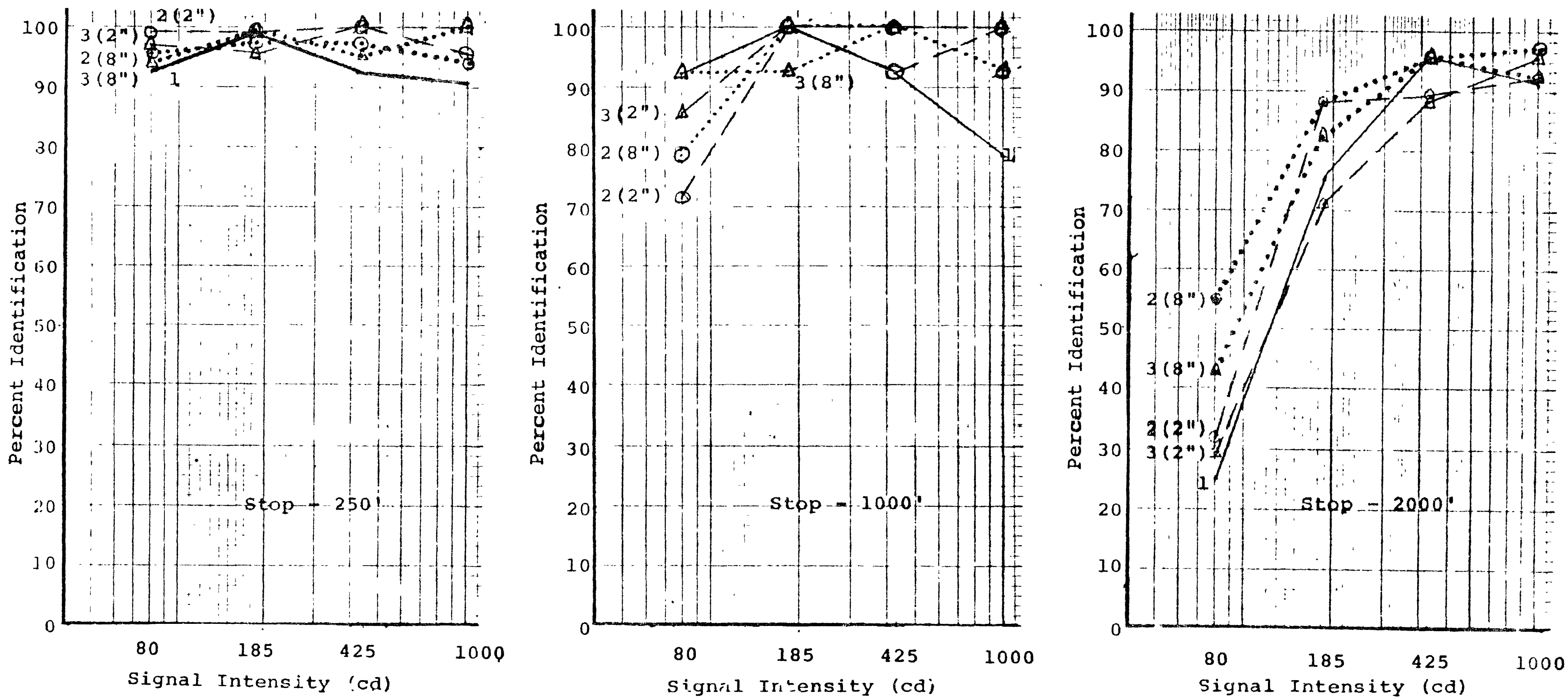



Figure 5.10. Signal identification of day signals (stop) as a function of signal intensity, system-separation, mode, and viewing distance (continued).

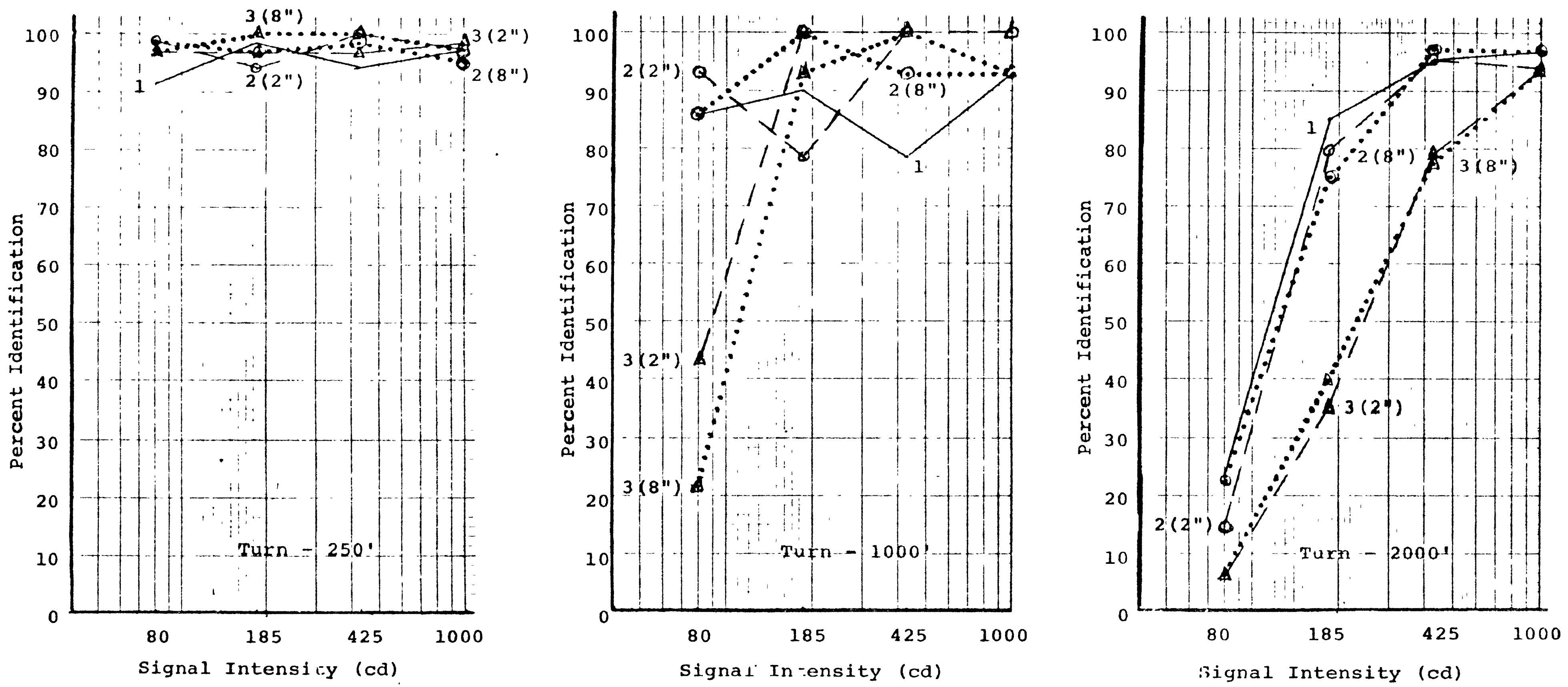



Figure 5.10. Signal identification of day signals (turn) as a function of signal intensity, system-separation, mode, and viewing distance (continued).

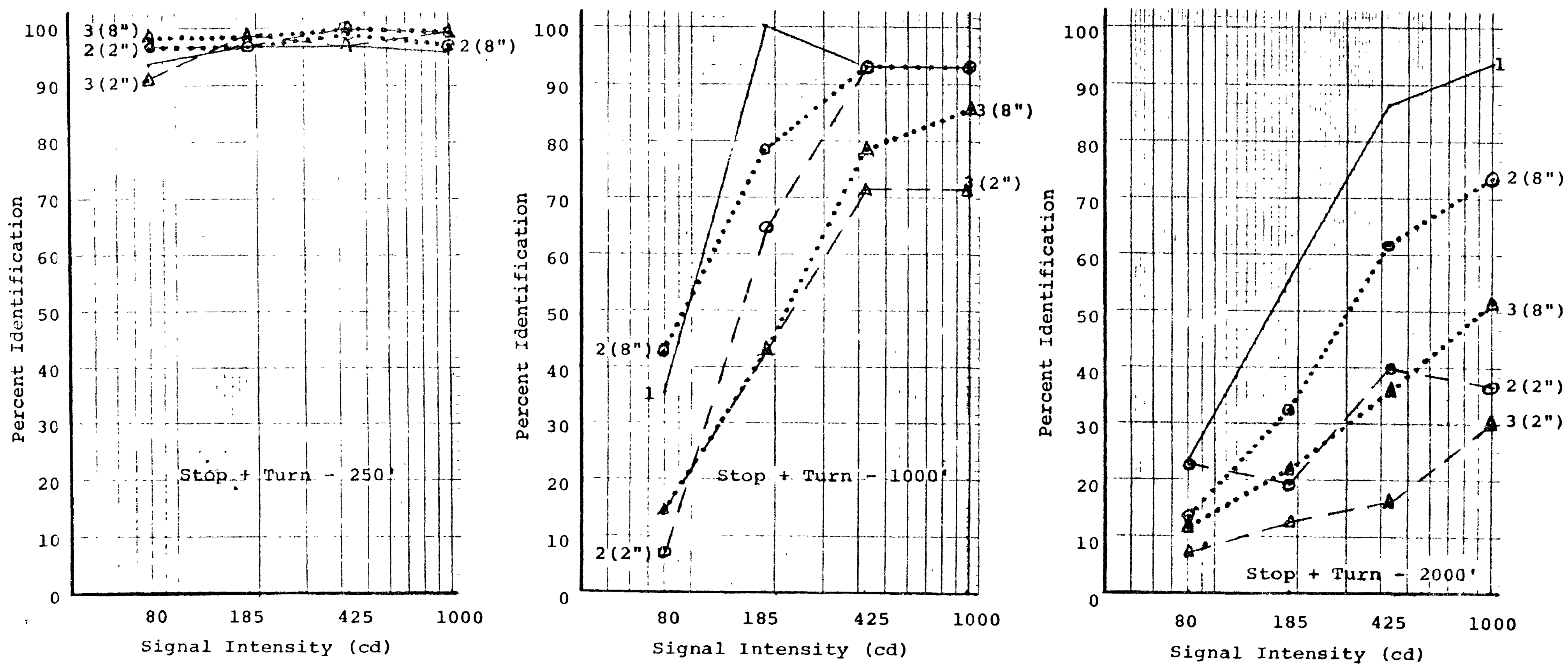



Figure 5.10. Signal identification of day signals (stop + turn) as a function of signal intensity, system-separation, mode, and viewing distance (concluded).

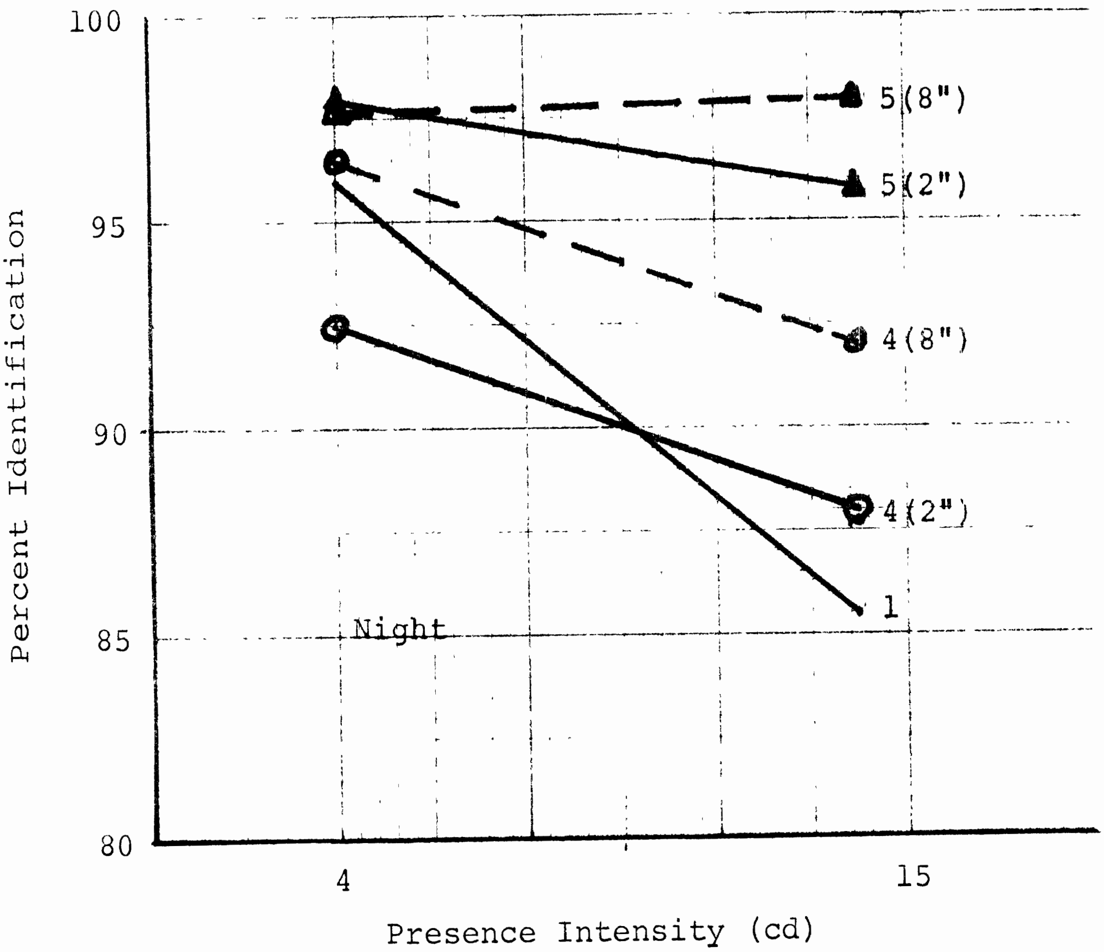



Figure 5.11. Percent identification of presence lights as a function of system-separation and presence intensity, in the night condition.

Tables 5.6 and 5.7. Across systems no significant differences were found at 4 cd because the identifications were all high. At 15 cd identification of systems 1 and 4(2") had deteriorated in comparison with system 5 at both separations.

TABLE 5.6. Newman-Keuls Tests of Presence Identification in the Night Condition Across Systems at Each Intensity.

| Presence Intensity (cd) | System(s) | Resulted in Significantly Greater Mean Percentage Identification | Than System(s) |
|---|---|---|---|
| 4 | None | " | |
| 15 | 5(2"), 5(8") | " | 1, 4(2") |

TABLE 5.7. Newman-Keuls Tests of Presence Identification in the Night Condition Across Presence Intensities for Each System.

| System(s) | Presence Intensity (cd) | Resulted in Significantly Greater Mean Percentage Identification | Than Presence Intensity (cd) |
|---|---|---|---|
| 4(8"), 5(2"), 5(8") | None | " | |
| 1, 4(2") | 4 | " | 15 |

Night + Glare - Presence Mode Only Signal Identification. Results in this section are based on presence when not accompanied by other signals. Viewing distance was the only significant factor and Newman-Keuls results are presented in Table 5.8. Identification deteriorated from 97% at 250 and 1000 feet to 90% at 2000 feet producing a significant decline, but performance remained relatively high across systems.

TABLE 5.8. Newman-Keuls Tests of Presence Identification in the Night + Glare Condition Across Distance.

| Distance(ft) | Resulted in Significantly Greater Mean Percentage Identification | Than Distance(ft) |
|---|---|---|
| 250, 1000 | " | 2000 |

Presence Light Identification Summary. Identification was marginally better at 250 and 1000 feet than at 2000 feet. In the night condition 4 cd was better than 15 cd for systems 1 and 4(2") due to confusion of the presence light at the higher intensity with the stop light.

Night - Signal Identification. Five factors were involved in the night tests. The findings can be described by analysis of three significant interactions: presence intensity x distance; presence intensity x signal intensity x mode; and system x signal intensity x distance x mode. The Newman-Keuls tests on mean percent signal identification as a function of viewing distance and presence intensity (Fig. 5.12) is shown in Table 5.9.

TABLE 5.9. Newman-Keuls Tests of Signal Identification in the Night Condition Across Presence Intensities at Each Distance.

| Distance(ft) | Presence Intensity(cd) | Resulted in Significantly Greater Mean Percentage Identification | Than Presence Intensity(cd) |
|---|---|---|---|
| 250, 1000 | None | " | |
| 2000 | 4 | | 15 |

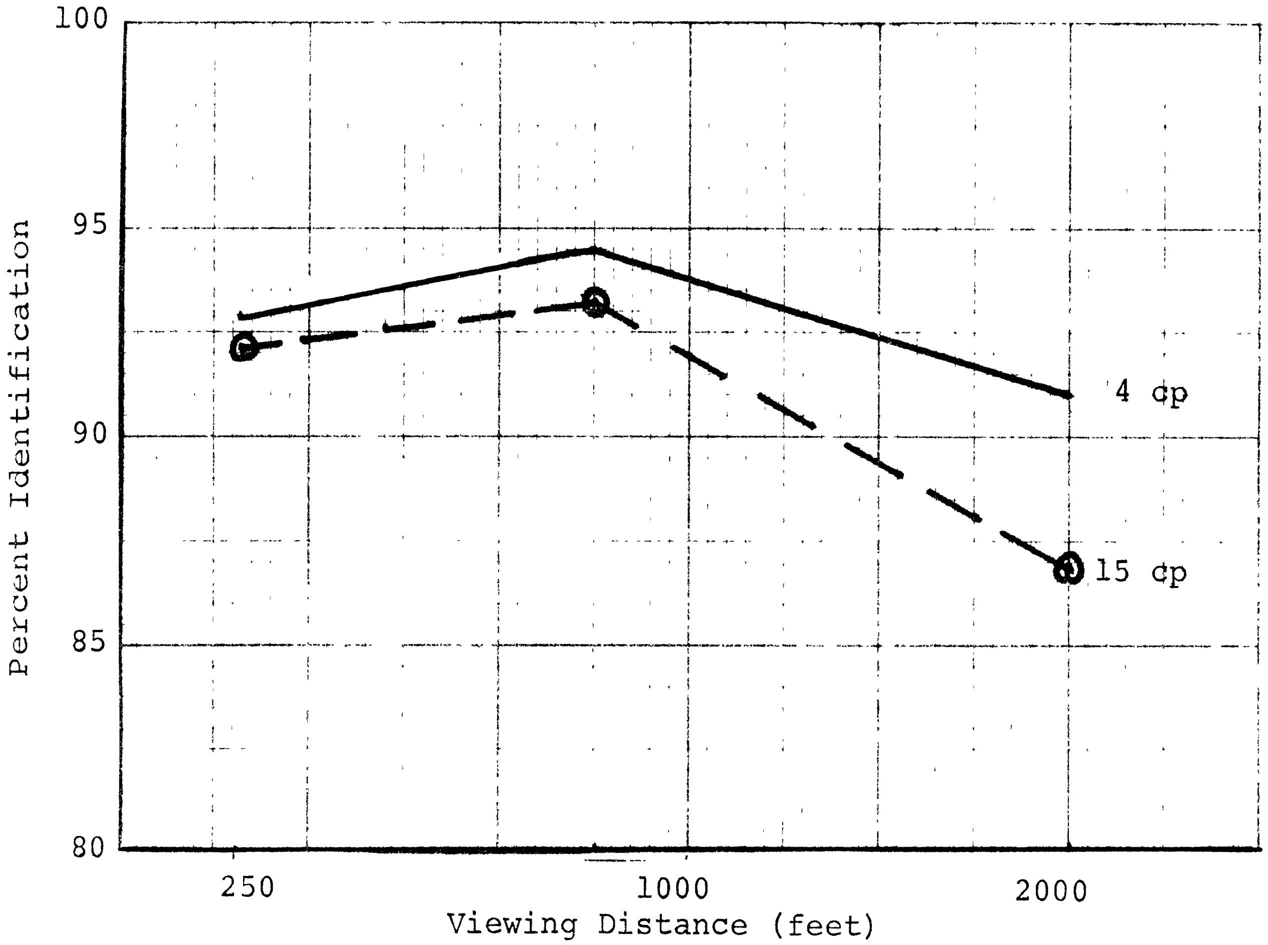



Figure 5.12. Percent identification of night signals as a function of presence intensity and viewing distance.

The analysis indicates that at 2000 feet 15 cd was significantly less effective than 4 cd.

Table 5.10 shows the Newman-Keuls test results on the interaction of presence intensity with signal intensity and mode (Fig. 5.13). At 80 cd for turn and stop + turn the lower presence intensity (4cd) was better. For presence + stop + turn at 80 cd, the presence light of 15 cd masked the stop and the turn signals with fewer of each being reported.

TABLE 5.10. Newman-Keuls Tests of Signal Identification in the Night Condition Across Presence Intensities at Each Signal Intensity and Mode.

| Mode | Signal Intensity (cd) | Presence Intensity (cd) | Resulted in Significantly Greater Mean Percentage Identification | Than Presence Intensity (cd) |
|---|---|---|---|---|
| Stop | All | None | " | |
| Turn | 185, 425, 1000 | None | " | |
| Turn | 80 | 4 | " | 15 |
| Stop + Turn | 185, 425, 1000 | None | " | |
| Stop + Turn | 80 | 4 | " | 15 |

Table 5.11 shows the Newman-Keuls analysis of the interaction of system separation, signal mode, distance and signal intensity (Fig. 5.14). In stop and turn signals, systems 5(2") and 5(8") were significantly better than system 1 at 80 cd regardless of viewing distance. This was also largely true for system 4. At 185, 425, and 1000 cd, there were mostly no significant differences between the systems regardless of distance.

For stop + turn at all distances, system 1 was the least effective with system 4(2") also poor. Systems 5(2") and 5(8") were the most effective.

TABLE 5.11. Newman-Keuls Tests of Signal Identification in the Night Condition Across System-Separation at Each Mode, Distance, and Signal Intensity.

| Mode | Distance (ft) | Signal Intensity (cd) | System(s) | Resulted in Significantly Greater Mean Percentage Identification | Than System(s) |
|---|---|---|---|---|---|
| Stop | 250 | 425, 1000 | None | " | |
| " | " | 80, 185 | All | " | 1 |
| " | 1000 | 185, 425, 1000 | None | " | |
| " | " | 80 | 4(2"), 5(8") | " | 1 |
| " | 2000 | 185, 425, 1000 | None | " | |
| " | " | 80 | 4(8"), 5(2"), 5(8") | " | 1 |
| Turn | 250 | 185, 425, 1000 | None | " | |
| " | " | 80 | 5(8") | " | 1 |
| " | 1000 | 185, 425, 1000 | None | " | |
| " | " | 80 | All | " | 1 |
| " | 2000 | 185, 425, 1000 | None | " | |
| " | " | 80 | 5(2"), 5(8") | " | 1, 4(2"), 4(8") |
| Stop + Turn | 250 | 1000 | None | " | |
| " | " | 425 | 4(8"), 5(2"), 5(8") | " | 1 |
| " | " | 185 | All | " | 1 |
| " | " | 80 | All | " | 1 |
| " | " | 80 | 4(8"), 5(2"), 5(8") | " | 4(2") |
| " | 1000 | 1000 | 1, 5(2"), 5(8") | " | 4(2") |
| " | " | 185, 425 | All | " | 4(2") |
| " | " | 80 | 5(2"), 5(8") | " | 4(8") |
| " | " | 80 | 5(8") | " | 4(2") |
| " | 2000 | 1000 | 1, 5(2"), 5(8") | " | 4(2") |
| " | " | 425 | All | " | 4(2") |
| " | " | 185 | 1, 5(2"), 5(8") | " | 4(2"), 4(8") |
| " | " | 80 | All | " | 4(2") |
| " | " | 80 | 5(2"), 5(8") | " | 4(8") |
| " | " | 80 | 5(8") | " | 1 |

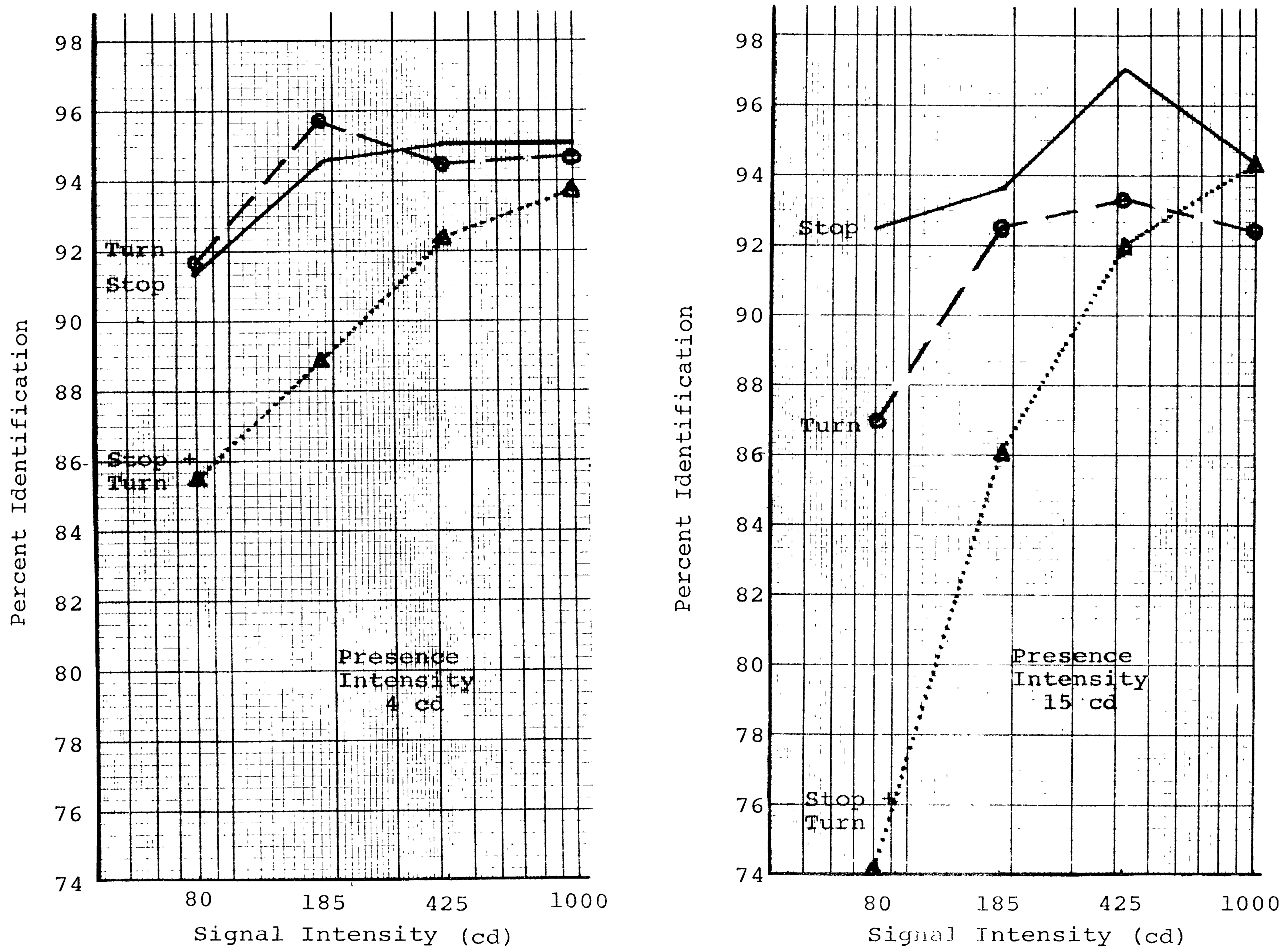



Figure 5.13. Percent identification of night signals (stop, turn, and stop + turn) as a function of signal intensity, presence intensity and mode.

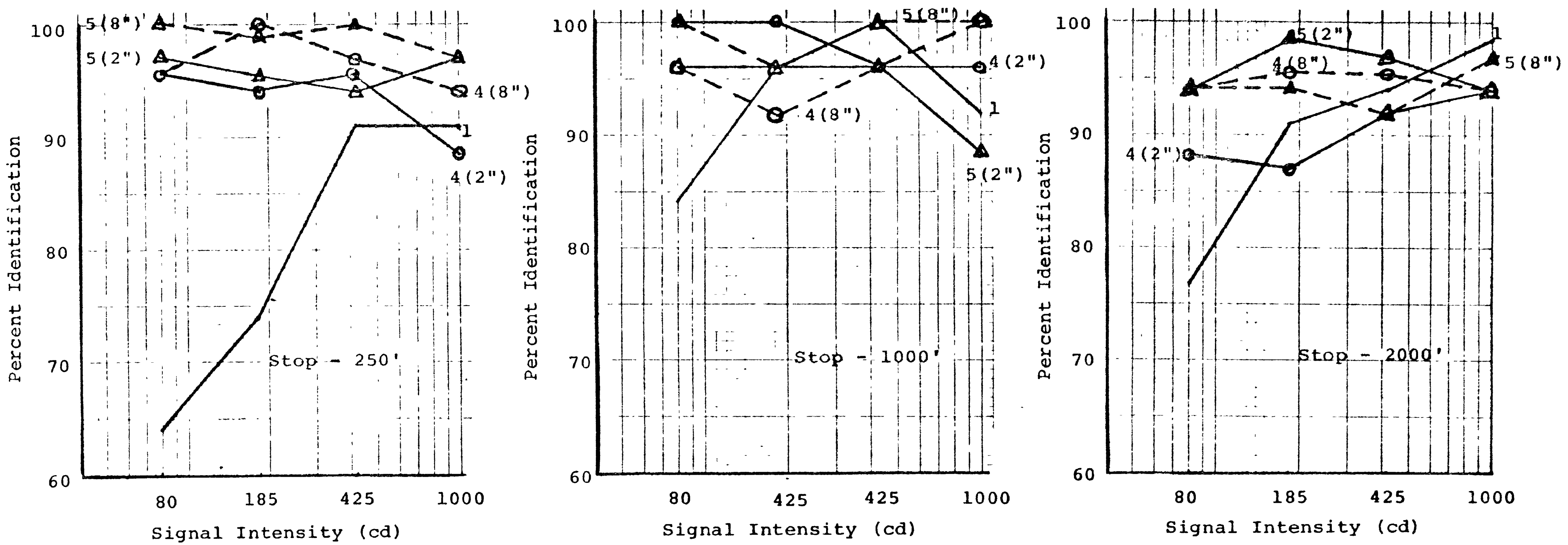



Figure 5.14. Percent identification of night signals (stop) as a function of system-separation, signal intensity, distance, and mode (continued).

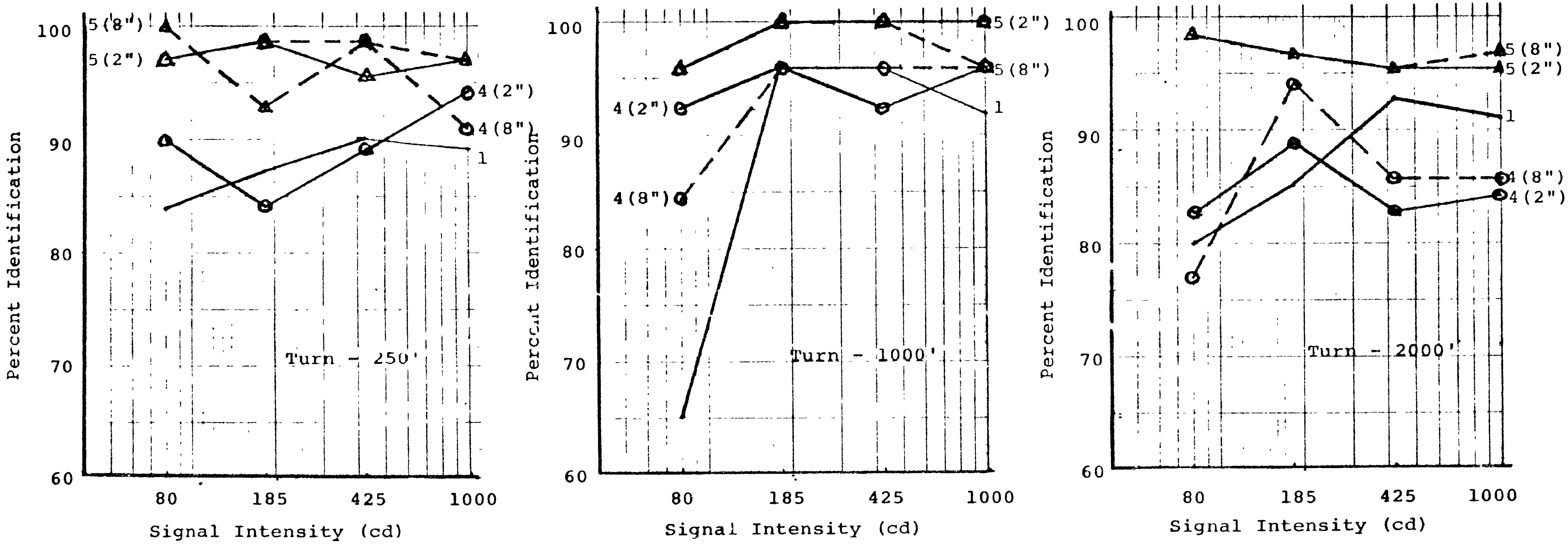



Figure 5.14. Percent identification of night signals (turn) as a function of system-separation, signal intensity, distance, and mode (continued).

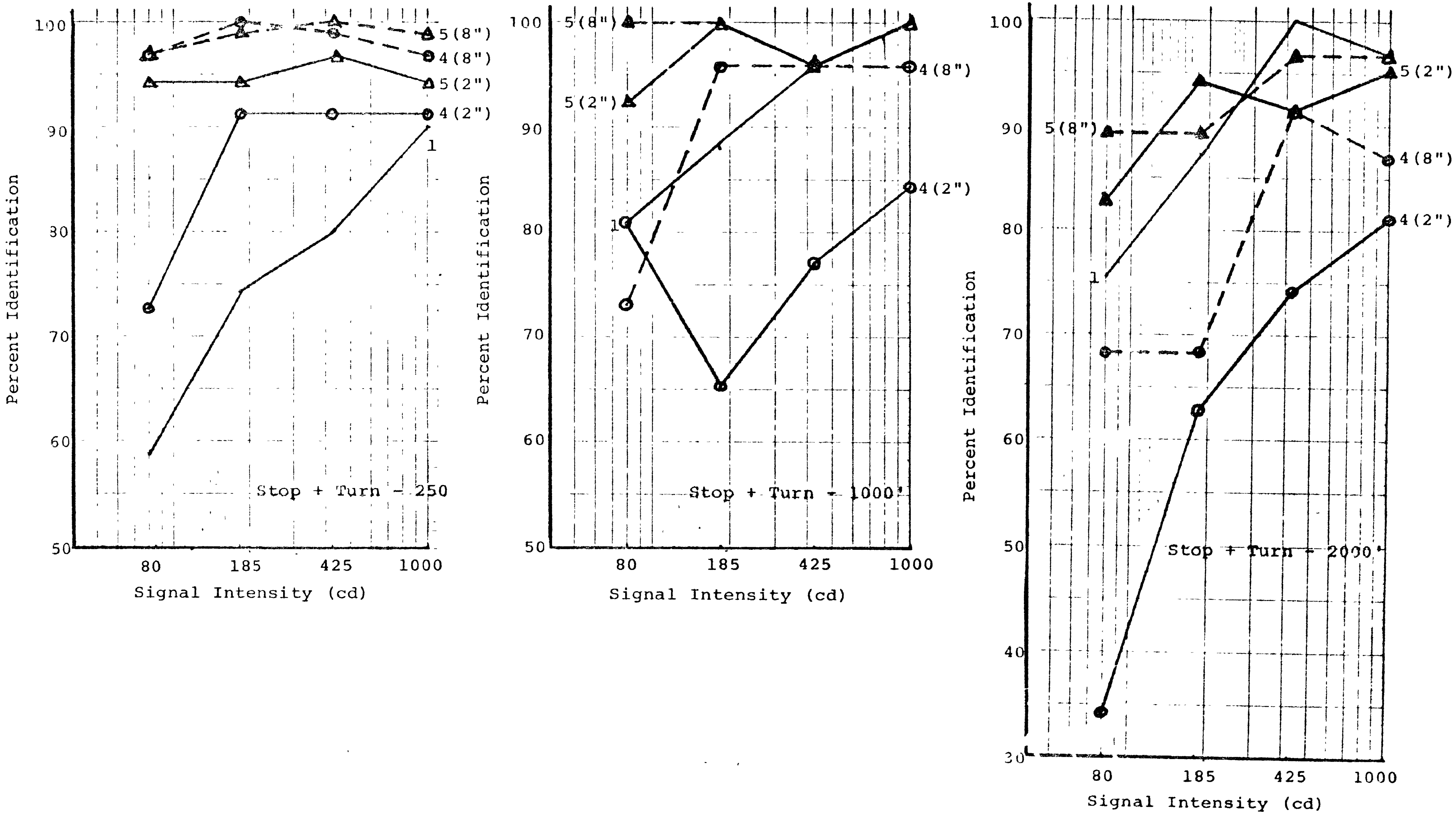



Figure 5.14. Percent identification of night signals (stop + turn) as a function of system-separation, signal intensity, distance, and mode (concluded).

Night Signal Identification Summary. Only at 2000 feet did the lower presence intensity produce higher signal identification than the 15 cd presence intensity. Presence intensity only affected signal identification at the lowest signal intensity. At 80 cd, the 4 cd presence intensity was better than 15 cd for turn and stop + turn in systems 1 and 4(2"). The 4 cd presence intensity would appear to be the more desirable intensity with systems not using well defined functional separation of presence lamps, or color coding.

The results from Table 5.11 indicate that, as the viewing distance increases, signal intensity decreases, and the signal modes are combined, the system using color coding and functional separation was superior even at the lowest signal intensity. System 1, the conventional system, was generally the least effective. Figure 5.14 shows that if system 1 is used, signal intensities of 185-425 cd should be used.

Night + Glare - Signal Identification. In this ambient condition only systems 1, 5(2") and 5(8") were used. Newman-Keuls tests were conducted on two significant interactions--system-separation and presence intensity; and system-separation, signal intensity, distance, and mode. The first interaction is analyzed in Tables 5.12 and 5.13.

TABLE 5.12. Newman-Keuls Tests of Signal Identification in the Night + Glare Condition Across System-Separation at Each Presence Intensity.

| Presence Intensity(cd) | System(s) | Resulted in Significantly Greater Mean Percentage Identification | Than System(s) |
|---|---|---|---|
| 4, 15 | 5(2"), 5(8") | " | 1 |

TABLE 5.13. Newman-Keuls Tests of Signal Identification in the Night + Glare Condition Across Presence Intensities for Each System-Separation.

| System(s) | Presence Intensity (cd) | Resulted in Significantly Greater Mean Percentage Identification | Than Presence Intensity (cd) |
|---|---|---|---|
| 1 | 4 | " | 15 |
| 5(2"), 5(8") | None | " | |

Under the night + glare condition system 5 at both separations was superior to system 1, regardless of presence intensity (Fig. 5.15). System 1 was more effective at 4 cd than at 15 cd.

The Newman-Keuls tests on the interaction of system-separation, signal intensity, distance, and mode are presented in Table 5.14.

Table 5.14 indicates that stop signal identification was generally significantly better with systems 5(2") and 5(8") than system 1 (Fig. 5.16). For turn signals there were no significant differences regardless of distance and signal intensity except at 2000 feet and 80 cd where systems 5(2") and 5(8") were more effective than system 1. For stop + turn, at 250 feet and all signal intensities, system 5 was superior to system 1. As the viewing distance increased to 1000 and 2000 feet, system 5 provided significantly better identification only at the lower signal intensities.

Night + Glare Signal Identification Summary. Regardless of mode or viewing distance, system 5 provided better identification than system 1. The advantage of system 5 usually decreased as signal intensity increased. Presence intensity had little effect on system 5, but 4 cd was more effective than 15 cd for system 1.

SUMMARY OF SIGNAL IDENTIFICATION ANALYSES. During the day the all red systems (1 and 2) produced the highest percent identification. Eight-inch lamp separation was better than two-inch separation.

TABLE 5.14. Newman-Keuls Tests of Signal Identification in the Night Glare Condition Across System-Separation at Each Mode, Distance, and Signal Intensity.

| Mode | Distance (ft) | Signal Intensity (cd) | System(s) | Resulted in Significantly Greater Mean Percentage Identification | Than System(s) |
|---|---|---|---|---|---|
| Stop | 250 | 80, 425, 1000 | 5(2"), 5(8") | " | 1 |
| " | " | 185 | 5(8") | " | 1 |
| " | 1000 | 185, 425 | None | " | |
| " | " | 80, 1000 | 5(2"), 5(8") | " | 1 |
| " | 2000 | 425 | None | " | |
| " | " | 80, 185 | 5(2"), 5(8") | " | 1 |
| " | " | 1000 | 5(2") | " | 1, 5(8") |
| Turn | 250, 1000 | All | None | " | |
| " | 2000 | 185, 425, 1000 | None | " | |
| " | " | 80 | 5(2"), 5(8") | " | 1 |
| Stop + Turn | 250 | All | 5(2"), 5(8") | " | 1 |
| " | 1000 | 425, 1000 | None | " | |
| " | " | 80 | 5(2"), 5(8") | " | 1 |
| " | " | 185 | 5(8") | " | 1 |
| " | 2000 | 1000 | None | " | |
| " | " | 80, 185 | 5(2"), 5(8") | " | 1 |
| " | " | 425 | 5(8") | " | 1 |

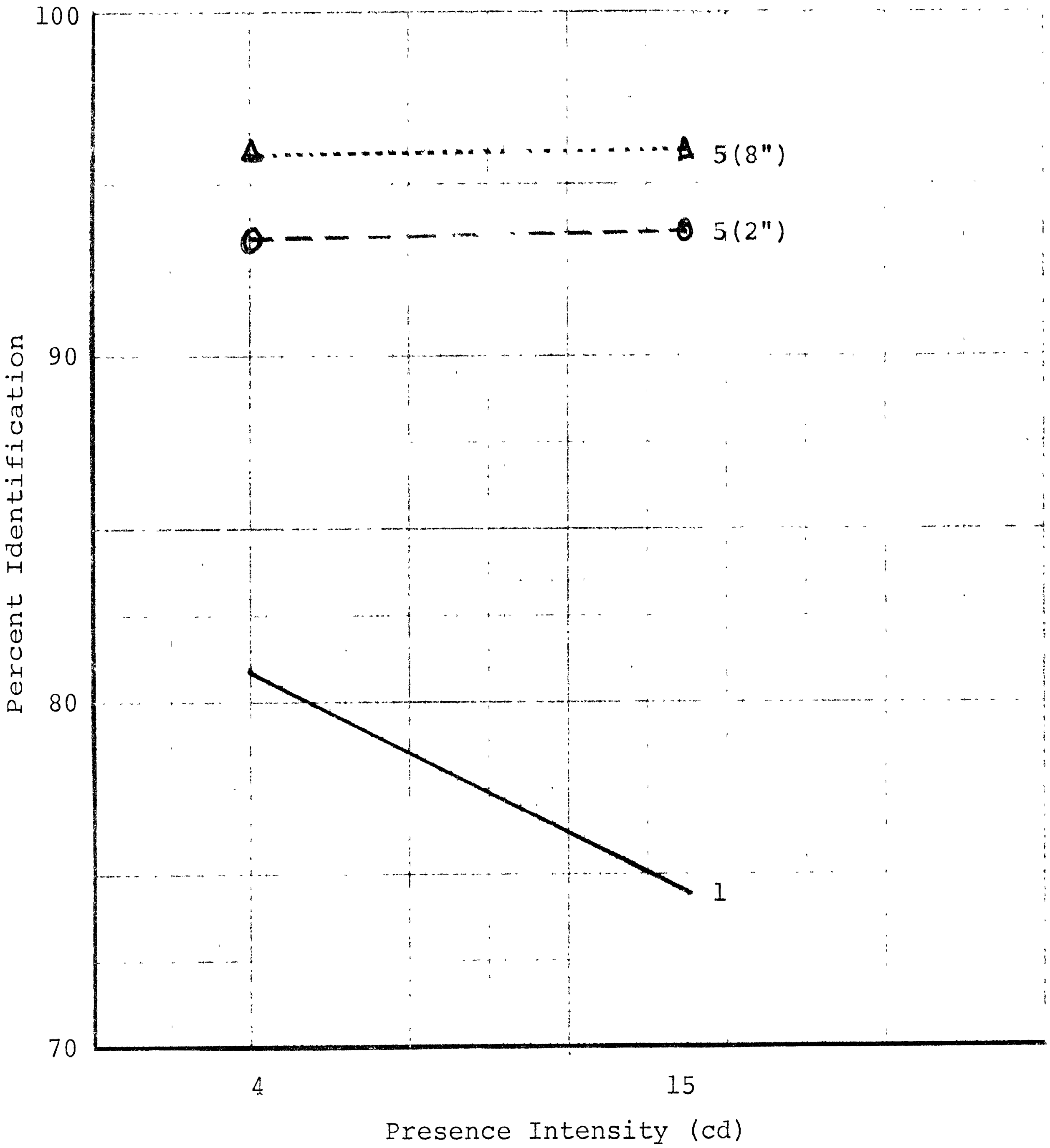



Figure 5 .15. Percent identification of night + glare signals as a function of system-separation and presence intensity.

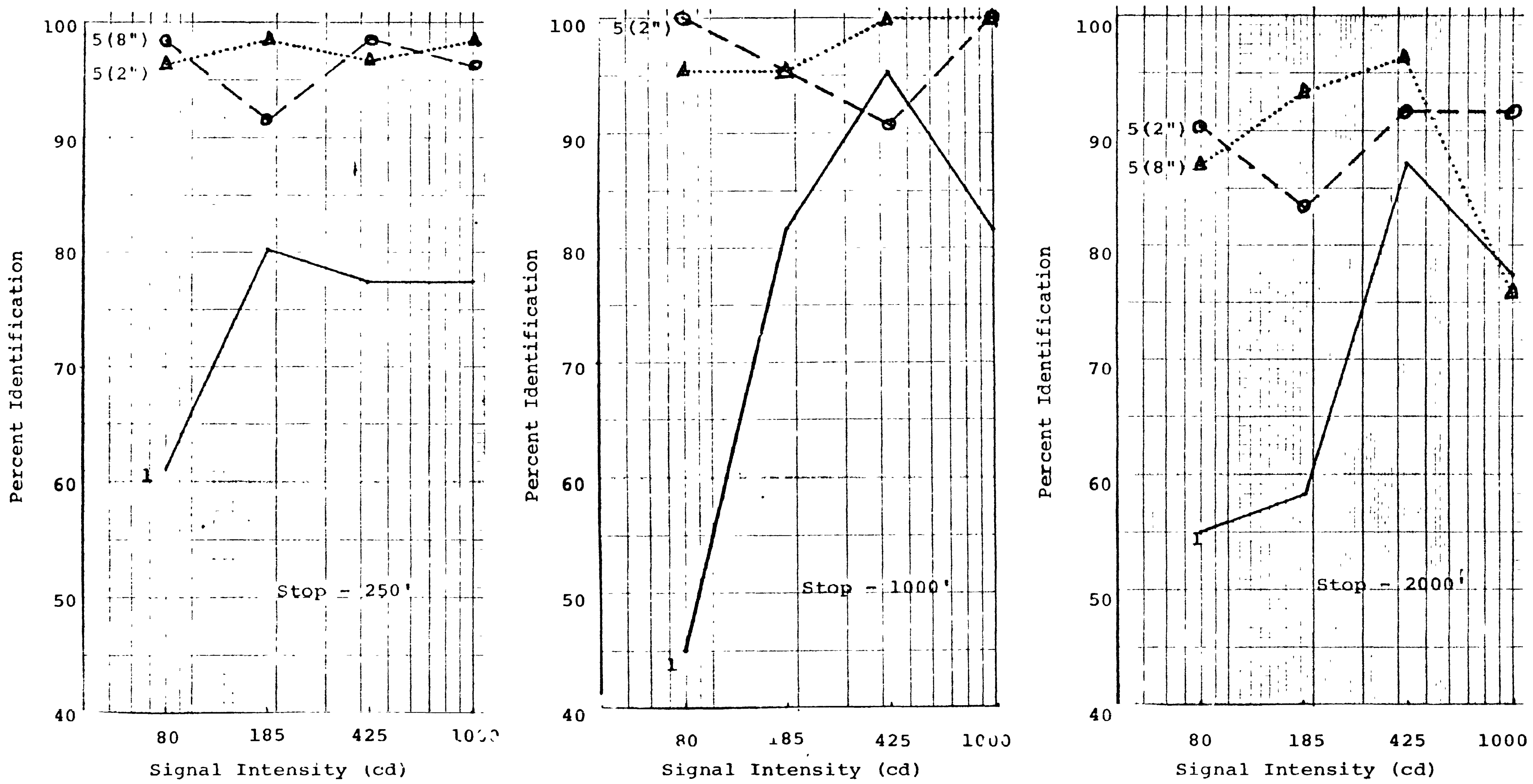



Figure 5.16. Percent identification of night glare (stop) signals as a function of system-separation, signal intensity, distance, and mode (continued).

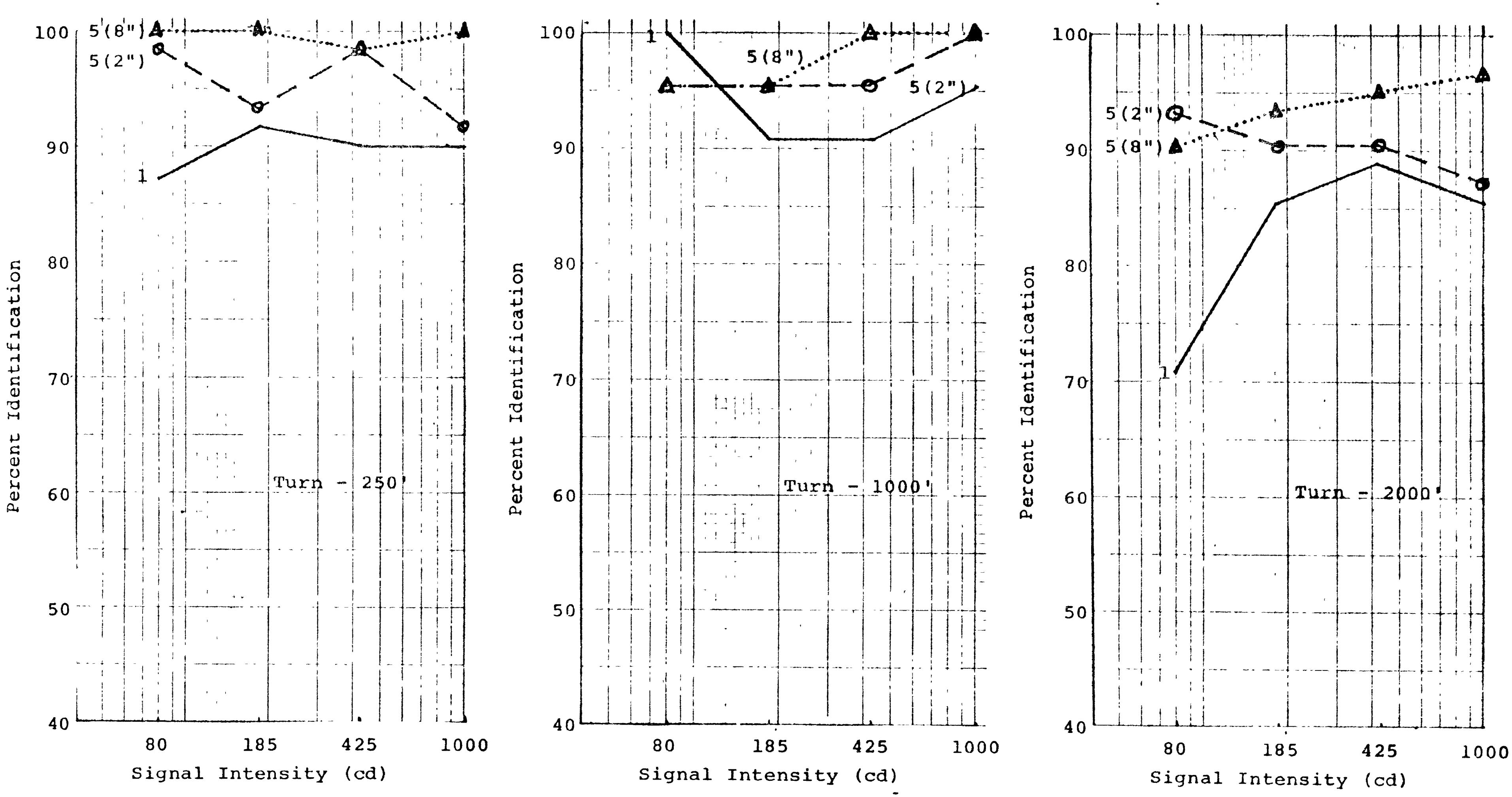



Figure 5.16. Percent identification of night glare (turn) signals as a function of system-separation, signal intensity, distance, and mode (continued).

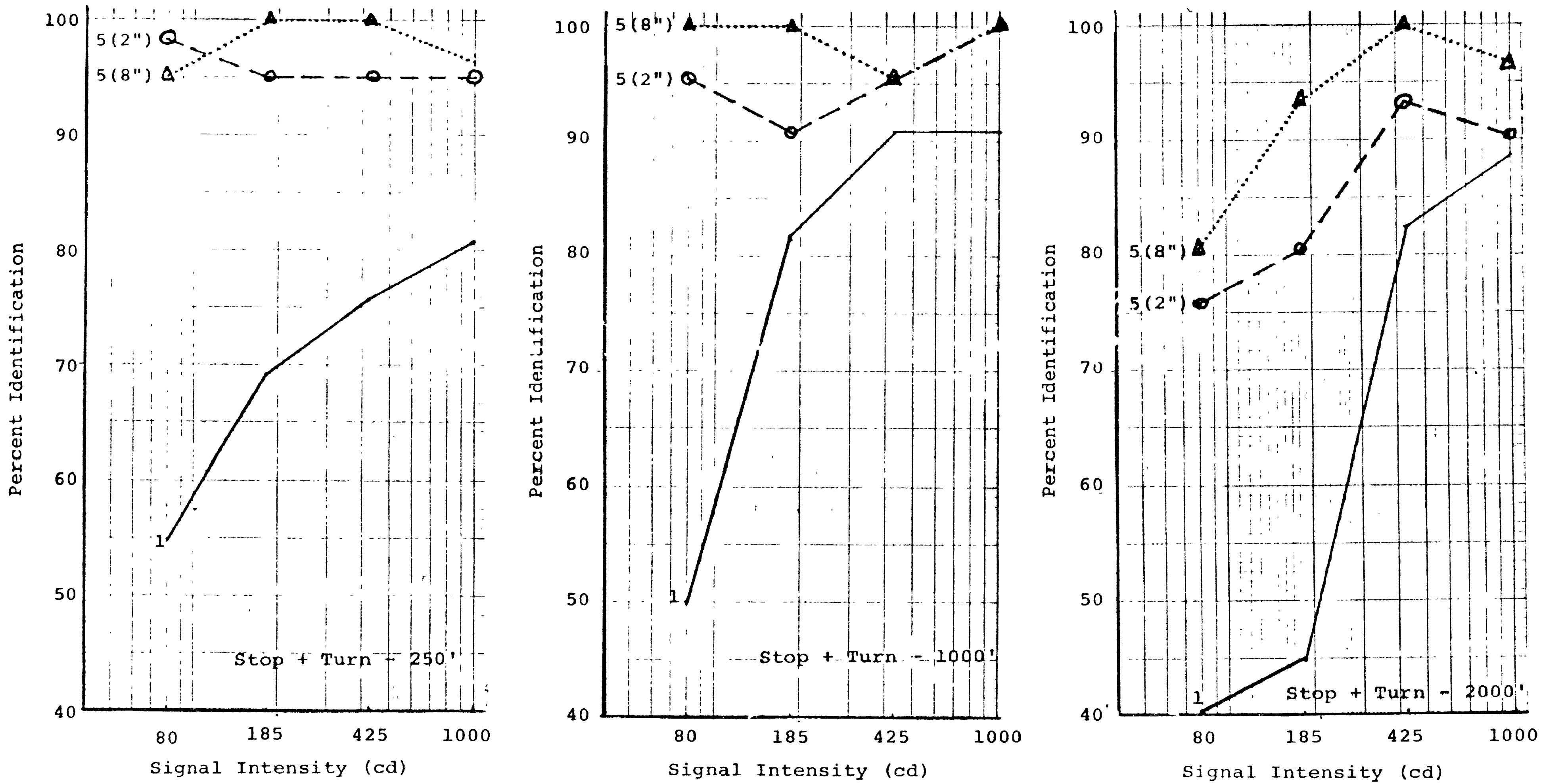



Figure 5.16. Percent identification of night glare (stop + turn) signals as a function of system-separation, signal intensity, distance, and mode (concluded).

At night and night + glare, identification of presence lights, when they were the only signal shown, decreased statistically significantly, but to a small extent quantitatively, as viewing distance increased to 2000 feet. The identification of presence signals was somewhat better for the color coded (green-blue presence lights) system 5 than those using only functional separation (System 4) and system 1, particularly at the 15 cd presence light intensity. The present lighting standard allows presence lights of up to 15 cd, which these data have shown can be confused with 80 cd stop signals, unless a color coding was used--or signals of at least 185 cd.

In the night and night + glare conditions the three-color system 5, especially with 8" lamp separation, was the most effective, with the conventional system 1 being significantly less effective in percent of signals identified in many conditions. The advantage of system 5(8") was most apparent under the more difficult viewing conditions. The lower presence intensity was better at 2000 feet and with 80 cd signal intensities in the night condition for systems 1 and 4(2"). Under the night + glare condition the lower presence intensity was more effective only for system 1. In both cases the lower presence intensity reduced confusions with signals. Comparison of the night and night + glare tests (Fig. 5.14 and 5.16) show that the identification of signals of system 5 was relatively unimpaired by the glare, whereas system 1 performance was degraded by the glare, particularly in the stop + turn mode.

Overall, the three-color system 5(8") appeared to be most effective in a given set of the night and night + glare conditions and would very likely be as effective during the day if the amber turn signals were of an adequate intensity.

In the night test, signal intensities of 185 cd are needed for systems 1 and 4 to provide adequate levels of signal identification, whereas 80 cd provided equivalent percent identification with system 5 (Fig. 5.14).

In the night + glare condition signal identification with system 1 was impaired compared to the no-glare test, as can be seen from Figures 5.11 and 5.15, whereas system 5 performance remained little affected by the glare from the headlamps.

While 80 cd provided good levels of signal identification for systems 5 in all modes and at all distances, system 1 required up to 425 cd for equivalent levels of identification in the stop and stop + turn modes.

SIGNAL BRIGHTNESS RATINGS. The ratings made by the subjects of the brightness of each of the signals and presence lights as presented in the day, night, and night + glare conditions, at each of the three viewing distances (250, 1000, and 2000 ft), at each of the two presence intensities (4 and 15 cd) and each of the four signal intensities (80, 185, 425 and 1000 cd) were evaluated for each of the system-separations (2", 8") by analyses of variance. Separate analyses of variance were made on the percent of "inadequate" (too dim) and on the "excessive" (too bright) responses made to each signal condition. Because the resulting significant interactions were not necessarily the same for the inadequate and excessive ratings Newman-Keuls tests were made directly on the highest order interaction of signal intensity, distance, system, mode, and ambient condition. Results were considered statistically significant if $P \leq .01$.

Analysis of Day Tests. The results of separate Newman-Keuls tests run on the inadequate and excessive ratings for stop signals (Fig. 5.17) in the day are shown in Table 5.15. There were no significant differences in brightness ratings among the systems.

TABLE 5 .15. Newman-Keuls Tests of Brightness Ratings for Stop Signals Presented During the Day, Across System-Separation for Each Signal Intensity and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|---|
| All | All | None | Inadequate | - |
| All | All | None | Excessive | - |

DAY - STOP

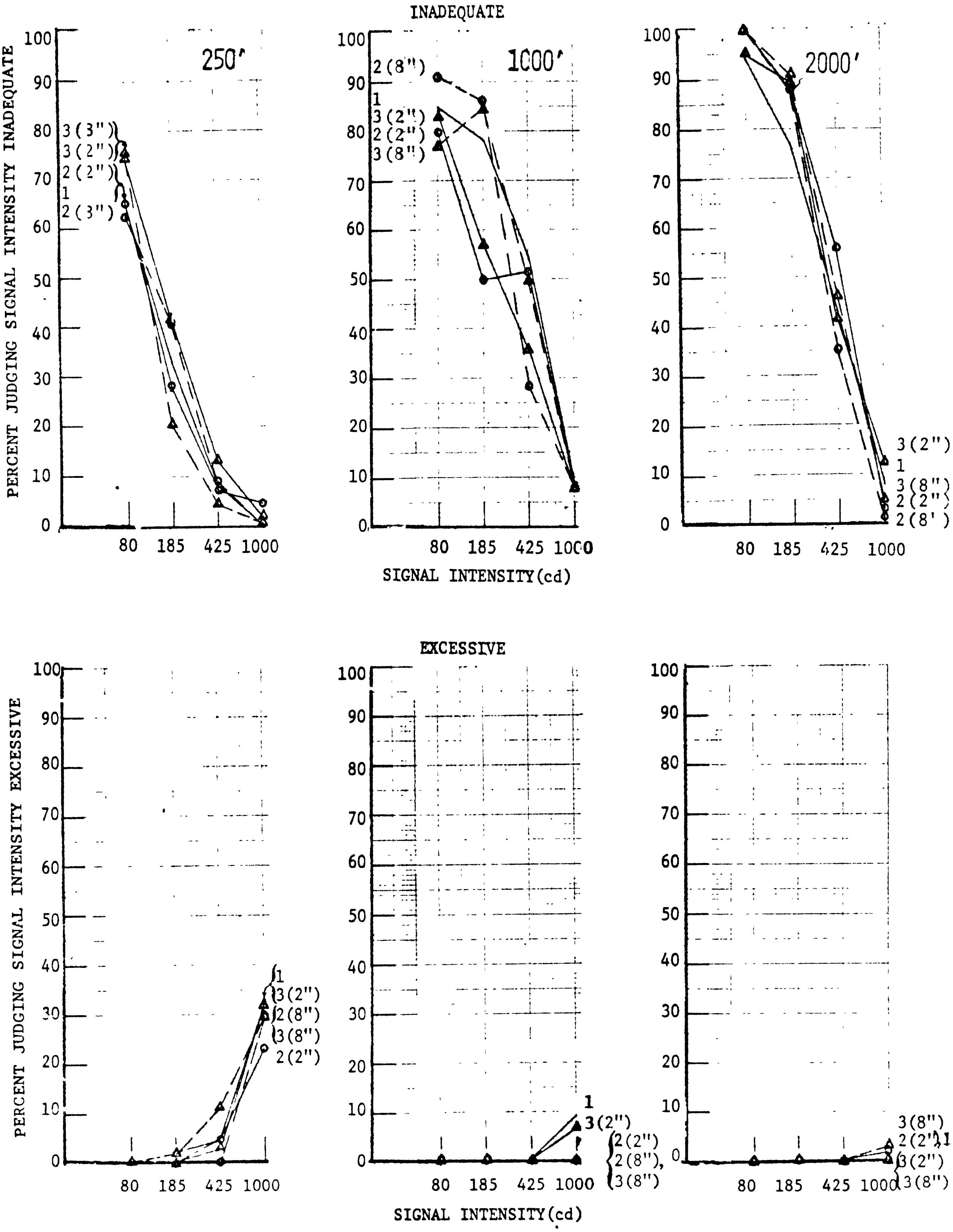



Figure 5.17. Percent inadequate and excessive ratings of stop signals in the day.

Newman-Keuls tests on the effect of stop signal intensity, in the day, are shown in Table 5.16.

TABLE 5.16. Newman-Keuls Tests of Brightness Ratings for Stop Signals in the Day. Across Signal Intensities for Each System-Separation and Distance.

| Distance (ft) | System(s) | Signal Intensity (cd) | Rated Significantly More Frequently | Than Signal Intensity (cd) |
|---|---|---|---|---|
| 250 | 1 | 80 | Inadequate | 425, 1000 |
| " | 2(2"), 3(8") | 80 | " | 185, 425, 1000 |
| " | 2(8"), 3(2") | 185 | " | 1000 |
| " | 2(8"), 3(2") | 80 | " | 425, 1000 |
| 1000 | 1, 2(2"), 3(8") | 80, 185, 425 | " | 1000 |
| " | 2(8") | 80, 185 | " | 425, 1000 |
| " | 3(2") | 185 | " | 1000 |
| " | 3(2") | 80 | " | 425, 1000 |
| 2000 | 1, 2(8"), 3(8") | 425 | " | 1000 |
| " | 1, 2(8") 3(8") | 80, 185 | " | 425, 1000 |
| " | 2(2") | 80, 185, 425 | " | 1000 |
| " | 2(2") | 80 | " | 425 |
| " | 3(2") | 80, 185 | " | 425, 1000 |
| All | All | None | Excessive | - |

At 250 feet and 1000 feet, 80 cd was almost always rated too dim significantly more frequently than 425 and 1000 cd for all systems. Thus, inadequate ratings decreased up to 425 cd (Fig. 5.17.

For all systems at 1000 feet, 185 cd was rated too dim significantly more frequently than 1000 cd, and 425 cd was too dim for systems 1, 2(2"), and 3(8"). At 2000 feet 80 and 185 cd were rated too dim significantly more frequently than 1000 cd, and 425 cd was too dim for all systems except 3(2"). No significant differences in excessive ratings occurred. Thus, in the day, stop signals would need to be over 185 cd for all systems to be of adequate brightness at only 250 feet and between 425 cd and 1000 cd for distances of 1000 feet or greater.

Newman-Keuls test results for turn signals are shown in Table 5.17, and the percent brightness ratings of inadequate and excessive are shown in Figure 5.18.

TABLE 5.17. Newman-Keuls Tests of Brightness Ratings for Turn Signals Presented Alone During the Day, Across System-Separations for Each Signal Intensity and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|---|
| 250 | 80, 1000 | None | Inadequate | |
| " | 185 | 3(2") | " | 1 |
| " | 425 | 3(2") | " | 1, 2(8") |
| 1000 | 80, 185, 1000 | None | " | |
| " | 425 | 1, 2(2"), 3(8") | " | 2(8") |
| 2000 | 80, 185, 425 | None | " | |
| " | 1000 | 3(2"), 3(8") | " | 2(2"), 2(8") |
| All | All | None | Excessive | |

## DAY - TURN

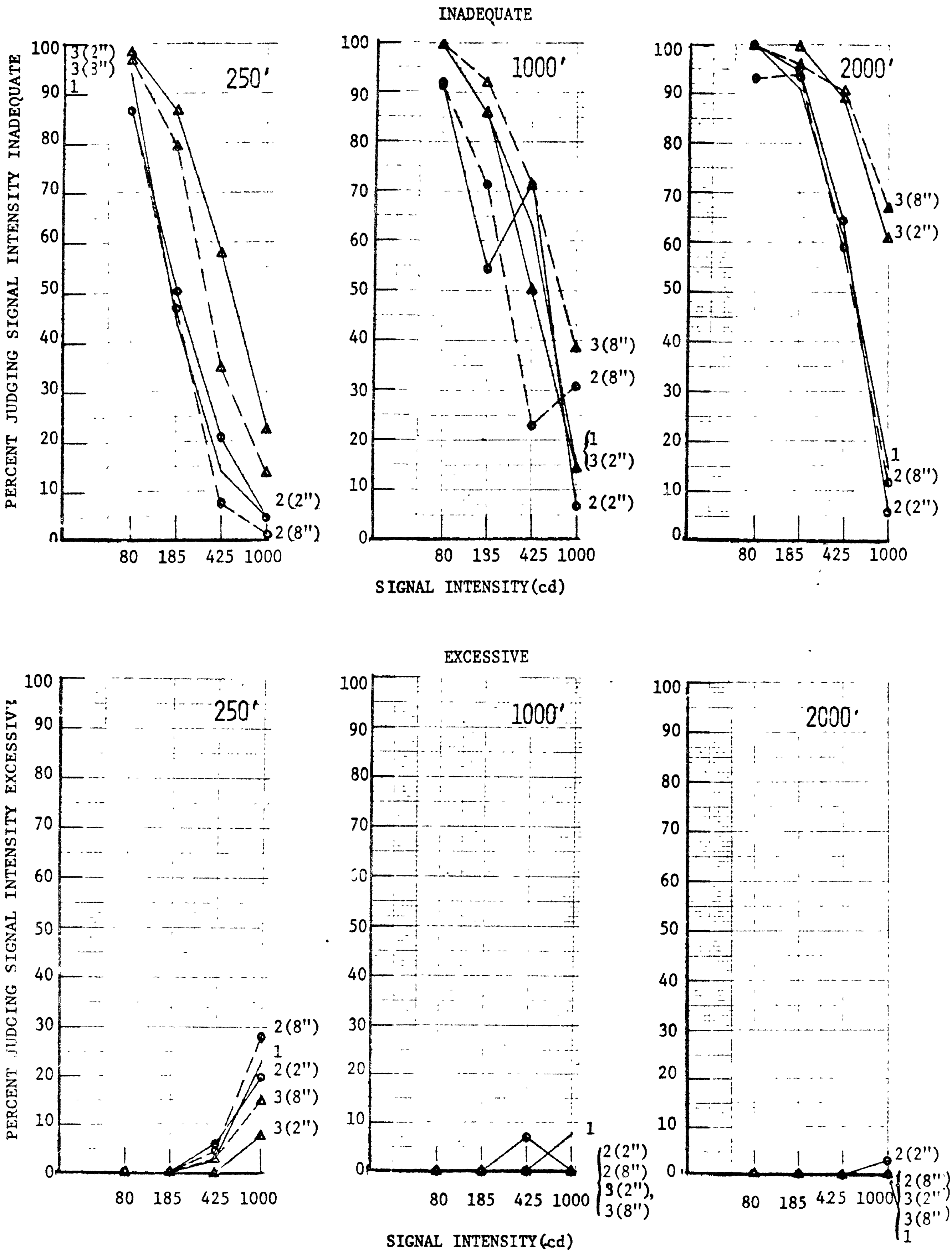



Figure 5.18. Percent inadequate and excessive ratings of turn signals in the day.

No significant differences in excessive ratings occurred. For inadequate ratings, at 80 cd there were no significant differences in the ratings of the systems, regardless of viewing distance. At 250 feet system 1 was significantly better (brighter) than system 3(2") at 185 and 425 cd. System 2(8") was also better at 425 cd. At 1000 feet the only significant differences occurred at 425 cd where system 2(8") was rated inadequate significantly less than systems 1, 2(2"), and 3(8"). At 2000 feet no significant differences occurred between systems at 80, 185, and 425 cd; but at 1000 cd system 2 were better than system 3.

Table 5.18 indicates the Newman-Keuls test results for turn

TABLE 5.18. Newman-Keuls Tests of Brightness Ratings for Turn Signals Presented Alone During the Day, Across Signal Intensities for Each System-Separation and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than Signal Intensity (cd) |
|---|---|---|---|---|
| 250 | 80 | 1, 2(2") | Inadequate | 185, 425, 1000 |
| " | 185 | " | " | " |
| " | 80, 185, 425 | 3(2") | " | " |
| " | 80 | " | " | 425 |
| " | 80, 185 | 2(8") | " | 425, 1000 |
| " | 80 | " | " | 185 |
| " | 80, 185 | 3(8") | " | 425, 1000 |
| 1000 | 80, 185, 425 | 1, 3(8") | " | 1000 |
| " | 80, 185, 425 | 2(2") | " | " |
| " | 80 | " | " | 185 |
| " | 80, 185, 425 | 3(2") | " | 1000 |
| " | 80, 185 | " | " | 425 |
| " | 80, 185 | 2(8") | " | 425, 1000 |
| 2000 | None | 3(2"), 3(8") | " | |
| " | 80, 185, 425 | 2(2"), 2(8") | " | 1000 |
| " | 80, 185, 425 | 1 | " | " |
| " | 80 | 1 | " | 425 |
| All | None | All | Excessive | |

signals, in the day, across signal intensities. At 250 feet 80 cd was always rated too dim when compared with 1000 cd. Other significant differences were highly dependent on the system-separation involved. At 1000 feet all signal intensities were too dim compared with 1000 cd except for system 2(8") where 425 cd was not rated less dim than 1000 cd. At 2000 feet there were no significant differences between signal intensities for system 3, which was rated as inadequate by over 60% of respondents even at 1000 cd. For the other systems all signal intensities were too dim compared with 1000 cd. No significant differences in excessive ratings occurred.

The results of the Newman-Keuls tests across systems for the stop signal when presented with a turn signal are shown in Table 5.19, and the percent brightness ratings of inadequate and excessive are shown in Figure 5.19. The only significant differences

TABLE 5.19. Newman-Keuls Tests of Brightness Ratings for Stop Signals Presented with Turn Signals During the Day, Across System-Separations for Each Signal Intensity and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|---|
| 250, 2000 | All | None | Inadequate | |
| 1000 | 425, 1000 | None | " | |
| " | 80 | 2(2"), 2(8"), 3(8") | " | 3(2") |
| " | 185 | 1, 3(8") | " | 2(2"), 2(8"), 3(2") |
| All | All | None | Excessive | |

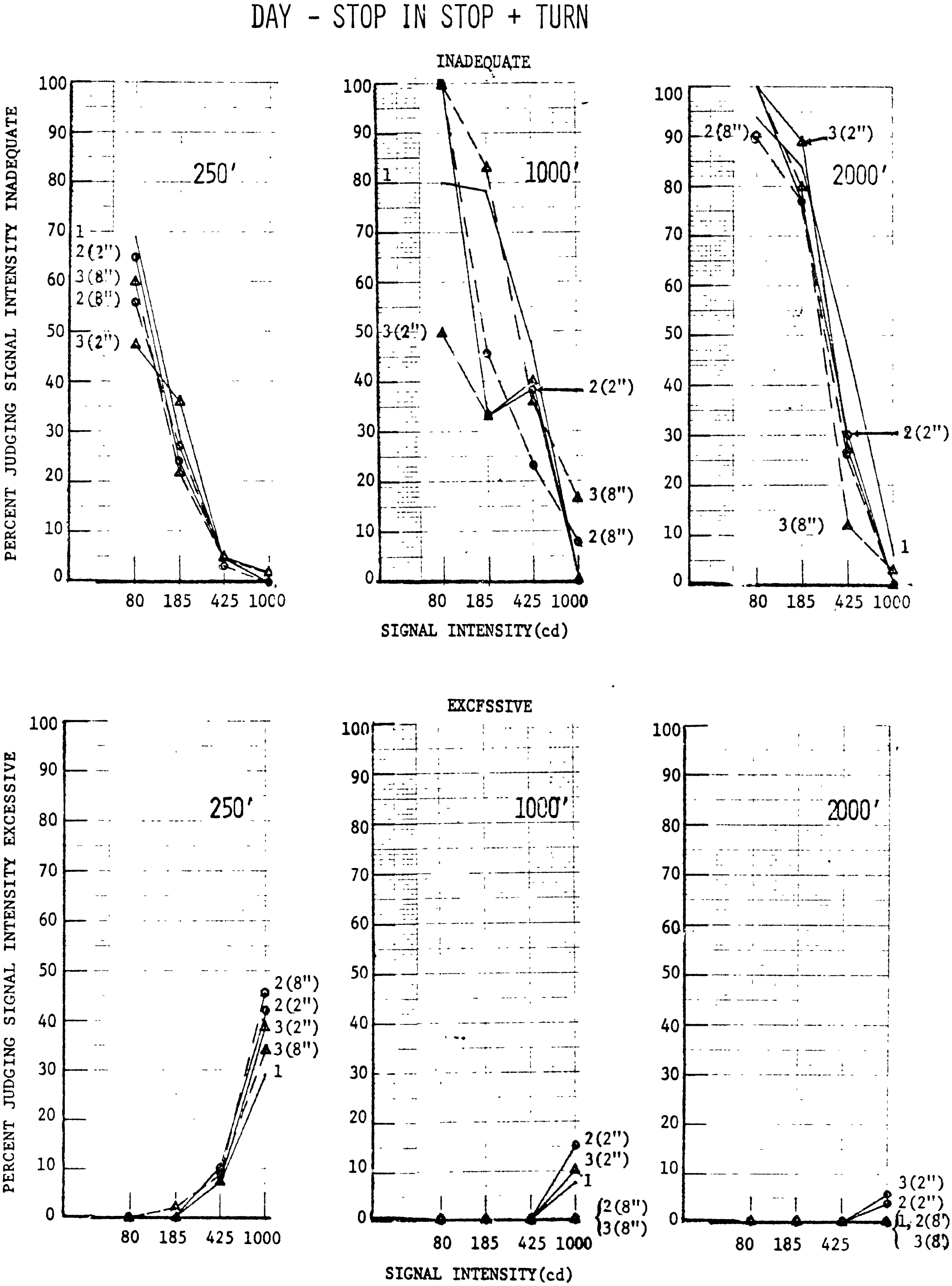



Figure 5.19. Percent inadequate and excessive ratings of stop in stop + turn signals in the day.

in systems occurred at 1000 feet. At 80 cd systems 2(2"), 2(8"), and 3(8") were rated too dim significantly more frequently than system 3(2"). At 185 cd systems 2(2"), 2(8"), and 3(2") were better than systems 1 and 3(8"). No significant differences in excessive ratings occurred.

For stop signals presented with turn signals during the day, the Newman-Keuls test results across signal intensities are presented in Table 5.20

TABLE 5.20. Newman-Keuls Tests of Brightness Ratings for Stop Signals Presented with Turn Signals During the Day, Across Signal Intensities for Each System-Separation and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than Signal Intensity (cd) |
|---|---|---|---|---|
| 250 | 80 | 1, 2(2"), 3(8") | Inadequate | 185, 425, 1000 |
| " | 80 | 2(8"), 3(2") | " | 425, 1000 |
| 1000 | 80, 185, 425 | 1, 3(2") | " | 1000 |
| " | 80, 185, 425 | 2(2") | " | " |
| " | 80 | " | " | 185, 425 |
| " | 80 | 2(8") | " | 185, 425, 1000 |
| " | 185 | " | " | 1000 |
| " | 80, 185 | 3(8") | " | 425, 1000 |
| 2000 | 80, 185, 425 | 1 | " | 1000 |
| " | 80, 185 | " | " | 425 |
| " | 80, 185 | 2(2"), 2(8"), 3(2"), 3(8") | " | 425, 1000 |
| 250 | None | 1 | Excessive | |
| " | 1000 | 2(2"), 2(8"), 3(2") | " | 80, 185, 425 |
| " | 1000 | 3(8") | " | 80, 185 |
| 1000, 2000 | None | All | " | |

Thus, 80 cd was found too dim for all systems at 250 feet. At 1000 feet 80, 185, and 425 cd were rated too dim for systems 1, 2(2"), 3(2") more often than 1000 cd. For systems 2(8") and 3(8"), 80 cd and 185 cd were too dim. At 2000 feet 80 and 185 cd were too dim for all systems and 425 cd was too dim for system 1. At 250 feet 1000 cd was considered too bright for all but system 1. No significant differences in brightness ratings occurred at other distances.

Newman-Keuls results across systems for turn, presented with stop, are in Table 5.21, and the percent of inadequate and excessive ratings are shown in Figure 5.20. At 250 feet, only at 185

TABLE 5.21. Newman-Keuls Tests of Brightness Ratings for Turn Signals, in Stop + Turn Signals, in the Day, Across System-Separations for Each Signal Intensity and Distance.

| Distance(ft) | Signal Intensity(cd) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|---|
| 250 | 80, 425, 1000 | None | Inadequate | |
| " | 185 | 3(2") | " | 1, 2(2"), 2(8") |
| " | 185 | 3(8") | " | 2(8") |
| 1000 | 425 | None | " | |
| " | 80 | 2(2"), 2(8"), 3(8") | " | 3(2") |
| " | 185 | 2(2"), 3(8") | " | 2(8") |
| " | 1000 | 3(2") | " | 1, 3(8") |
| 2000 | 80, 185 | None | " | |
| " | 425 | 3(2") | " | 1, 2(8") |
| " | 1000 | 3(8") | " | 1 |
| " | " | 3(2") | " | 1, 2(8") |
| All | All | None | Excessive | |

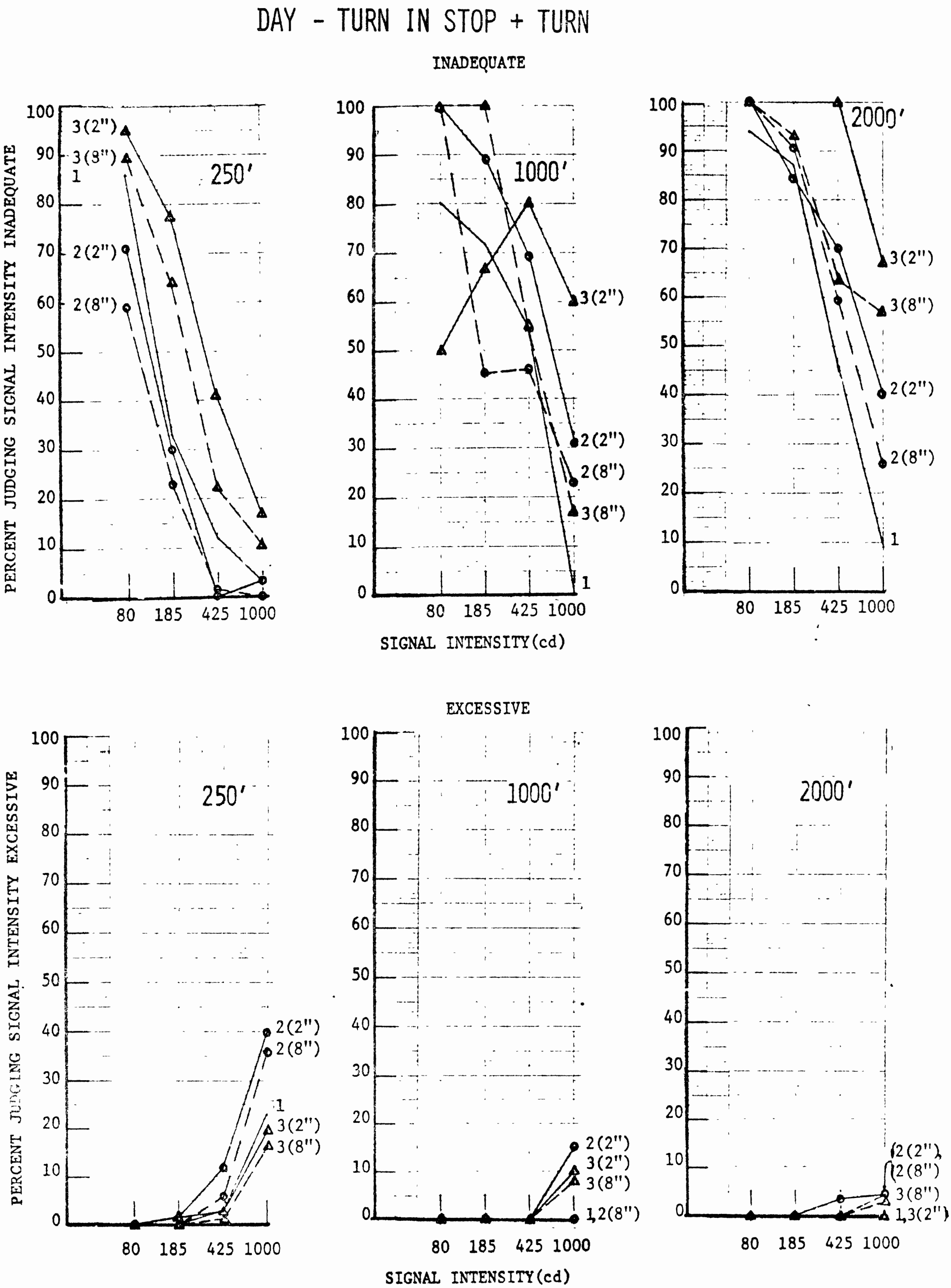



Figure 5.20. Percent inadequate and excessive ratings of turn in stop + turn signals in the day.

cd were there significant differences with system 3 usually being judged too dim more frequently than system 2(8"). At 1000 feet, significant differences occurred at all but 425 cd. No one system was consistently better or worse than another over the range of signal intensities, suggesting variability in the data due to the fewer subjects used at this distance than 250 or 2000 feet. Systems 1 and 2(8") were significantly more effective at 2000 feet than system 3(2") at 425 and 1000 cd. No significant differences in excessive ratings occurred.

Newman-Keuls test results across signal intensities for turn signals presented during the day with stop signals are shown in Table 5.22.

Table 5.22 indicates that 80 cd was rated too dim than greater intensities for all systems at 250 feet, and that 185 cd was too dim for system 3. At 1000 feet there were no significant differences due to intensity for system 3(2"), but these data should best be ignored as their behavior is unusual (Fig. 5.20). Intensities up to 425 cd were rated too dim significantly more often than 1000 cd for all systems. At 2000 feet, no significant improvement occurred for system 3(2") as intensity was increased, and the other system using amber turn signals, 3(8"), was rated consistently inadequate. For all other systems, up to 1000 cd would be required for adequate brightness. At 250 feet, system 2 at 1000 cd was rated significantly more frequently as excessively bright than lower intensities.

<u>Summary of Results - Day Condition</u>. For stop signals, presented alone or in the stop + turn mode, system-separation had no significant effect on brightness ratings. Eighty and 185 cd were too dim for almost all systems at all distances. More than 425 cd would be needed at 2000 feet.

The red turn signals in systems 2 and 1 required lower intensities for equivalent ratings than the amber turn signal in system 3.

TABLE 5.22. Newman-Keuls Tests of Brightness Ratings for Turn Signals, in Stop + Turn Signals, in the Day, Across Signal Intensities for Each System-Separation and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than Signal Intensity (cd) |
|---|---|---|---|---|
| 250 | 80 | 1,2(2"), 2(8") | Inadequate | 185, 425, 1000 |
| " | 80,185 | 3(2"), 3(8") | " | 425, 1000 |
| 1000 | None | 3(2") | " | |
| " | 80, 185, 425 | 1, 2(2") | " | 1000 |
| " | 80 | 2(8") | " | 185, 425, 1000 |
| " | 80, 185, 425 | 3(8") | " | 1000 |
| " | 80, 185 | " | " | 425 |
| 2000 | None | 3(2") | " | |
| " | 80 | 3(8") | " | 1000 |
| " | 80, 185 | 2(2") | " | 1000 |
| " | 80, 185, 425 | 2(8") | " | 1000 |
| " | 80 | " | " | 425 |
| " | 80, 185, 425 | 1 | " | 1000 |
| " | 80, 185 | " | " | 425 |
| 250 | None | 1, 3(2"), 3(8") | Excessive | |
| " | 1000 | 2(2"), 2(8") | " | 80, 185, 425 |
| 1000, 2000 | None | All | " | |

Up to 425 cd was needed by the most satisfactory systems at 250 feet, and up to 1000 cd at 2000 feet. Quite similar results were found for the ratings of the turn signal when presented alone as in the stop + turn mode.

For all signal presentations during the day a stop signal intensity of up to 425 cd, and turn signal intensities up to 1000 cd, particularly for amber signals, would appear to be desirable. Other differences between system characteristics did not appear to be of much importance in affecting the ratings.

Analysis of Night Tests. Results of Newman-Keuls tests on brightness ratings (Fig. 5.21) for stop signals in the night are shown in Table 5.23. No significant differences between systems in inadequate brightness ratings occurred. Intensities between 80 cd and 185 cd provided adequate signal brightness under all conditions. However, at 250 feet and 185 cd system 5(8") was considered too bright significantly more frequently than system 1. At 425 cd systems 4(8"), 5(2") and 5(8") were rated too bright more often than system 1, and at 1000 cd systems 5(2") and 5(8") were rated too bright more often than systems 1 and 4(2").

TABLE 5.23. Newman-Keuls Tests of Brightness Ratings for Stop Signals in the Night, Across System-Separation for Each Signal Intensity and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|---|
| All | All | None | Inadequate | |
| 1000, 2000 | All | None | Excessive | |
| 250 | 80 | None | " | |
| " | 185 | 5(8") | " | 1 |
| " | 425 | 4(8"), 5(2"), 5(8") | " | 1 |
| " | 1000 | 5(2"), 5(8") | " | 1, 4(2") |

NIGHT - STOP

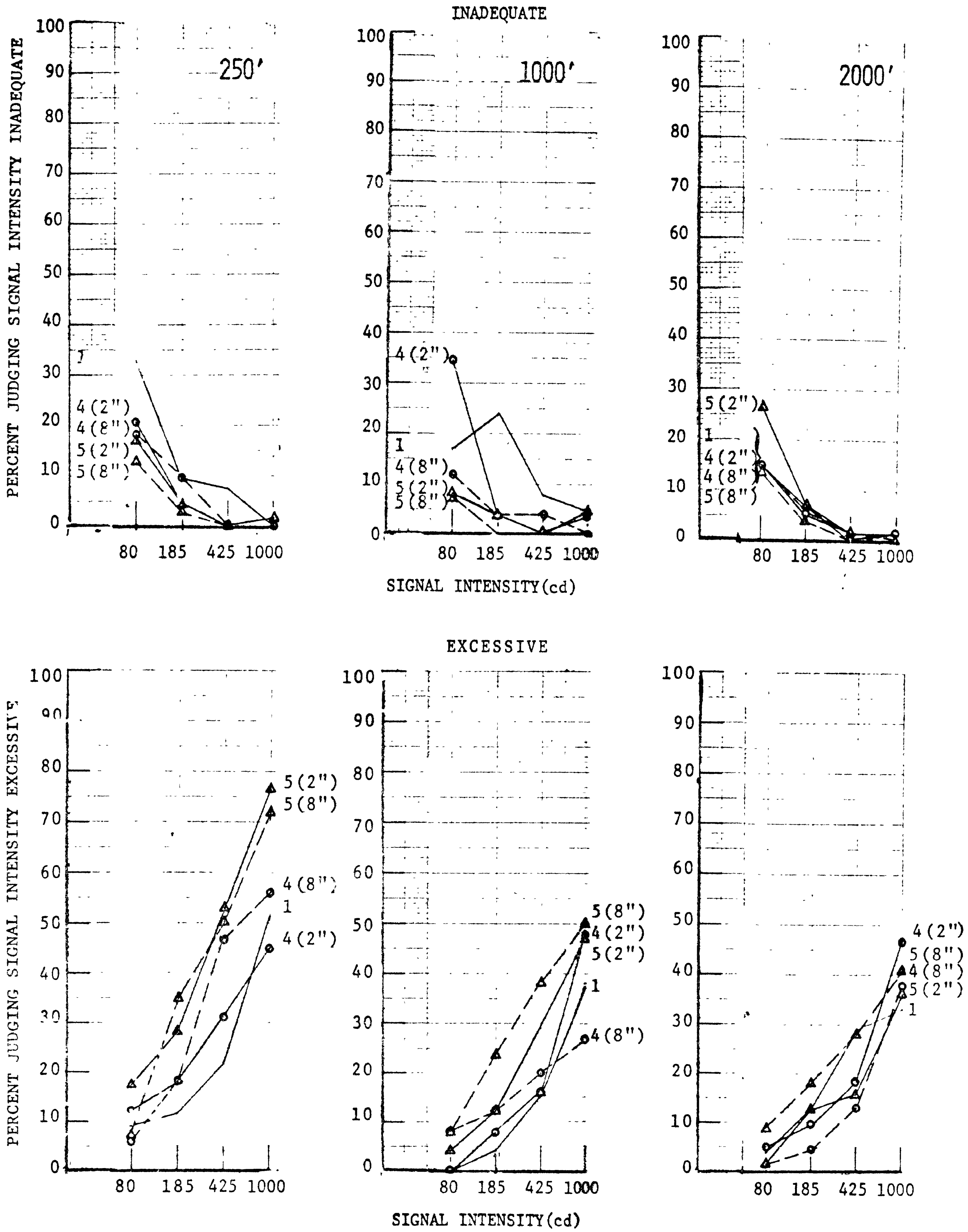



Figure 5.21. Percent inadequate and excessive ratings of stop signals in the night.

A comparison across signal intensities for the stop signal is presented in Table 5.24.

TABLE 5.24. Newman-Keuls Tests of Brightness Ratings for Stop Signals in the Night, Across Signal Intensities for Each System-Separation and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than Signal Intensity (cd) |
|---|---|---|---|---|
| 250 | None | 4(2"), 4(8"), 5(2"), 5(8") | Inadequate | |
| " | 80 | 1 | " | 1000 |
| 1000 | None | 1, 4(8"), 5(2"), 5(8") | " | |
| " | 80 | 4(2") | " | 185, 425, 1000 |
| 2000 | None | All | " | |
| 250 | 1000 | 1 | Excessive | 80, 185, 425 |
| " | " | 4(2") | " | 80, 185 |
| " | 425, 1000 | 4(8") | " | 80, 185 |
| " | 425 | 5(2") | " | 80, 185 |
| " | 1000 | " | " | 80, 185, 425 |
| " | 185, 425, 1000 | 5(8") | " | 80 |
| " | 1000 | " | " | 185, 425 |
| 1000 | None | 4(8") | " | |
| " | 1000 | 1, 4(2"), 5(2") | " | 80, 185, 425 |
| " | 425 | 5(8") | " | 80 |
| " | 1000 | " | " | 80, 185 |
| 2000 | 1000 | 4(2"), 4(8"), 5(2") | " | 80, 185, 425 |
| " | 425 | 1 | " | 80 |
| " | 1000 | 1 | " | 80, 185 |
| " | 1000 | 5(8") | " | 80, 185 |

For the inadequate brightness ratings at 250 feet there were no significant differences due to signal intensity for all systems except system 1 where 80 cd was too dim. At 1000 feet 80 cd was too dim only for system 4(2"). At 2000 feet there were no significant differences in inadequate brightness ratings. Thus, 80 cd was generally rated adequately bright for all systems.

The frequency of excessive brightness ratings increased sharply with intensity, particularly as functional separation and color coding of presence lights was used. Increases of intensity above 80 cd for system 5, above 185 cd for system 2 and above 425 cd for system 1 significantly increased excessive brightness responses. In general the converse was true of inadequate brightness ratings, as would be expected.

The Newman-Keuls tests for inadequate and excessive brightness ratings for turn signals (Fig. 5.22) are shown in Tables 5.25 and 5.26.

From Table 5.25, only at 80 cd and 250 feet was there a significant difference between systems in inadequate ratings with systems 1, 4(2"), and 4(8") being rated more often as too dim. Excessive ratings were more plentiful with 1000 cd too bright more frequently for systems 5(2") and 5(8") at 250 feet. At 1000 feet the amber turn signal of system 5(8") was rated too bright more often than others except at 80 cd. From 2000 feet system 4(2") was rated brighter than 4(8") at 1000 cd. No other differences between systems were significant.

In Table 5.26, 80 cd was found too dim for systems 1, 4(2"), and 4(8") at all distances and too dim for system 5(2") at 1000 feet than greater intensities. For all systems 425 cd and 1000 cd were rated too bright significantly more often than lower intensities at 250 feet. At 1000 feet 1000 cd was too bright for all systems, 425 cd was too bright for systems 1, 4(2"), 5(2"), and 185 cd was too bright for system 5(8") than lower intensities.

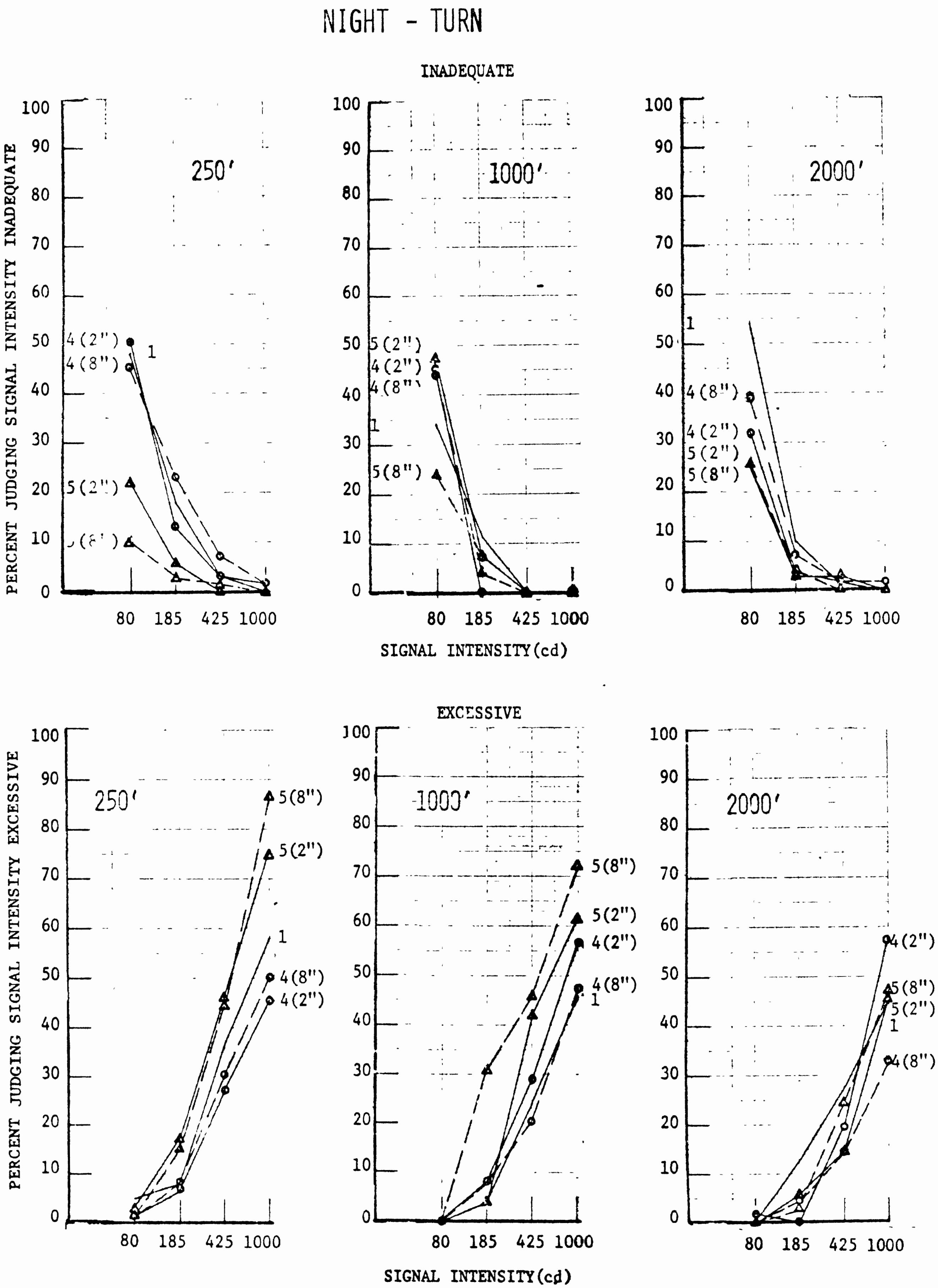



Figure 5.22. Percent inadequate and excessive ratings of turn signals in the night.

At 2000 feet 1000 cd was too bright for all systems and 425 cd was too bright for systems 1 and 5(8").

TABLE 5.25. Newman-Keuls Tests of Brightness Ratings for Turn Signals in the Night, Across System-Separations for Each Signal Intensity and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|---|
| 250 | 185, 425, 1000 | None | Inadequate | |
| " | 80 | 1, 4(2"), 4(8") | " | 5(2"), 5(8") |
| 1000, 2000 | All | None | " | |
| | | | | |
| 250 | 80, 185, 425 | None | Excessive | |
| " | 1000 | 5(2") | " | 4(2"), 4(8") |
| " | " | 5(8") | " | 1, 4(2"), 4(8") |
| 1000 | 80 | None | " | |
| " | 185 | 5(8") | " | 1, 4(2"), 4(8"), 5(2") |
| " | 425 | 5(8") | " | 4(8") |
| " | 1000 | 5(8") | " | 1, 4(8") |
| 2000 | 80, 185, 425 | None | " | |
| " | 1000 | 4(2") | " | 4(8") |

TABLE 5.26. Newman-Keuls Tests of Brightness Ratings for Turn Signals in the Night, Across Signal Intensities for Each System-Separation and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than Signal Intensity (cd) |
|---|---|---|---|---|
| 250 | None | 5(2"), 5(8") | Inadequate | |
| " | 80 | 1, 4(2") | " | 185, 425, 1000 |
| " | 80 | 4(8") | " | 425, 1000 |
| 1000 | None | 5(8") | " | |
| " | 80 | 1 | " | 425, 1000 |
| " | 80 | 4(2"), 4(8"), 5(2") | " | 185, 425, 1000 |
| 2000 | None | 5(2"), 5(8") | " | |
| " | 80 | 1, 4(2"), 4(8") | " | 185, 425, 1000 |
| 250 | 425, 1000 | 4(2") | Excessive | 80, 185 |
| " | 425 | 1, 4(8"), 5(2"), 5(8") | " | 80, 185 |
| " | 1000 | 1, 4(8"), 5(2"), 5(8") | " | 80, 185, 425 |
| 1000 | 1000 | 4(8") | " | 80, 185, 425 |
| " | 425 | 1, 4(2"), 5(2") | " | 80, 185 |
| " | 1000 | 1, 4(2"), 5(2") | " | 80, 185, 425 |
| " | 185, 425 | 5(8") | " | 80 |
| " | 1000 | " | " | 80, 185, 425 |
| 2000 | 425 | 1 | " | 80 |
| " | 1000 | 1 | " | 80, 185 |
| " | 1000 | 4(2"), 4(8"), 5(2") | " | 80, 185, 425 |
| " | 425 | 5(8") | " | 80, 185 |
| " | 1000 | " | " | 80, 185, 425 |

The results for stop signals in stop + turn signals, are shown in Figure 5.23 and Newman-Keuls tests in Tables 5.27 and 5.28.

TABLE 5.27. Newman-Keuls Tests of Brightness Ratings for Stop Signals in Stop + Turn Signals in the Night, Across System-Separations for Each Signal Intensity and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|---|
| All | All | None | Inadequate | |
| 250 | 80, 185, 425 | None | Excessive | |
| " | 1000 | 5(2") | " | 4(2") |
| | | 5(8") | " | 1, 4(2") |
| 1000 | 80, 185 | None | " | |
| " | 425 | 4(8") | " | 1 |
| " | 425 | 5(8") | " | 1, 5(2") |
| " | 1000 | 5(8") | " | 1 |
| 2000 | All | None | " | |

There were no significant differences between systems or between signal intensities in inadequate ratings which were uniformly low (Fig. 5.23). At 250 feet excessive ratings across system-separation, for systems 5(2") and 5(8") were more frequent at 1000 cd than at lower intensities. At 1000 feet system 5(8") was too bright at 425 and 1000 cd and system 4(8") was too bright at 425 cd. At 2000 feet there were no significant differences among systems at all signal intensities. Across signal intensities 1000 cd was too bright at all distances and for all systems. Four hundred and twenty five cd was too bright for all systems except 1 at all distances, 185 cd was too bright for system 5(8") at 250 feet, system 5(2") and 5(8") at 1000 feet, and system 5(8") at 2000 feet.

# NIGHT - STOP IN STOP + TURN

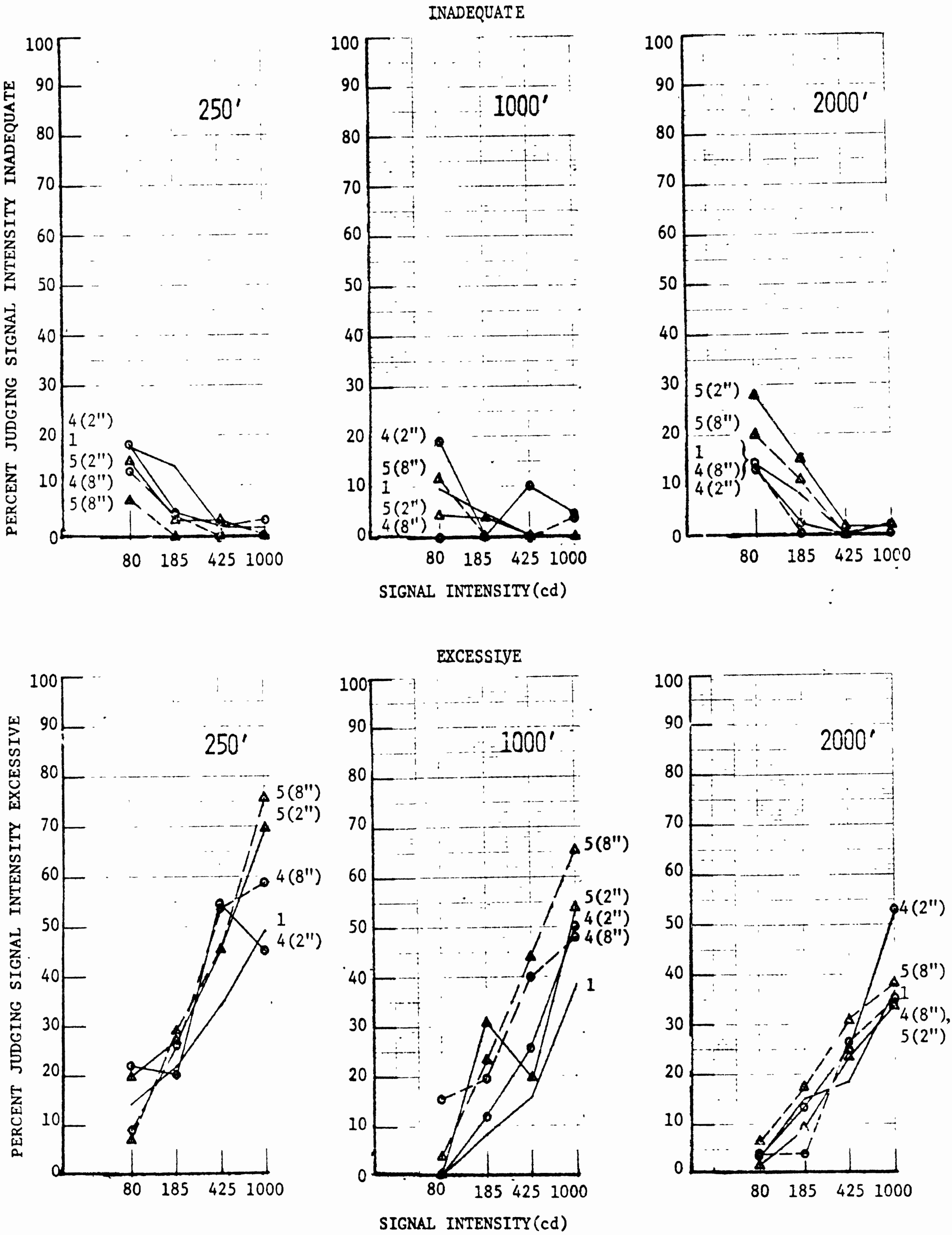



Figure 5.23. Percent inadequate and excessive ratings of stop signals in stop + turn in the night.

TABLE 5.28. Newman-Keuls Tests of Brightness Ratings for Stop Signals in Stop + Turn Signals in the Night, Across Signal Intensities for Each System-Separation and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than Signal Intensity (cd) |
|---|---|---|---|---|
| All | None | All | Inadequate | |
| 250 | 1000 | 1 | Excessive | 80, 185 |
| " | 425, 1000 | 4(2"), 4(8") | " | 80, 185 |
| " | 425, 1000 | 5(2") | " | 80, 185 |
| " | 1000 | " | " | 80, 185, 425 |
| " | 185, 425 | 5(8") | " | 80 |
| " | 1000 | " | " | 80, 185, 425 |
| 1000 | 1000 | 1 | " | 80, 185, 425 |
| " | 425 | 4(2") | " | 80 |
| " | 1000 | " | " | 80, 185, 425 |
| " | 425, 1000 | 4(8") | " | 80, 185 |
| " | 185, 425 | 5(2") | " | 80 |
| " | 1000 | " | " | 80, 185, 425 |
| " | 1000 | 5(8") | " | 80, 185, 425 |
| " | 425 | " | " | 80, 185 |
| " | 185 | " | " | 80 |
| 2000 | 1000 | 1 | " | 80, 185 |
| " | 425 | 4(2") | " | 80 |
| " | 1000 | " | " | 80, 185, 425 |
| " | 425, 1000 | 4(8") | " | 80, 185 |
| " | 425 | 5(2") | " | 80, 185 |
| " | 1000 | " | " | 80, 185, 425 |
| " | 185, 425 | 5(8") | " | 80 |
| " | 1000 | " | " | 80, 185, 425 |

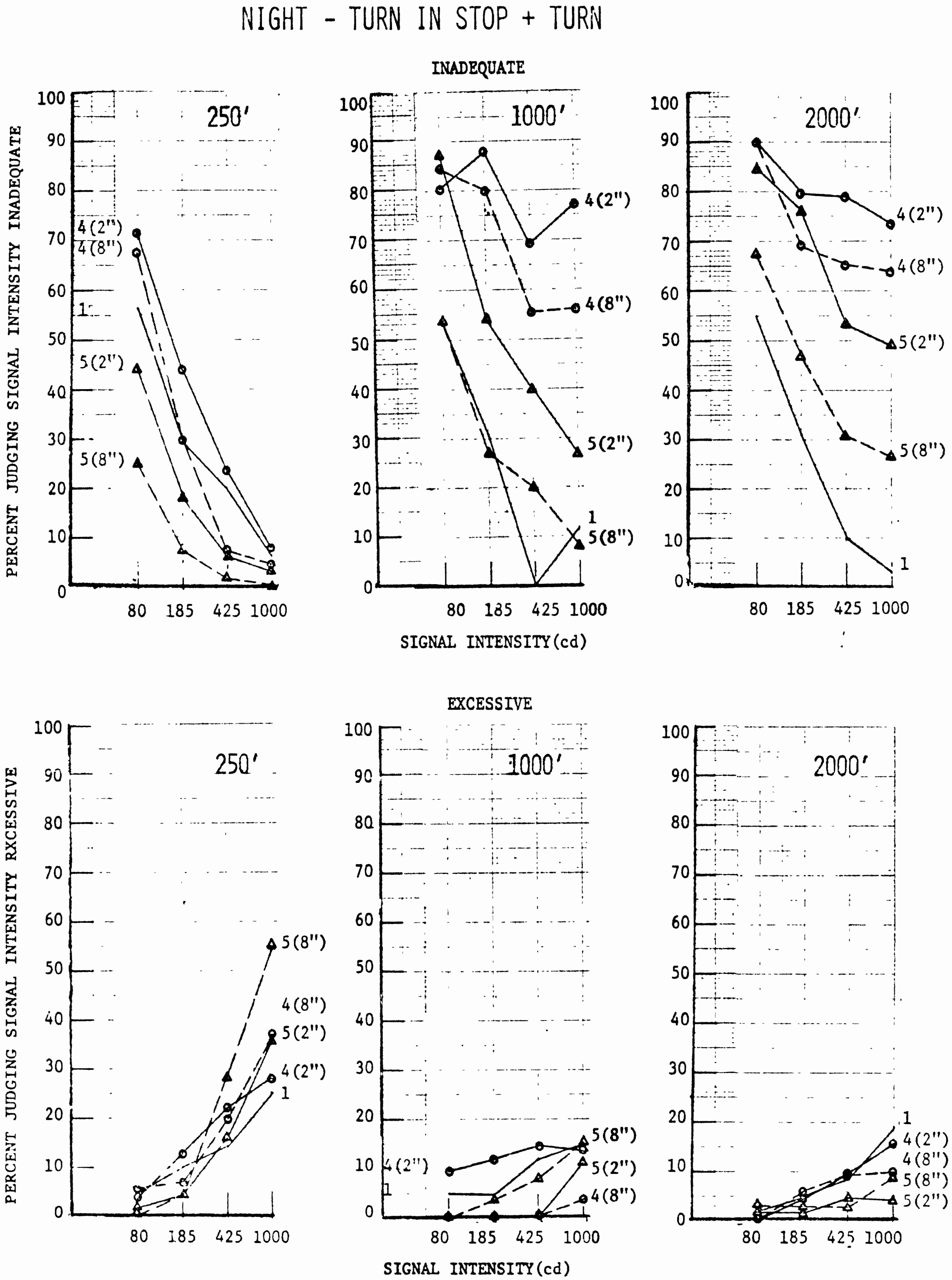



Figure 5.24. Percent inadequate and excessive ratings of turn signals in stop + turn in the night.

The ratings for turn signals, in stop + turn signals, are shown in Figure 5.24, and the Newman-Keuls tests are shown in Tables 5.29 and 5.30.

TABLE 5.29. Newman-Keuls Tests of Brightness Ratings for Turn Signals in Stop + Turn Signals in the Night, Across System-Separation for Each Signal Intensity and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|---|
| 250 | 425, 1000 | None | Inadequate | |
| " | 80 | 1, 4(8") | " | 5(8") |
| " | " | 4(2") | " | 5(2"), 5(8") |
| " | 185 | " | " | 5(8") |
| 1000 | 80 | 4(2"), 4(8"), 5(2") | " | 1, 5(8") |
| " | 185 | 5(2") | " | 1, 5(8") |
| " | " | 4(2"), 4(8") | " | 1, 5(2"), 5(8") |
| " | 425 | 5(2") | " | 1 |
| " | " | 4(8") | " | 1, 5(8") |
| " | " | 4(2") | " | 1, 5(2"), 5(8") |
| " | 1000 | 4(2"), 4(8") | " | 1, 5(2"), 5(8") |
| 2000 | 80 | 4(2"), 4(8"), 5(2") | " | 1 |
| " | 185 | 4(8") | " | 1 |
| " | " | 4(2"), 5(2") | " | 1, 5(8") |
| " | 425 | 5(2") | " | 1 |
| " | " | 4(8") | " | 1, 5(8") |
| " | " | 4(2") | " | 1, 5(2"), 5(8") |
| " | 1000 | 5(8") | " | 1 |
| " | " | 4(2"), 4(8"), 5(2") | " | 1, 5(8") |
| 250 | 80, 185, 425 | None | Excessive | |
| " | 1000 | 5(8") | " | 1, 4(2") |
| 1000, 2000 | 1000 | None | " | |

TABLE 5.30. Newman-Keuls Tests of Brightness Ratings for Turn Signals in Stop + Turn Signals in the Night, Across Signal Intensities for Each System-Separation and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than Signal Intensity (cd) |
|---|---|---|---|---|
| 250 | None | 5(8") | Inadequate | |
| " | 80 | 1, 5(2") | " | 185, 425, 1000 |
| " | 185 | 4(2") | " | 1000 |
| " | 80 | " | " | 185, 425, 1000 |
| " | 185 | 4(8") | " | 1000 |
| " | 80 | " | " | 185, 425, 1000 |
| 1000 | None | 4(2") | " | |
| " | 185 | 1 | " | 425 |
| " | 80 | 1 | " | 425, 1000 |
| " | 80 | 4(8") | " | 425, 1000 |
| " | 185 | 5(2") | " | 1000 |
| " | 80 | " | " | 185, 425, 1000 |
| " | 80 | 5(8") | " | 185, 425, 1000 |
| 2000 | None | 4(2"), 4(8") | " | |
| " | 185 | 1 | " | 1000 |
| " | 80 | 1 | " | 185, 425, 1000 |
| " | 80, 185 | 5(2") | " | 425, 1000 |
| " | 80 | 5(8") | " | 425, 1000 |
| | | | | |
| 250 | None | 1 | Excessive | |
| " | 1000 | 4(2") | " | 80 |
| " | " | 4(8") | " | 80, 185 |
| " | " | 5(2") | " | 80, 185, 425 |
| " | 425 | 5(8") | " | 80, 185 |
| " | 1000 | " | " | 80, 185, 425 |
| 1000, 2000 | None | All | " | |

Inadequate ratings of turn signals presented with stop signals were numerous, undoubtedly due to the fact that stop and turn signals were always presented at equal intensities. Across system-separations system 4(2") was rated too dim at 250 feet and 80 and 185 cd. Systems 1 and 4(8") were also rated too dim at 80 cd. From a viewing distance of 1000 feet systems 4(2"), 4(8"), and 5(2") were more often rated too dim than systems 1 and 5(8") at all signal intensities. The only exception was for system 5(2") at 1000 cd. At 2000 feet systems 4(2"), 4(8"), and 5(2") were more frequently rated too dim at all intensities than 5(8") and 1. System 5(8") at 250 feet and 1000 cd was the only case where a turn signal in stop + turn was more often rated as excessively bright.

There were no significant differences in inadequate ratings due to intensity differences for system 5(8") at 250 feet, for system 4(2") at 1000 feet, nor for systems 4(2") and 4(8") at 2000 feet. Eighty and 185 cd were rated too dim compared to higher intensities for systems 4(2") and 4(8") at 250 feet, but only 80 cd was too dim for systems 1 and 5(2"). At 1000 feet 80 cd was too dim for all but system 4(2). One hundred eighty five cd was too dim for systems 1 and 5(2"). At 2000 feet 80 cd was too dim for systems 1, 5(2"), and 5(8"), and 185 cd was too dim for systems 1 and 5(2). Excessive ratings occurred only at 250 feet among signal intensities. One thousand cd was rated too bright more often than other intensities for all but system 1, and 425 cd was too bright for system 5(8").

Summary of Results - Night Condition. An overview of the results of the night tests can best be seen by scrutiny of Figures 5.21 - 5.24. This shows that for all signal modes the percent of inadequate brightness responses had declined to about 30% for systems 1 and 5(8"), at all distances, at intensities of 185 cd or less. It is also noted that less than 30% of respondents rated the stop signal inadequate in intensity at 80 cd. The turn signals required a higher intensity than the stop for equal ratings, particularly in the stop + turn mode. In regard to discomfort glare from the signals, ratings of excessive decreased with increasing distance. There was a tendency for signals of system 1 to be rated less frequently as excessive than systems 4 or 5. Since the stop and turn signals of systems 1 and 4 were the same color, differences between these systems in excessive brightness ratings suggest that the subjects were rating the signals on brightness in an absolute sense, but also in terms of brightness necessary to adequately see the signal. Thus, the greater frequency of excessive brightness ratings for stop signals in systems 5 and 4 than in 1, in which systems the stop signals are the same, probably reflects the subjects' judgments that the signals in systems 5 and 4 were brighter than necessary, i.e., excessive, for adequate perception as stop signals. This is considered to be due to the easier discrimination of the signals from presence lights in those systems at night due to separation of function and color coding. The excessive ratings made on system 1 probably are the best indication of the effects of intensity on discomfort glare. Taking the data of system 1 to indicate discomfort glare effects and a criterion of not more than 15% excessive responses suggests that the signals should not exceed 185 cd at 250 feet nor 425 cd at 2000 feet.

Analysis of Night + Glare Tests. The brightness ratings for the stop signal in the night + glare test are shown in Figure 5.25, and the results of the Newman-Keuls tests are shown in Tables 5.31 and 5.32.

No significant differences in the percent of inadequate ratings were found in each distance and signal intensity for different systems. Across signal intensities at 250 feet 1000 cd was rated

# NIGHT + GLARE - STOP

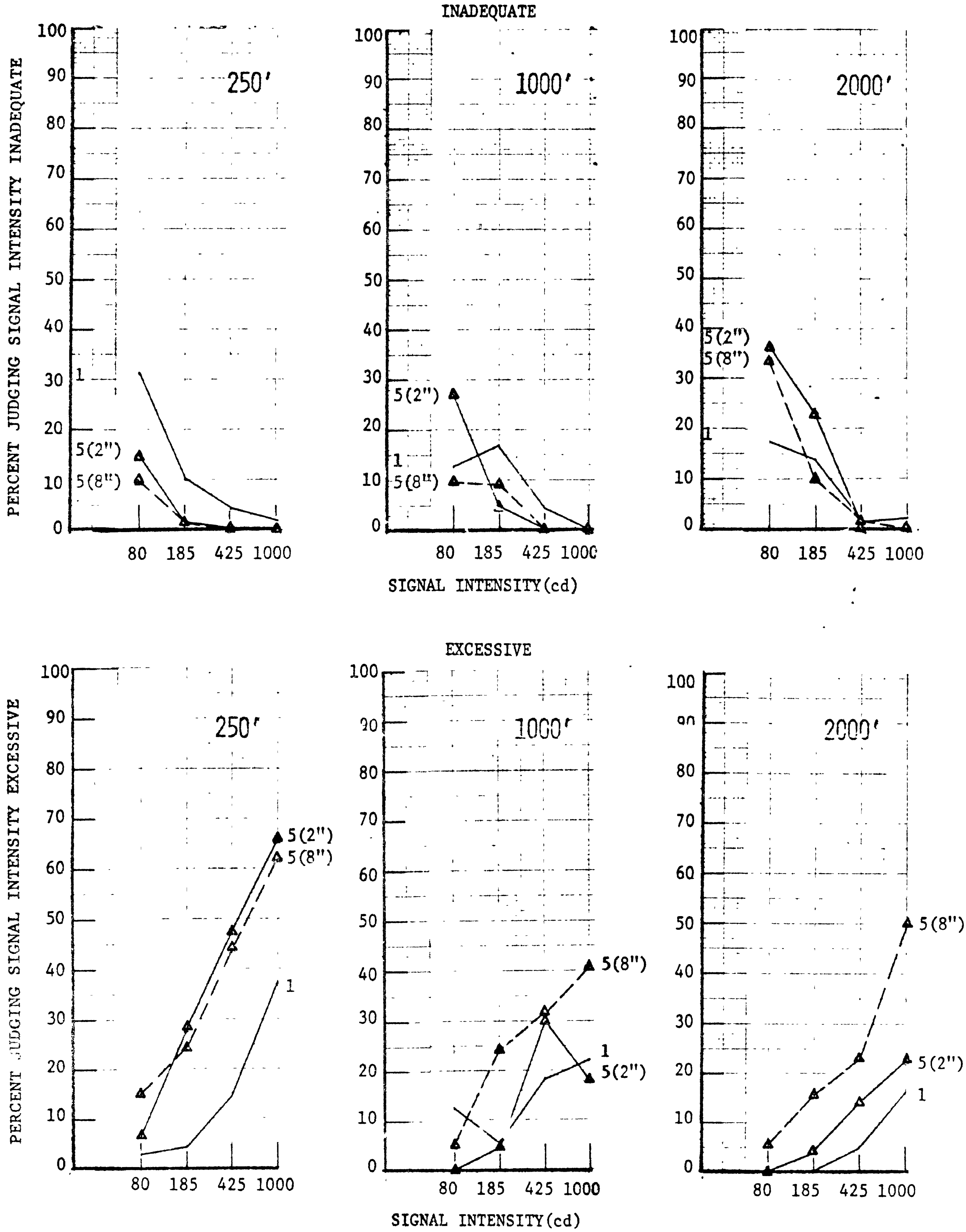



Figure 5.25. Percent inadequate and excessive ratings of stop signals in night + glare condition.

TABLE 5.31. Newman-Keuls Tests of Brightness Ratings for Stop Signals in the Night + Glare Condition, Across Signal Intensities for Each System-Separation and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than Signal Intensity (cd) |
|---|---|---|---|---|
| All | All | None | Inadequate | |
| 250 | 1000 | 1 | Excessive | 80, 185, 425 |
| " | 185, 425 | 5(2") | " | 80 |
| " | 1000 | " | " | 80, 185 |
| " | 425 | 5(8") | " | 80 |
| " | 1000 | " | " | 80, 185 |
| 1000 | None | 1 | " | |
| " | 425 | 5(2") | " | 80, 185 |
| " | 425, 1000 | 5(8") | " | 80 |
| 2000 | None | 1, 5(2") | " | |
| " | 1000 | 5(8") | " | 80, 185, 425 |

TABLE 5.32. Newman-Keuls Tests of Brightness Ratings for Stop Signals in the Night + Glare Condition, Across System-Separation for Each Signal Intensity and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|---|
| All | All | None | Inadequate | |
| 250 | 80 | None | Excessive | |
| " | 185, 425, 1000 | 5(2"), 5(8") | " | 1 |
| 1000 | 80, 185, 425 | None | " | |
| " | 1000 | 5(8") | " | 5(2") |
| 2000 | 80, 185, 425 | None | " | |
| " | 1000 | 5(8") | " | 1, 5(2") |

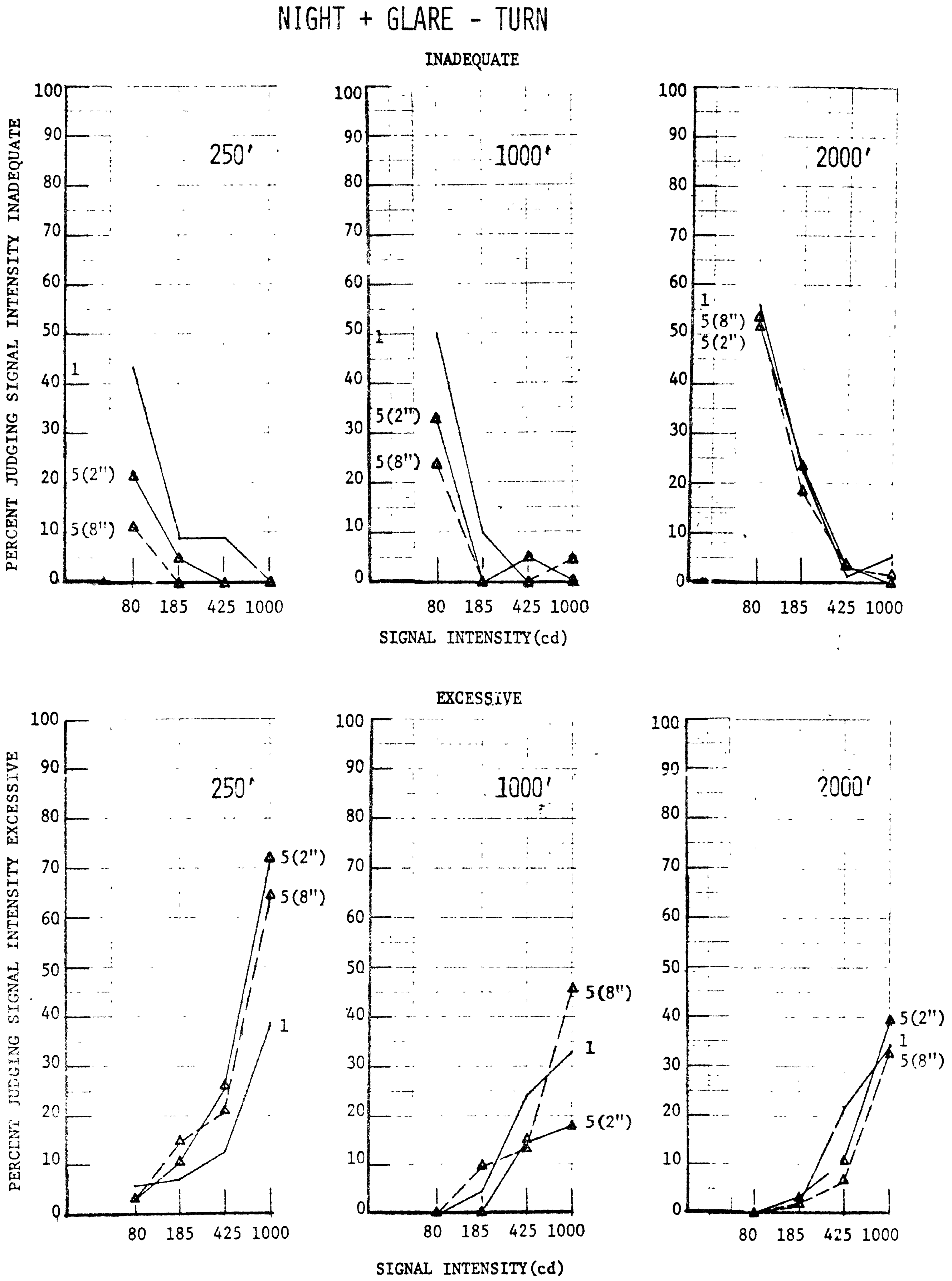



Figure 5.26. Percent of inadequate and excessive ratings of turn signals in the night + glare condition.

significantly more often too bright for all systems, 425 cd for 5(2") and 5(8"), and 185 cd for 5(2"). At 1000 feet there were no significant differences for system 1, 425 cd was more frequently rated too bright for 5(2") and 5(8"), and 1000 cd for 5(8") than lower intensities. At 2000 feet only 1000 cd was rated too bright more often than lower intensities for system 5(8"). There were no significant differences across system-separations for 80 cd regardless of distance or at 185 and 425 cd at 1000 and 2000 feet. Systems 5(2") and 5(8") were more often rated too bright at 250 feet and 185, 425, and 1000 cd than 80 cd. At greater distances and 1000 cd, system 5(8") was rated too bright more often than lower intensities.

For turn signals the percent inadequate and excessive brightness ratings are shown in Figure 5.26.

Newman-Keuls results for turn signals are shown in Tables 5.33 and 5.34. There were no significant differences between

TABLE 5.33. Newman-Keuls Tests of Brightness Ratings for Turn Signals in the Night + Glare Condition, Across Signal Intensities for Each System-Separation and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than Signal Intensity (cd) |
|---|---|---|---|---|
| All | None | All | Inadequate | |
| 250 | 1000 | 1, 5(8") | Excessive | 80, 185, 425 |
| " | 425 | 5(2") | " | 80 |
| " | 1000 | " | " | 80, 185, 425 |
| 1000 | None | " | " | |
| " | 425 | 1 | " | 80 |
| " | 1000 | 1 | " | 80, 185 |
| " | 1000 | 5(8") | " | 80, 185, 425 |
| 2000 | 1000 | 1 | " | 80, 185 |
| " | 1000 | 5(2"), 5(8") | " | 80, 185, 425 |

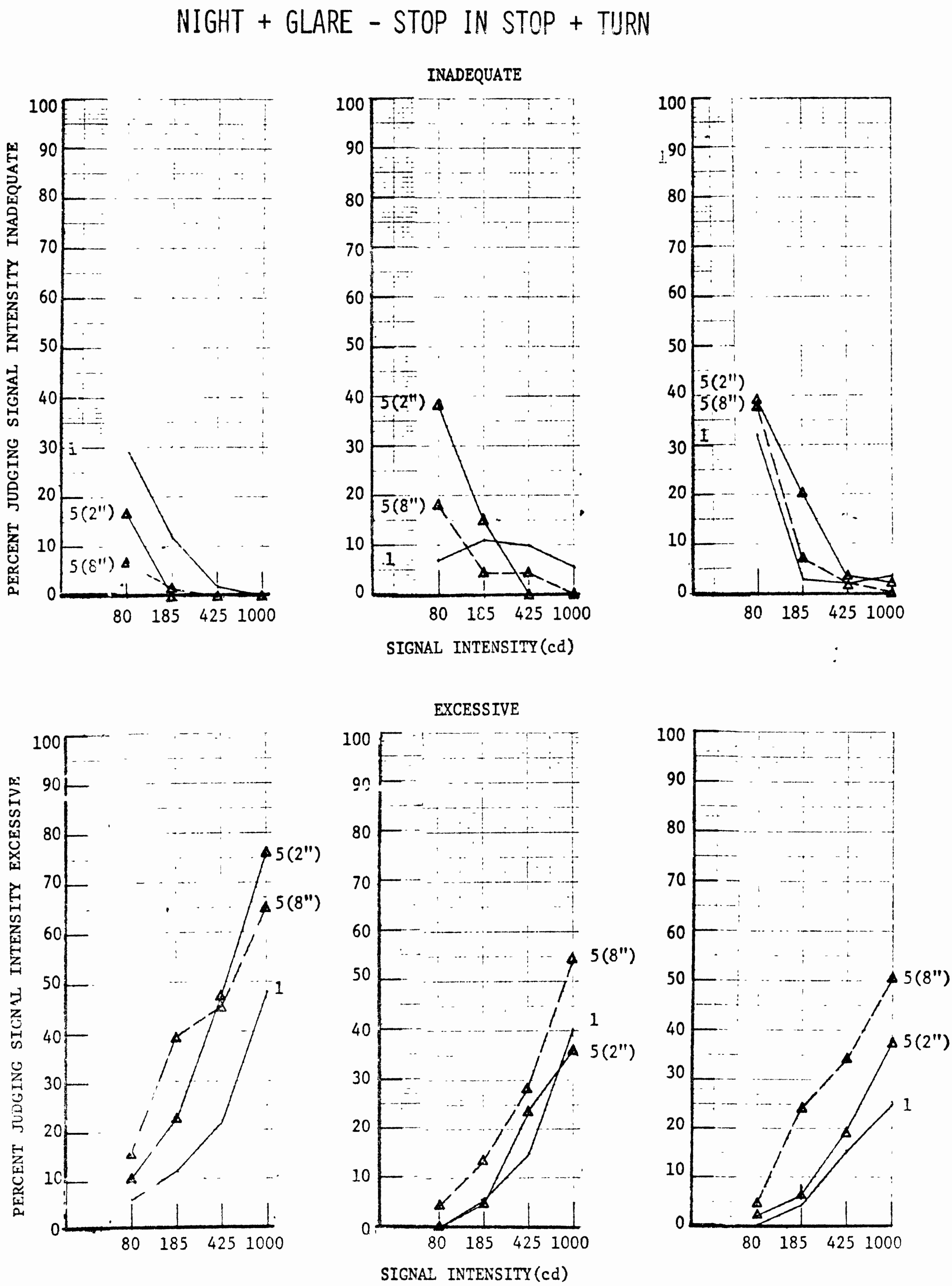



Figure 5.27. Percent inadequate and excessive ratings of stop signals in stop + turn in the night glare condition.

TABLE 5.34. Newman-Keuls Tests of Brightness Ratings for Turn Signals Presented Alone Under the Night Glare Condition, Across System-Separations for Each Signal Intensity and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|---|
| All | All | None | Inadequate | |
| 250 | 80, 185, 425 | None | Excessive | |
| " | 1000 | 5(2"), 5(8") | " | 1 |
| 1000 | 80, 185, 425 | None | " | |
| " | 1000 | 5(8") | " | 5(2") |
| 2000 | All | None | " | |

systems, at a given intensity, in inadequate ratings. One thousand cd was rated excessive for all systems and distances, except system 5(2") at 1000 feet. Four hundred twenty five cd was too bright for system 5(2") at 250 feet and system 1 at 1000 feet. Across system-separations at 250 feet and 1000 cd systems 5(2") and 5(8") were too bright. At 1000 feet and 1000 cd system 5(8") was too bright. There were no other significant differences.

For stop signals, in stop + turn signals, the percent inadequate and excessive ratings are shown in Figure 5.27, and the Newman-Keuls test results in Tables 5.35 and 5.36.

No significant differences between systems in inadequate ratings were found for stop signals presented with turn signals. Across signal intensities, 1000 cd was too bright for all systems at all distances. Four hundred twenty five cd was too bright for 5(2") at 250 feet and 1000 feet and for 5(8") at all distances. One hundred eighty five cd was too bright for system 5(8") at 250 feet and 2000 feet. Across system-separations at 250 feet systems 5(2") and 5(8") were usually too bright above 80 cd. No

TABLE 5.35. Newman-Keuls Tests of Brightness Ratings for Stop Signals, in Stop + Turn Signals, in the Night + Glare Condition, Across Signal Intensities for Each System-Separation and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than Signal Intensity (cd) |
|---|---|---|---|---|
| All | None | All | Inadequate | |
| 250 | 1000 | 1 | Excessive | 80, 185, 425 |
| " | 425 | 5(2") | " | 80, 185 |
| " | 1000 | " | " | 80, 185, 425 |
| " | 185, 425 | 5(8") | " | 80 |
| " | 1000 | " | " | 80, 185 |
| 1000 | " | 1 | " | 80, 185, 425 |
| " | 425 | 5(2") | " | 80 |
| " | 1000 | " | " | 80, 185 |
| " | 425 | 5(8") | " | 80 |
| " | 1000 | " | " | 80, 185, 425 |
| 2000 | " | 1 | " | 80 |
| " | " | 5(2") | " | 80, 185 |
| " | 185, 425 | 5(8") | " | 80 |
| " | 1000 | " | " | 80, 185 |

TABLE 5.36. Newman-Keuls Tests of Brightness Ratings for Stop Signals, in Stop + Turn Signals, in the Night Glare Condition, Across System-Separations for Each Signal Intensity and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|---|
| All | All | None | Inadequate | |
| 250 | 80 | None | Excessive | |
| " | 185 | 5(8") | " | 1 |
| " | 425 | 5(2"), 5(8") | " | 1 |
| " | 1000 | 5(2") | " | 1 |
| 1000 | All | None | " | |
| 2000 | 80, 185, 425 | None | " | |
| " | 1000 | 5(8") | " | 1 |

other significant differences between intensities in systems occurred except at 2000 feet where system 5(8") was too bright at 1000 cd.

For turn signals, in stop + turn signals, the percent inadequate and excessive ratings are shown in Figure 5.28.

The Newman-Keuls tests for turn signals presented with stop signals are shown in Tables 5.37 and 5.38.

TABLE 5.37. Newman-Keuls Tests of Brightness Ratings for Turn Signals, in Stop + Turn Signals in the Night Glare Condition, Across Signal Intensities for Each System-Separation and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than Signal Intensity (cd) |
|---|---|---|---|---|
| All | None | All | Inadequate | |
| 250 | None | 1 | Excessive | |
| " | 1000 | 5(2"), 5(8") | " | 80, 185, 425 |
| 1000, 2000 | None | All | " | |

TABLE 5.38. Newman-Keuls Tests of Brightness Ratings for Turn Signals, in Stop + Turn Signals, in the Night Glare Condition, Across System-Separations for Each Signal Intensity and Distance.

| Distance (ft) | Signal Intensity (cd) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|---|
| All | All | None | Inadequate | |
| All | All | None | Excessive | |

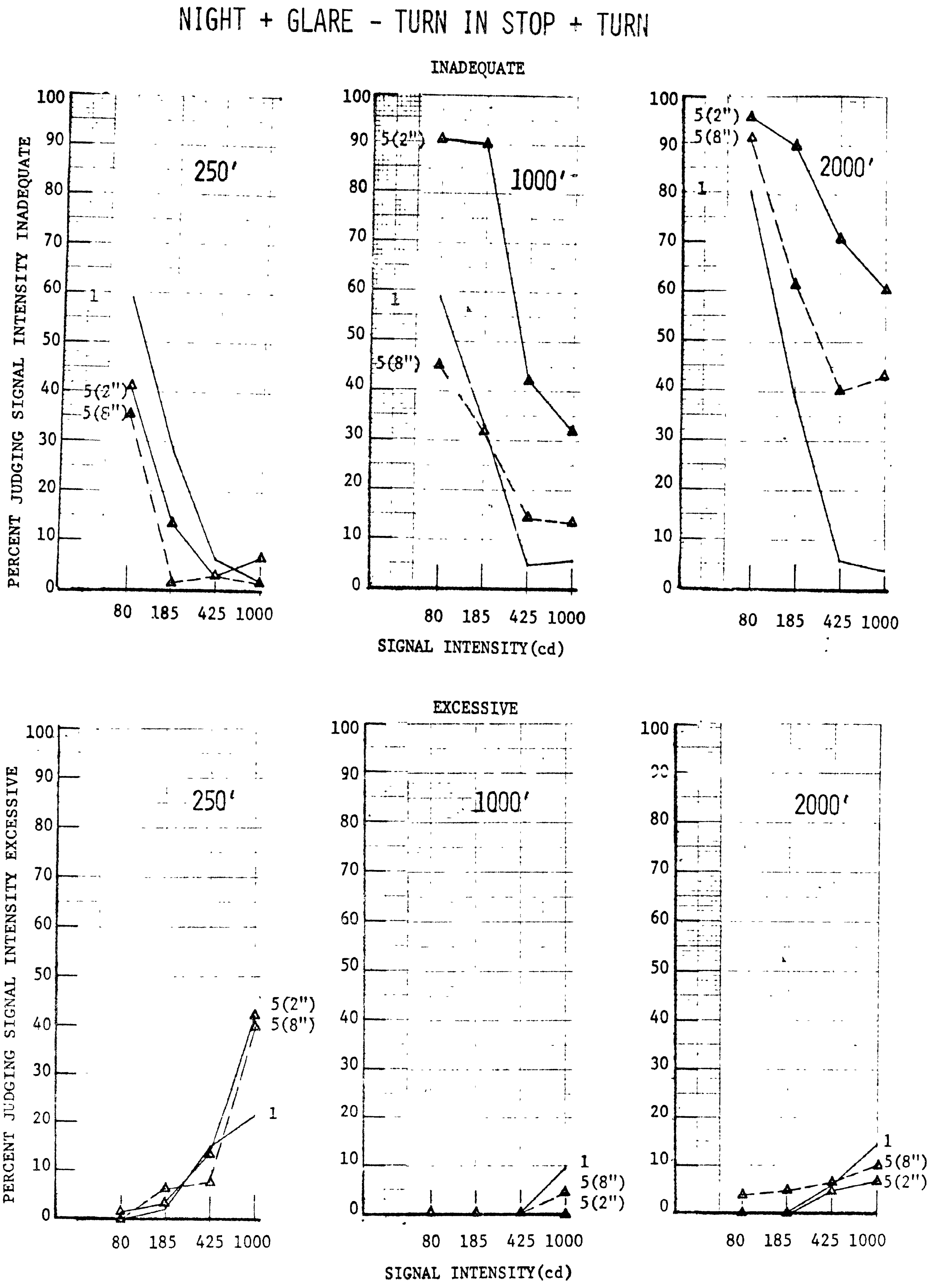



Figure 5.28. Percent of inadequate and excessive ratings of turn signals in stop + turn in the night + glare condition.

For turn signals presented with stop signals the only significant difference occurred at 250 feet where 1000 cd was too bright for systems 5(2") and 5(8").

Summary of Results - Night + Glare Condition. For the stop signals, at almost all distances, 80 cd was considered adequate in intensity, particularly for system 5. However, at 2000 feet 185 cd provided some improvement. This is also true of the turn signal presented alone. The turn signal, in stop + turn signals, at 2000 feet required up to 425 cd for system 1, and greater than this for the other system, although the differences were not statistically significant. In most cases a criterion of 15% excessive responses was exceeded at signal intensities greater than 185 cd for system 1 at 250 feet. As mentioned before the excessive ratings on this system probably best show the effect of discomfort glare, and values obtained for system 1 should be used to measure this effect.

Summary of Results of the Brightness Ratings. During the day the findings indicate that inadequate brightness ratings decreased significantly until intensities of up to 425 cd were used for stop signals, at 250 feet. Since each system gave the identical stop signal in the day the findings were expected to be the same for each, and this is confirmed by the close match of the data shown in Figures 5.17 and 5.19.

For turn signals, in the day, 425 cd was also rated adequate for red signals but up to 1000 cd was considered necessary for the amber signals.

Greater intensities were judged necessary for adequate brightness at the 2000 feet viewing distance.

The frequency of excessive brightness ratings at 250 feet for signals of 425 cd or less were negligible in the day tests.

The findings at night and night + glare differ dramatically in terms of intensities rated inadequate and excessive from those obtained in the day, with substantially lower intensities being acceptably bright, and with intensities rated desirable in the day being rated excessively bright in both night tests.

Differences between systems are more evident in the night tests, with the color coded system (5) providing adequate stop signal brightness at 80 cd, whereas 185 cd was generally required for the other systems. Turn signals were more often rated as inadequate at 80 cd than 185 cd, and up to 425 cd for the turn signal was necessary in the stop + turn mode. In these night tests the amber turn signal was generally less often rated inadequately bright compared to the equivalent red turn signal, in contrast to the daytime findings.

The effect of the glare from the headlamps of an opposing car upon the inadequate brightness ratings was to require a small increase in signal intensity for equivalent ratings to the no-glare case.

Inadequate brightness ratings were only affected to a small extent by the viewing distance, except in the ratings of the turn signals in the stop + turn mode at 2000 feet in which at least 425 cd was required for system 1 and 1000 cd for the other systems to provide adequate brightness.

As intensity was increased the frequency of excessive brightness ratings also increased, though inversely with the distance. It is apparent that "excessive" ratings were influenced by glare discomfort and by the brightness necessary to clearly see the signal. The latter effect is indicated by comparing the percentage of excessive ratings for the stop signal between systems 1, 4 and 5, in which the conditions are the same, except for the use of functional separation of red presence lamps in system 4, and the use of green-blue presence lamps in system 5, separated from the red stop lamps. If the excessive ratings were based on the signal intensity alone then all three systems should have produced the same ratings. It was found that system 5, and to a lesser extent system 4, were more often rated excessive than system 1 at the same intensity (e.g., Figures 5.21, 5.25). The ratings on those systems are, therefore, probably influenced by the subjects' estimates that the signals are brighter than necessary for good visibility, due to contrast with the presence lights, rather than only excessively bright in terms of discomfort glare.

For this reason the ratings on system 1 are taken to best show the effect of discomfort glare, which is the judgmental variable of interest in the present context.

The frequency of excessive brightness responses tended to decrease with increasing viewing distance, and in the night + glare test compared to the night test.

The Newman-Keuls tests on the effect of signal intensity, for system 1, on the frequency of excessive ratings show that 1000 cd is rated excessively bright significantly more often than 80 and 185 cd, and in some instances than 425 cd. No significant decrease in the frequency of excessive ratings was noted for intensities less than 185 cd and in some tests (e.g., Table 5.24) between 80 cd and 425 cd. This suggests that an upper limit on intensity of 185-425 cd should be used to control discomfort glare, for the red, 12.6 square inches, lamps used in this test.

SIGNAL SYSTEM EFFECTIVENESS RATINGS.

Results. The ratings made by the subjects of the overall effectiveness of each of the systems in presenting signals in the day, night, and night + glare conditions, at each of the three viewing distances (250 ft, 1000 ft, 2000 ft) were evaluated by analyses of variance. Single factor analyses of variance were conducted at each viewing distance in each of the ambient lighting conditions. Where the analyses of variance indicated that there were significant differences in the ratings for the signaling systems, Newman-Keuls tests were conducted to test the differences between the mean system ratings (Figure 5.29).

The results of the Newman-Keuls tests for system ratings made in the daytime are shown in Table 5.39.

TABLE 5.39. Newman-Keuls Tests of System Effectiveness Ratings in the Day Condition.

| Distance (ft) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|
| 250 | 2(8") | Effective | 1, 3(2"), 3(8") |
| " | 2(2") | " | 3(2") |
| 1000 | 2(8") | " | 3(2") |
| 2000 | 2(8"), 1 | " | 3(2"), 3(8") |

The analysis indicates that of the three systems (1, 2, 3) which were used in the daytime tests, system 2 was rated significantly more effective than most other systems in each of the three viewing distances. This was true only when the separation distance between the stop and the turn signal lamps was eight inches, and did not hold when this separation distance was reduced to two inches.

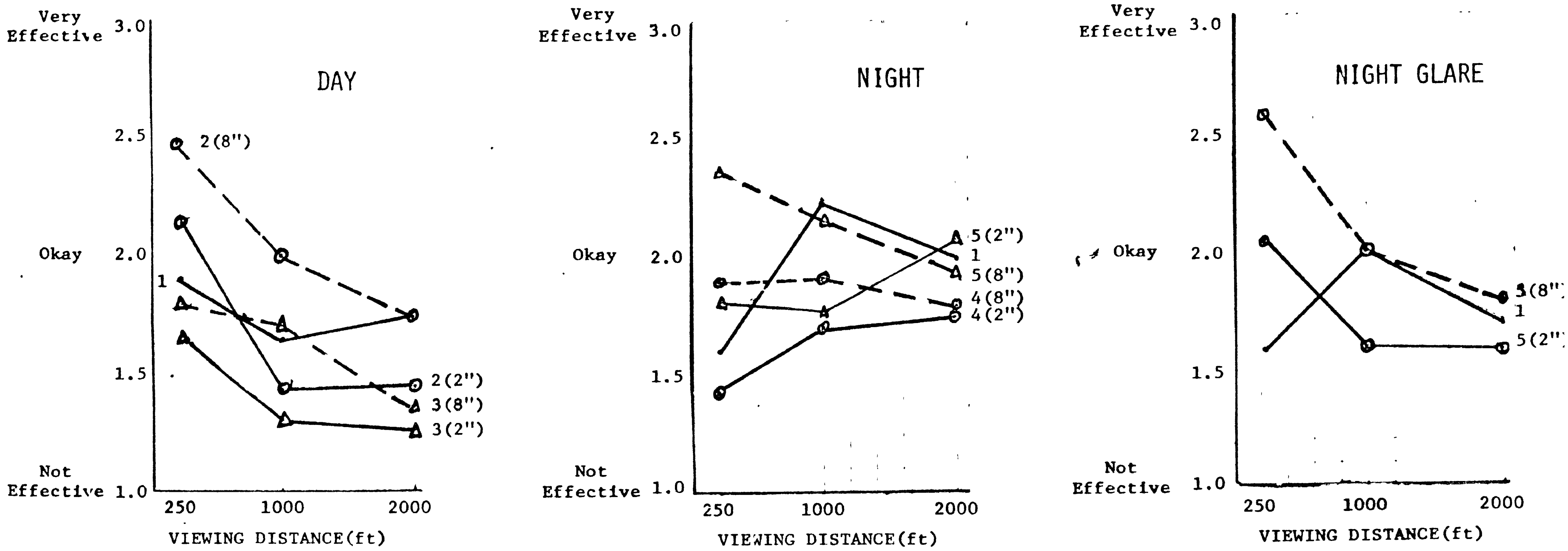



Figure 5.29. Overall ratings of effectiveness of each system as a function of system, lamp separation, viewing distance, and ambient condition.

In the nighttime tests, systems 1, 4, and 5 were used. Newman-Keuls tests on the mean ratings, at each of the three viewing distances, for these systems are shown in Table 5.40. At 250 feet system 5(8") was rated significantly more effective than system 1 and 4(2"). No significant differences were found at 1000 and 2000 feet.

TABLE 5.40. Newman-Keuls Tests of System Effectiveness Ratings in the Night Condition.

| Distance(ft) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|
| 250 | 5(8") | Effective | 1, 4(2") |
| 1000 | None | " | |
| 2000 | None | " | |

Table 5.41 shows the Newman-Keuls results for the test conducted in the night + glare condition in which systems 1 and 5 were used. It was found that system 5(8") was rated significantly more effective than system 1 or system 5(2") at 250 feet. There were no significant differences between the ratings of systems at 1000 feet or 2000 feet.

TABLE 5.41. Newman-Keuls Tests of System Effectiveness Ratings in the Night + Glare Condition.

| Distance(ft) | System(s) | Rated Significantly More Frequently | Than System(s) |
|---|---|---|---|
| 250 | 5(8") | Effective | 1, 5(2") |
| 1000, 2000 | None | " | |

Summary of Results of Effectiveness Ratings. Subjects rated those systems more effective in the day, night, and night + glare conditions in which separation of function was employed. In the daytime they considered that the system which utilized red stop and red turn signals was more effective than a system which used red stoplights combined with amber turn signals. In the two night conditions the system which used green taillights, amber turn signals and red stop signals was considered superior to the other systems. It is concluded that separation of function was considered to improve signal effectiveness, but the lamps need to be separated by about eight inches to achieve clear demarcation between the turn and the stop lamps when they are given simultaneously. The red turn signal was considered somewhat more effective than the amber turn signal in the daytime. In the night conditions the system employing amber turn signals was considered more effective than the one using red turn signals. This may have been due to the preference for the former system because it was also combined with green-blue presence lamps, which enhanced effectiveness of either amber turn or red stop signals, compared to the system which utilized red presence lights whose lamps were also used to provide the turn signal.

Overall, the results indicate that a separation between stop and turn signals should be of approximately eight inches and that, although the amber signal is less effective in the daytime than a red signal, it is considered effective at night and could be made equally effective in the daytime if relatively greater intensities were used, as shown by other data obtained in this test.

## DISCUSSION

The findings of this study can be discussed in terms of the three measures that were taken: signal identification, brightness ratings and overall system effectiveness ratings.

In the daytime tests the ability to correctly identify signals decreased sharply as the viewing distance was increased between 250 feet and 2000 feet. In order to obtain at least 85% signal identification at 2000 feet, signal intensities somewhat less than 425 cd would be needed for red stop or turn signals, and above 425 cd for amber turn signals (Figure 5.10). Identification of the combined stop + turn signals was generally poor at 2000 feet, requiring at least 425 cd for system 1, and greater turn signal intensities for systems using separation of function or color coding. The advantage of 8 inches of edge-to-edge lamp separation in the latter systems compared to 2 inches, was evident (Figure 5.10). Based on these findings it could be recommended that the minimum red signal lamp intensity (for lamps 12.6 square inches, as used here) should be 300 cd to provide 85th percentile identification of red stop or turn signals and above 425 cd for amber turn signals at a viewing distance of about 2000 feet. Intensities closer to 425 cd would be needed for a similar level of identification of stop + turn signals appearing simultaneously for system 1. For systems 4 and 5* increased intensity of the turn signal is needed, up to 1000 cd, because this signal was often missed in the stop + turn mode (Table 2, Appendix B) while 425 cd is adequate for the stop signal in the stop + turn mode at 2000 feet.

In the night tests the differences between the effectiveness of various coding methods became more marked, probably due to the addition of the presence signal as an added signal mode and the comparable or greater effectiveness of amber turn signals than red turn signals.

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*Systems 4 and 5 are the same as systems 2 and 3, respectively, in the day (i.e., presence lamps are off).

One finding was that, with the present, two red lamp system, presence lights of 15 cd were confused with stop signals. This was also true, to a lesser extent, with system 4(2"). At 4 cd this problem was removed. Since the present standard allows presence lamp intensities of 2-15 cd, and since most lamps are in the middle of this range (Finch, 1968), it can be expected that confusions between presence and stop signals occur. Presence lamp intensities at the higher end of the range would otherwise be advantageous to maintain adequate marking in inclement weather.

The tendency to confuse presence with stop signals was reduced by separation of presence and stop lamps by 8 inches (Figure 5.11), and was eliminated by color coding of presence and stop lamps.

A stop signal intensity of 80 cd was adequate for 85% correct identification at 2000 feet for systems 4 and 5, with no increased benefits due to a separation distance of 8 inches compared to 2 inches between the presence and stop lamps. System 1 would require at least 185 cd in the no-glare condition and up to 425 cd in the night + glare condition for equivalent identification of the stop signal.

A red turn signal, combined with the presence signal (systems 1 and 4) would require about 185 cd to provide 85% correct identification. The equivalent level of identification was achieved at 80 cd for the amber turn signal of system 5.

The identification of stop + turn signals appearing simultaneously was significantly improved by separation of the stop and turn signal lamps by 8 inches compared to 2 inches for system 4, but not system 5. In the night test system 5 provided acceptable (85%) stop + turn identification at 80 cd, whereas system 1 required 185 cd and system 4 up to 425 cd for equivalent performance.

The glare of opposing low beam lamps degraded signal identification at 2000 feet in the stop + turn mode for system 1, but relatively little for system 5.

Examination of other tables (Appendix B) showing the confusions made by subjects, indicated the cause of the low percent of correct identifications of the stop + turn mode in the nighttime tests. It was found that in system 1 the stop signal was frequently missed; in system 4 the turn signal was not identified adequately, and the same problem appeared in system 5, though to a much lesser extent. This suggests that different approaches should be taken to improve signal identification in the stop + turn mode, and to account for headlamp glare, dependent on the system characteristics. System 1 will require stop signals of up to 425 cd to become identifiable adequately at 200 feet when a turn signal is also given. The turn signal would provide adequate performance in this mode at about 185 cd.

In system 4 it is necessary to alleviate poor turn signal conspicuity. Table 3, Appendix B, suggests that performance of the system in the stop + turn mode would be improved by using stop lamps of not more than 185 cd and turn signals of up to 425 cd.

In system 5 the problem could probably be resolved by the use of up to 185 cd for the amber turn signals used with 80 cd stop signals (Tables 4, 5, Appendix B).

Since these recommendations for differential stop and turn lamp intensities are extrapolated from the data, the systems should be tested in these configurations for purposes of verifying the values. The recommended minimum intensities to satisfy all signal modes, for the lamps in the three systems, based on the results of the signal identification test, are summarized in Table 5.42.

TABLE 5.42. Intensities Recommended for Presence, Stop and Turn Lamps Based on Signal Identification Test Only, for Adequate (85%) Identification of All Signal Modes at 2000 Feet.

| Signal Lamp | System | | | | | |
|---|---|---|---|---|---|---|
| | 1 | | 4 | | 5 | |
| | Night | Day | Night | Day | Night | Day |
| Presence | 4 | - | 15 | - | 15 | - |
| Stop | 425 | 425 | 185 | 425 | 80 | 425 |
| Turn | 185 | 425 | 425 | 1000 | 185 | 1000 |

The analogous intensities that were necessary for 85% identification of presence, stop or turn signals, excluding the stop + turn mode, are shown in Table 5.43. The value of 300 cd has been extrapolated from the curves, such as shown in Figure 5.16.

TABLE 5.43. Intensities Recommended for Presence, Stop and Turn Lamps Based on Signal Identification Test Only, for Adequate (85%) Signal Identification (Not Including Stop + Turn) at 2000 Feet.

| Signal Lamp | System | | | | | |
|---|---|---|---|---|---|---|
| | 1 | | 4 | | 5 | |
| | Night | Day | Night | Day | Night | Day |
| Presence | 4 | - | 15 | - | 15 | - |
| Stop | 300 | 300 | 80 | 300 | 80 | 300 |
| Turn | 185 | 300 | 185 | 300 | 80 | 425 |

The findings of the brightness ratings, of those signals correctly identified, were intended to indicate the percent of signals, in a given set of conditions, that were considered to be inadequately bright for ease of identification or excessively bright for visual comfort. The plots for comparable conditions have been arranged so as to provide a quick view of the manner in which inadequate and excessive brightness ratings changed with intensity, while other factors were held constant. It is clearly shown that as the percent of judgments of inadequate brightness decrease there is a growing increase in the frequency of excessive brightness ratings, particularly in the night tests. This was to be expected.

Interpretation of the excessive brightness ratings to indicate the effect of glare discomfort is limited to the findings from system 1, because, as already mentioned, excessive ratings on systems 4 and 5 were probably interpreted by subjects in terms of brightness necessary to adequately see the signals <u>and</u> glare discomfort.

During the day, red stop or turn signals were rated inadequate in less than 15% of occasions when intensities of 425 cd or greater were used at 250 feet, while up to 1000 cd was judged necessary for amber turn signals. Intensities greater than these were judged necessary for adequate brightness as the viewing distance was increased.

In the night and night + glare tests the percent of inadequate brightness ratings was not affected by the viewing distance, except for the ratings of turn signals in the stop + turn mode. System 5 generally received less than 15% of inadequate brightness ratings for the stop signal at 80 cd, whereas other systems required 185 cd. Turn signals were rated inadequate more often at 80 cd than 185 cd. In the stop + turn mode subjects' ratings showed that they felt greater intensities were needed for the turn signal in systems 4 and 5, than the stop signal, and increased intensities were needed in this mode at 2000 feet than shorter distances for all systems. These data of subjective ratings of inadequate brightness of signals show that in the day signals were perceived to require at least 425 cd. At night, stop and turn signals of system 5 were adequate at 80 cd whereas 185 cd was needed for systems 1 and 4. The need to increase turn signal intensities in systems 4 and 5 in the stop + turn mode was perceived by the subjects. These subjective evaluations follow, quite closely, the effects of signal intensity and system coding upon signal identification (Tables 5.42, 5.43).

The data concerned with ratings of excessive brightness on system 1, in particular, can be used to assist in setting maximum signal intensities to reduce the incidence of discomfort glare.

The findings from the night tests show (Figures 5.21-5.28) that the percent of excessive brightness responses increase with increases in signal intensity, and decrease with increasing viewing distance.

The percent of excessive ratings does not decrease significantly for intensities below 185 cd and in some cases below 425 cd, at the shortest viewing distance (250 feet), for all signal modes. The interpolated 15 percentile value of excessive brightness ratings, taken from Figures 5.21-5.28, for stop and turn signals provided the mean values shown in Table 5.44, and indicate maximum intensities of about 270 cd and 400 cd for stop and turn signals, respectively, viewed at 250 feet.

TABLE 5.44. Mean 15 Percentile Intensities (cd) Rated Excessively Bright in Night and Night + Glare Tests for System 1, at 250 Feet.

| Signal Lamp | Viewing Distance -250 Feet |
|---|---|
| Stop | 270 |
| Turn | 400 |

The overall system effectiveness ratings also made in this test, showed that the subjects considered systems using separation of function as most effective, with 8 inches of inter-lamp separation rated as producing greater effectiveness than 2 inches. The red turn signal was considered more effective than amber in the day. At night system 5(8") appeared most effective.

Development of Lamp Intensity Requirements. The major findings of the study bear on the intensities needed for good signal identification in day and night driving, and low incidence of discomfort glare at night.

Tables 5.42 and 5.43 show that a minimum of 300 cd is needed in daytime for 85% identification, at up to 2000 feet, of red stop and turn signals, and above 425 cd for amber turn signals. At night these intensities would tend to be judged excessively bright by about 15% of drivers, except for the red turn signals at 300 cd. However, the 15th percentile intensities shown in Table 5.44 represent findings obtained at 250 feet. At closer viewing distances these values would need to be reduced for the same level of glare discomfort.

In a previous study (Mortimer, 1970) it was found that the intensities causing glare discomfort to 15% of drivers at 75 feet were 0.56 of the intensities causing glare discomfort to 15% of drivers at 275 feet.

A criterion distance of 75 feet for glare discomfort appears reasonable since much driving on rural roads and expressways is carried out at such inter-vehicle spacings, and much shorter distance headways are common on city streets and expressways.

Therefore, the intensities giving rise to 15% excessive brightness ratings at 250 feet in this test were multiplied by a factor of 0.62 (i.e., 275/250 x 0.56) to estimate the intensities causing the same level of glare discomfort at 75 feet. The resulting values are shown in Table 5.45.

TABLE 5.45. Intensities (cd) of 15th Percentile Excessive Brightness Ratings in Night, and Night + Glare Tests for System 1, at 75 Feet.

| Signal Lamp | Viewing Distance - 75' |
|---|---|
| Stop | 168(190)[1] |
| Turn | 245 |

[1]From Figure 2.6, (Mortimer, 1970)

Based on this analysis, the maximum nighttime intensity desirable for red stop and turn signal lamps, 12.6 square inches in area, is about 170 and 245 cd, respectively. The previous study (Mortimer, 1970), using only steady-burning lamps, suggested a maximum intensity of about 190 cd for the same lamp area, color and viewing distance.[1] This value (190 cd) is close to that (170 cd) obtained in this test and analysis.

Furthermore, the daytime minimum, red, stop signal intensity of 300 cd found in this test (Table 5.43) is the same value reported in the previous study; and the minimum daytime amber turn signal intensity of 425 cd found in this study is the same value as reported for an amber signal in the previous study. The extent of the agreement between the two studies is good. Therefore, it is recommended that the values reported in the previous study for lamps of various areas can be used for the maximum night intensities and the minimum day intensities for stop signals, and minimum daytime intensities for turn signals.

An interesting finding of this study suggests that turn signals can be 1.5 times the intensity of stop signals for equivalent night glare discomfort (Table 5.44). This finding at 250 feet is corroborated by the mean ratio of 1.4 found at the 2000-foot viewing distance. The maximum nighttime turn signal inten-

[1]See Figures 1-3, Appendix C.

sities can, therefore, be taken as 1.5 times the maximum allowable night intensities ($N_{MAX}$) shown in Figures 1-3, Appendix C, for red, amber and green-blue, steady-burning lamps.

The minimum nighttime signal intensities are dependent on the values needed for adequate signal identification for the different systems, as shown in Table 5.43.

The intensities that would be recommended, for lamps of 12.6 square inches for each of the three basic systems used in these tests, and meeting the criteria for 85% signal identification at 2000 feet, and 15% glare discomfort at 75 feet are shown in Table 5.46.

TABLE 5.46. Intensities of 12.6 Square Inch Lamps Required to Meet 85% Signal Identification[1] and 15% Glare Discomfort[2] Criteria.

| Signal Lamp | System Type | | | | | |
|---|---|---|---|---|---|---|
| | 1 | | 4 | | 5 | |
| | Night | Day | Night | Day | Night | Day |
| | Min Max | Min | Min Max | Min | Min Max | Min |
| Presence | 4-15 | | 4-15 | | 4-15 | |
| Stop | 300-190 | 300 | 80-190 | 300 | 80-190 | 300 |
| Turn | 185-285 | 300 | 185-285 | 300 | 80-320 | 425 |

[1]Criterion for setting minimum day and night intensity.

[2]Criterion for setting maximum night intensity.

It will be noted that system 1 requires 300 cd for 85% stop signal identification at night, which exceeds the maximum of 190 cd to control discomfort glare. Thus, stop signal identification will have to be compromised to reduce signal identification or to cause excessive glare. The turn signal requires intensities of 185-285 cd. In the daytime, intensities for stop and turn lamps of 300 cd or greater are needed.

System 4, using red stop lamps separated from combined red presence and turn lamps, requires intensities of 80-190 cd for stop lamps, and 185-285 for turn lamps at night. In the day, intensities of 300 cd are needed for stop and turn lamps.

System 5, using red stop lamps, amber turn lamps and green-blue presence lamps, requires 80-190 cd for stop lamps and 80-320 cd for turn lamps at night. In the day, intensities of 300 cd are needed for stop lamps and 425 cd for turn lamps.

Presence lamp intensities of 4-15 cd are recommended.

It is concluded that system coding must be taken into account in order to determine the intensities required for signal lamps in the day and at night. The intensity ranges that can be used are different in the day and at night, and are dependent on the signal mode (steady-burning or flashing), color, area, inter-lamp separation distance and functional separation.

For these reasons the present standard, based on SAE J-575d, should be revised to improve rear signal system effectiveness.

Derivation of Intensity Requirements. The intensities needed for presence, stop and turn signal lamps can be derived by the following procedure:

1. Presence lamps: 4-15 cd
2. Night Minimum $(N_{MIN})$ Stop or Turn:
    a) Determine the system type (e.g., 1, 4 or 5).
    b) Find intensity (I) for 12.6 sq. inch lamp from Table 5.46 for that system type.

c) Modify value found in (b) by multiplying by the intensity ratio, R, where:

$$R = \frac{N_{MIN} \text{ Candlepower Required for Lamp of Area A (Figures 1-3 Appendix C)}}{N_{MIN} \text{ Candlepower Required for Lamp of 12.6 Inches (Figures 1-3, Appendix C)}}$$

A = The area of the lamp whose intensity is being determined.

Then, $N_{MIN}$, for lamp of area A = R x I candelas.

3. <u>Night Maximum ($N_{MAX}$), for Stop</u>:

Use $N_{MAX}$, Figures 1-3, Appendix C, for lamp of area A, candelas.

4. <u>Night Maximum ($N_{MAX}$), for Turn</u>:

Use $N_{MAX}$ (Stop) x 1.5, candelas.

5. <u>Day Minimum ($D_{MAX}$), for Stop or Turn</u>:

Use $D_{MIN}$, Figures 1-3, Appendix C, for lamp of area A, candelas.

## 6. DEVELOPMENT OF COLORED FILTER CHARACTERISTICS FOR REAR LIGHTING SYSTEMS BASED ON COLOR DISCRIMINATION AND IDENTIFICATION OF NORMAL AND COLOR-BLIND DRIVERS.

At present the principal techniques of light coding in rear lighting systems are lights which flash and lights which change in intensity. For the most part color coding is not used in such systems. However, psychological research has shown that the attention-getting and informational values of visual displays can be enhanced by the appropriate use of color coding. Furthermore, research (Mortimer, 1969; 1970) has shown that drivers have shorter reaction times and make fewer mistakes when interpreting the meanings of signals if color coding is used in rear lighting systems. Color coding is, therefore, a useful way to improve vehicle rear lighting and improve highway safety.

In order to maximize the contribution of color coding to a rear lighting system, the set of colors chosen must satisfy many requirements. From a psychological viewpoint the colors must have at least the following two properties: (1) when two of these colors are simultaneously presented they must not be confused with each other, and (2) when one color is presented by itself it must be readily recognized as which color of the set it is. In addition, it is highly desirable that the colors retain these properties when viewed by color-blind drivers.

The aim of this study is to find a set of three colors (plus white) which will satisfy the above criteria. In pursuit of this goal two experiments were conducted. The pilot study was directed at establishing the needed experimental procedures and at finalizing the equipment design. The main study incorporated the knowledge gained from the pilot study to extend and broaden the research, in order that colored filters for use in vehicle rear lighting systems can be selected that can be readily identified and are not confused with each other or with the white lights of approaching vehicles at night.

BACKGROUND

COLOR SPECIFICATION. The color of light is a function of its spectral composition and of the spectral sensitivities of the human eye. That is, color is a psychophysical concept associated both with radiant energy and with sensation.

Any color can be specified in terms of three psychophysical variables--luminance, dominant wavelength and purity. Luminance is analogous to the sensation of brightness. Dominant wavelength is analogous to the sensation of hue and is the property of color which makes it red, blue, etc. Purity is the counterpart of the sensation of saturation. It refers to the proportion of a color attributable to its dominant wavelength. For example, blue and powder blue can result from the same dominant wavelength but different purities. By taking the blue dominant wavelength and mixing it with white light, the proportion of the dominant wavelength in the mixture is reduced and a less pure form of blue is obtained, i.e., powder blue.

Another frequently used term is chromaticity. Its sensation counterpart is chromacticness, and it refers to the combination of dominant wavelength and purity in a color without regard to its luminance. Thus a color can also be specified by its chromaticity and luminance.

Chromaticity Diagrams. It is a principle in color vision that any given color can be matched by an additive mixture of three suitably chosen primary colors. (The primary colors are suitably chosen if: (1) there exists an additive mixture of the three which results in white, and (2) no one of the three can be matched by an additive mixture of the other two.) This principle is the basis for an experimental technique known as tristimulus color matching.

The tristimulus color matching technique requires an observer to simultaneously view a target color and a matching color while adjusting the matching color until it appears identical to the target. The matching stimulus is produced by combining the light from three primary colors chosen as above. Adjustments to the color of the matching stimulus are made by individually adjusting the luminance of each primary color in the mixture. When a match is achieved the luminance of primary one (P1), the luminance of primary two (P2), and the luminance of primary three (P3) are recorded. The values of P1, P2 and P3 are known as the tristimulus values for that target color. A new target color is selected and the procedure is repeated to obtain tristimulus values for the new color. By this method all colors can be expressed in terms of tristimulus values, though these values would change if a new set of three primaries were selected to form the matching stimulus.

Tristimulus values, in turn, form the basis for generating chromaticity diagrams. A chromaticity coordinate is defined as the ratio of one tristimulus value divided by the sum of all three tristimulus values. Thus, from the above discussion:

$$\text{Chromaticity coordinate 1} = \frac{P1}{P1 + P2 + P3} = C1$$

$$\text{Chromaticity coordinate 2} = \frac{P2}{P1 + P2 + P3} = C2$$

$$\text{Chromaticity coordinate 3} = \frac{P3}{P1 + P2 + P3} = C3$$

Notice that the ratios which define C1, C2 and C3 have luminance units in both their numerators and denominators. Therefore, the chromaticity coordinates are not themselves luminances, they are dimensionless ratios. However, since each color has a particular combination of dominant wavelength and purity associated with its luminance, ordering colors according to their chromaticity coordinates is equivalent to ordering them by their combinations of dominant wavelength and purity without regard to their respective luminances. In other words, it is equivalent to ordering colors according to their chromaticity, hence the name chromaticity coordinates.

Another important aspect of chromaticity coordinates is that they sum to one, i.e., C1 + C2 + C3 = 1. Therefore, knowing any two of the three chromaticity coordinates completely specifies the chromaticity of a color. Thus, one can plot on ordinary graph paper a chromaticity diagram. In such a diagram the x-axis would represent the value of one chromaticity coordinate and the y-axis would be the value of another chromaticity coordinate. (Since the value of the third chromaticity coordinate is easily determined from the other two, it need not be plotted.)

In a chromaticity diagram generated in this fashion the values on the axes range from -1 through 0 to +1. Any point on such a diagram would represent the set of all colors having the same chromaticity but differing in luminance. The location of the point on the diagram would indicate the chromaticity of that set of colors.

The CIE Chromaticity Diagram. Prior to 1931 the CIE (Commission Internationale de l'Eclairage - International Commission on Illumination) developed a chromaticity diagram for all real colors by using the tristimulus color matching technique. The three primary colors which were combined to produce the matching color were defined as follows: (1) pure red with wavelength of 700 nm, (2) pure green with wavelength of 546.1 nm, and (3) pure blue with wavelength of 435.8 nm (1 nm = 1 nanometer = 1 millimicron). This system, known as the RGB System, had certain inherent difficulties. For example, researchers began to think of color perception as involving a red receptor, a green receptor and a blue receptor (which is not necessarily the case) because of the three primaries used to develop the chromaticity diagram. Another problem was that many of the chromaticity coordinates had negative values which greatly complicated computations in the system. (A negative chromaticity coordinate means that one of the primary colors was added to the target stimulus instead of the matching stimulus in order to obtain a match. Adding to the target stimulus is the same as subtracting from the matching stimulus, hence a negative tristimulus value and a negative chromaticity coordinate.)

For these reasons, in 1931 the CIE defined a procedure to mathematically transform the RGB System into a new one known as the XYZ System, which is currently used in colorimetric research. In this system X, Y, and Z are not associated with any particular real colors. In fact, X, Y, and Z represent tristimulus values based on imaginary primary colors which cannot be obtained in the real world. (The XYZ System is mathematically real, however, and has a one-to-one correspondence with the real world RGB System.) One of the RGB System's problems is thus avoided, since one would have to think in terms of an imaginary X receptor, Y receptor, or Z receptor as a means of explaining color perception.

Chromaticity coordinates in this system are called $x$, $y$, and $z$. As before, $x + y + z = 1$, but these have the additional property that they never take on negative values for a real color. Thus, the RGB System's other problem is avoided.

The 1931 CIE Chromaticity Diagram based on the XYZ System is shown in Figure 6.1, which is based on work by K.L. Kelly, as reported by Sheppard (1966).

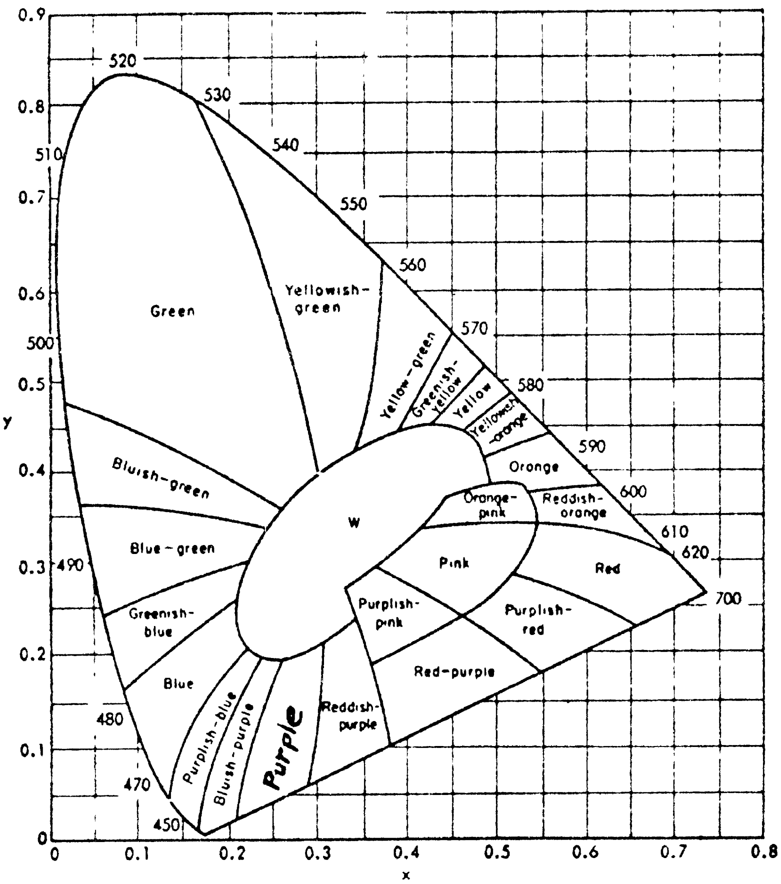


Figure 6.1. CIE chromaticity diagram with names for color regions added.

All real colors have chromaticities contained within the triangular area obtained when plotting x against y as shown in the figure. Pure spectrum colors are located at the border of the triangular area. The numbers around the border of the triangular area in the figure indicate the wavelength (in nanometers) of the spectral color located at that point of the border. The diagram indicates the names commonly used to describe colors whose chromaticities fall within the delineated regions. (The color names are not part of the CIE System.)

Along the bottom of the real color area are found the red-blue combinations. These are not pure spectrum colors, rather they are colors obtained by mixtures of two spectral colors. Accordingly, no wavelength designations appear along this line.

The region in the center of the diagram labeled W shows the chromaticity locations of white. The purity of a color is indicated by how close its chromaticity is to the white region or to the border of the diagram.

In summary, a change in the dominant wavelength of a color is analogous to a movement along the border of the real color area of the chromaticity diagram. A change in the purity of a color is analogous to a movement toward or away from the white region. A change in the luminance of a color is not reflected in the chromaticity diagram, since each point on the diagram represents all colors of the same chromaticity but differing in luminance.

Figure 6.2, shows the locations of color as defined by certain standards. In the diagram the regions labeled SAE Red, Yellow, and White are defined by specifications SAE J578a. Any color whose chromaticity point falls within one of these boundaries is red, yellow or white, whichever is applicable, by SAE definition. Also shown are two types of green and a blue as defined by the United States Standard for the Colors of Signal Lights (Breckenridge, 1964). The point in the diagram marked E is for reference. It is the chromaticity location of the color seen when the eye is presented with equal energy at all visible wavelengths. It is a white and is known as the equal energy point. The chromaticity coordinates for E are $x = y = z = 1/3$.

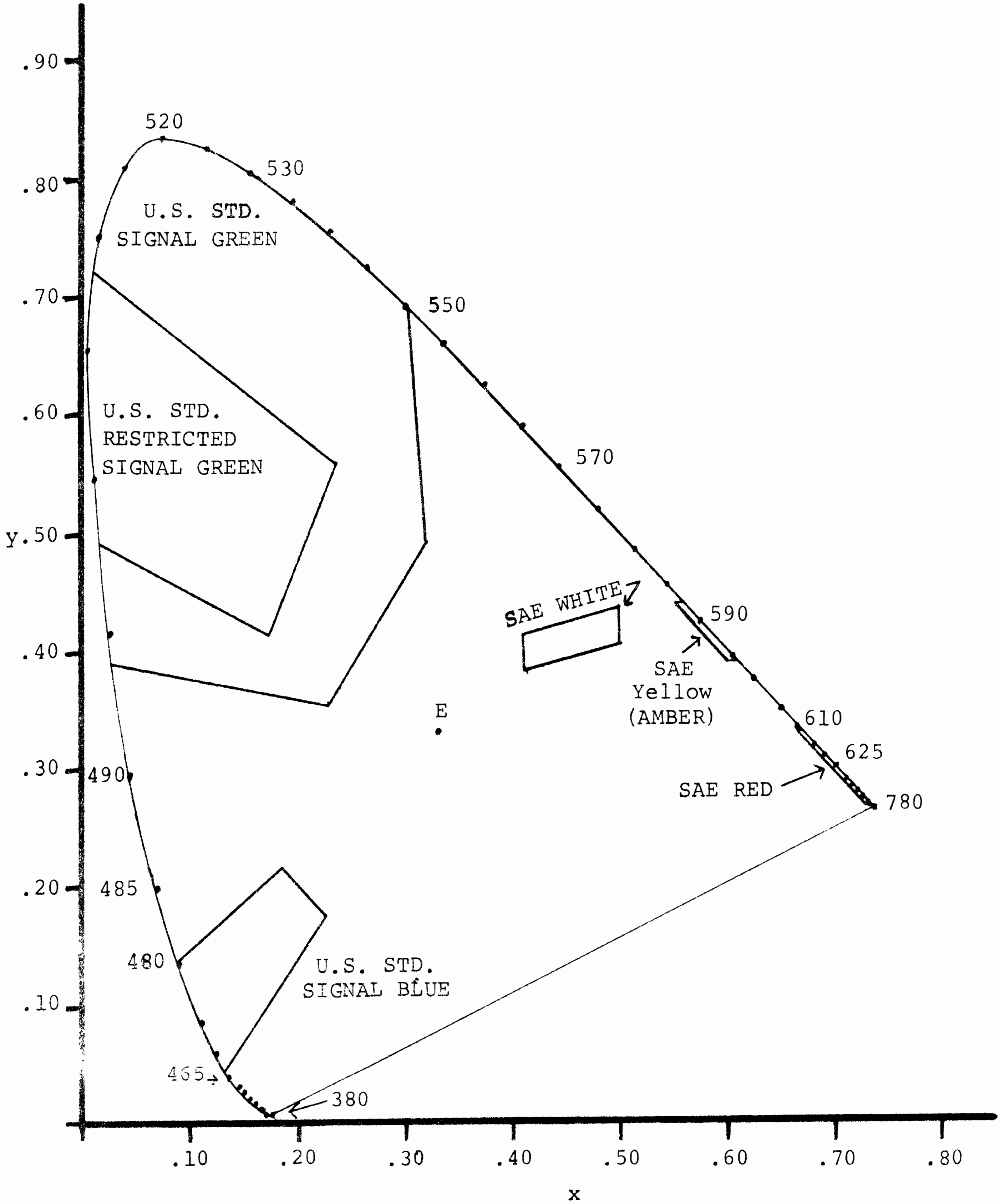


Figure 6.2. Some standard colors on the CIE chromaticity diagram.

TYPES OF COLOR BLINDNESS. A person who has full color vision is called a trichromat, because three primary colors are required in a mixture to match all the colors he can see. A dichromat, on the other hand, requires only two primary colors in a mixture to match all the colors he can perceive. Finally, a monochromat (totally color-blind) can match all the colors he can see by adjusting the luminance of a single primary.

There are three types of dichromats--protanopes, deuteranopes and tritanopes. Protanopes and deuteranopes confuse reds with greens and are described as having "red-green color blindness." Tritanopes confuse reddish-blues with yellowish-greens and are described as having "yellow-blue color blindness."

Corresponding to the categories of dichromats, there are three categories of anomalous trichromatic vision. These trichromats have color weaknesses and show some of the characteristics of dichromatic vision. The categories are protanomalous, deuteranomalous and tritanomalous trichromatic vision.

The frequency of occurrence of each type of color-defective vision in the total population is shown in Table 6.1.

TABLE 6.1. Distribution of Color Defective Vision in the Population (Legrand, 1957).

| Type of Color Defect | Percent | |
|---|---|---|
| | Male | Female |
| Trichromats | | |
| Protanomalous | .9 | .02 |
| Deuteranomalous | 4.7 | .38 |
| Tritanomalous | <.01 | <.01 |
| Dichromats | | |
| Protanope | 1.2 | .02 |
| Deuteranope | 1.4 | .01 |
| Tritanope | <.01 | <.01 |
| Monochromats | <.01 | <.01 |

PILOT STUDY

EQUIPMENT. Essentially the same equipment was used for the pilot study and for the main study. For this reason, a detailed description of the equipment used in both studies is presented here with the differences between the two studies noted.

Color stimuli were presented by means of a dual-path monochromator. This instrument is composed of two single monochromators which operate independently of each other and are placed such that the outputs of each are focused on the same ground glass screen to form two separate areas of colored light. In the pilot study, these two areas were rectangular, 1/8 in. x 7/8 in. each, being separated by 1/4 in. In the main study these areas were rounded/rectangular, 1/8 in. x 3/8 in. each, being separated by 1/4 in. The two monochromators share a common projector lamp as the input source for monochromatic light; but they each have their own miniature lamp as the source for white desaturating (purity reducing) light. The optical system for one of the monochromators is shown in Figure 6.3.

As shown in Figure 6.3, white light from the projector lamp (General Electric Co., Type CPR) is reflected by a mirror and passed through two masks, a lens, a neutral density wedge, and a neutral density filter before entering the Farrand No. 132106, Foci-Flex monochromator. The lens position is adjustable and is used to focus the white light at the entrance slit of the Farrand monochromator. The neutral density wedge and filter are used to vary the intensity of the entering light. A lead screw, operated from outside the dual-path monochromator enclosure, positions the neutral density wedge, while neutral density filters may be removed or replaced through an opening in the enclosure. (No neutral density filters were used in either the pilot study or the main study, as the intensity range provided by the wedge alone was sufficient.)

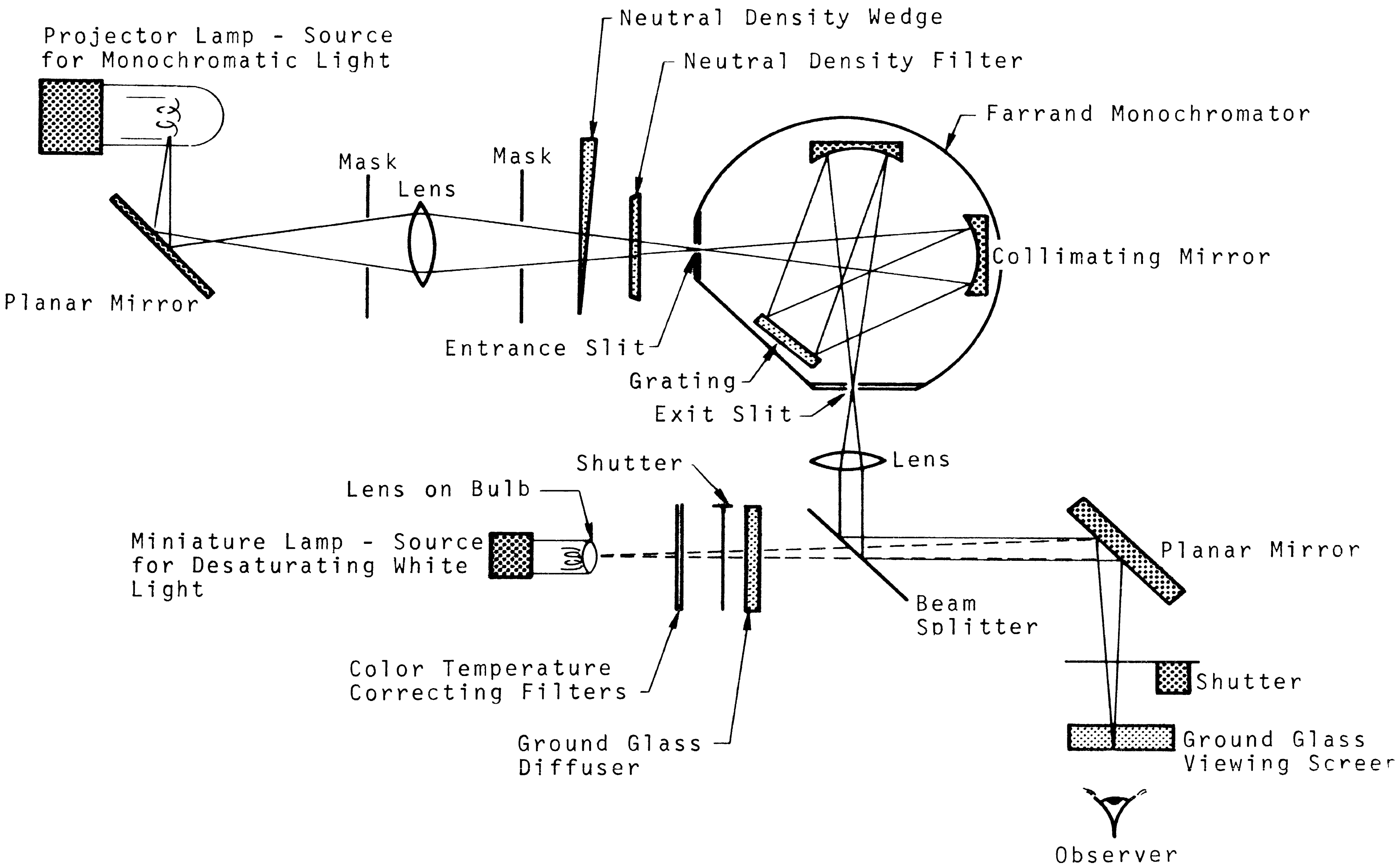


Figure 6.3. Optical system for one side of the dual-path monochromator.

Inside the Farrand Monochromator the light is reflected from a collimating mirror onto the reflective grating. The dispersed beam is directed onto the other collimating mirror and focused at the exit slit. By adjusting the angular position of the grating with a knob external to the enclosure, a pure color of the desired wavelength is obtained at the exit slit. The monochromator is specified to have a range of 210-800 nm and has about 28,000 grating lines per inch. Both the entrance and exit slits may be changed to produce desired bandwidths from 2.0-20.0 nm.

From the exit slit, the pure-color light passes through another lens, is reflected off a beam splitter and a mirror, passes a shutter, and finally comes to a focus on the ground glass viewing screen. The position of the lens at the exit slit is adjustable and is used to focus the light at the viewing screen. The beam splitter is actually used as a beam combiner and is the means by which white desaturating light is mixed with the pure monochromatic light. The shutter is electromagnetically operated by means of a solenoid.

Desaturating white light from the miniature lamp (Chicago Miniature Co., Type CM-20) passes through a dispersing lens on the end of the bulb, two color-temperature correcting filters, and a ground glass diffuser before entering the beam splitter, where it is mixed with the monochromatic light. Color-temperature correcting filters were not used in the pilot study, but two were used in each light path for the main study. One light path had two Kodak Wratten, Type 80C filters and the other light path had one Kodak Wratten, Type 80B and one Type 82A. These filters were used to bring the color temperature of the light from the CM-20 lamps up to the color temperature of a white standard, known as CIE Source A. The Shutter, shown between the filters and the ground glass diffuser, is manually operated. It was not used in the pilot study, since no pure colors were presented to the subjects.

The assembly which houses the CM-20 lamp and its color-temperature correcting filters is mounted on a slider arm perpendicular to the dual-path monochromator enclosure wall (Figure 6.4). The percentage of desaturating white light mixed with the pure monochromatic light is varied by moving the CM-20 lamp assembly back and forth along the slider arm, with the manual shutter in place when zero percent is desired.

Aside from the desaturating light and slider arm assemblies, the Farrand monochromators and their optical system components are mounted in an enclosure which contains internal baffles to minimize external light interference and to minimize dilution and mixing of the two light beams.

The power supply for the projector lamp (operated at a constant 5.9 vdc in both studies) and the electronic control circuits for the dual-path monochromator (Figure 6.5) are housed in a separate unit. These control circuits operate the electromagnetic shutters and allow the color stimuli to be presented for variable time periods either simultaneously or consecutively with a variable delay period interspersed as desired.

In a pilot study the CM-20 lamps were operated at a constant 2.5 vdc by means of a Variac which stepped down 110v wall current. This power supply required constant adjustment, however, to maintain constant voltage at the lamp filaments. Therefore, in the main study the CM-20 lamps were powered by a 12v car battery and 1/2 amp charger in parallel. For any experimental run the voltage across these lamps was constant, but over the entire experiment it varied from 2.4 to 2.5 vdc in order to maintain the desired color temperature as the filaments aged. (The CM-20 lamps were wired in parallel in both studies.)

A digital voltmeter is also part of the equipment and allows monitoring of the voltages of all the lamps. In addition, periodic calibration and check of the dual-path monochromator is accomplished with a Pritchard photometer, Model No. 1970-PR.

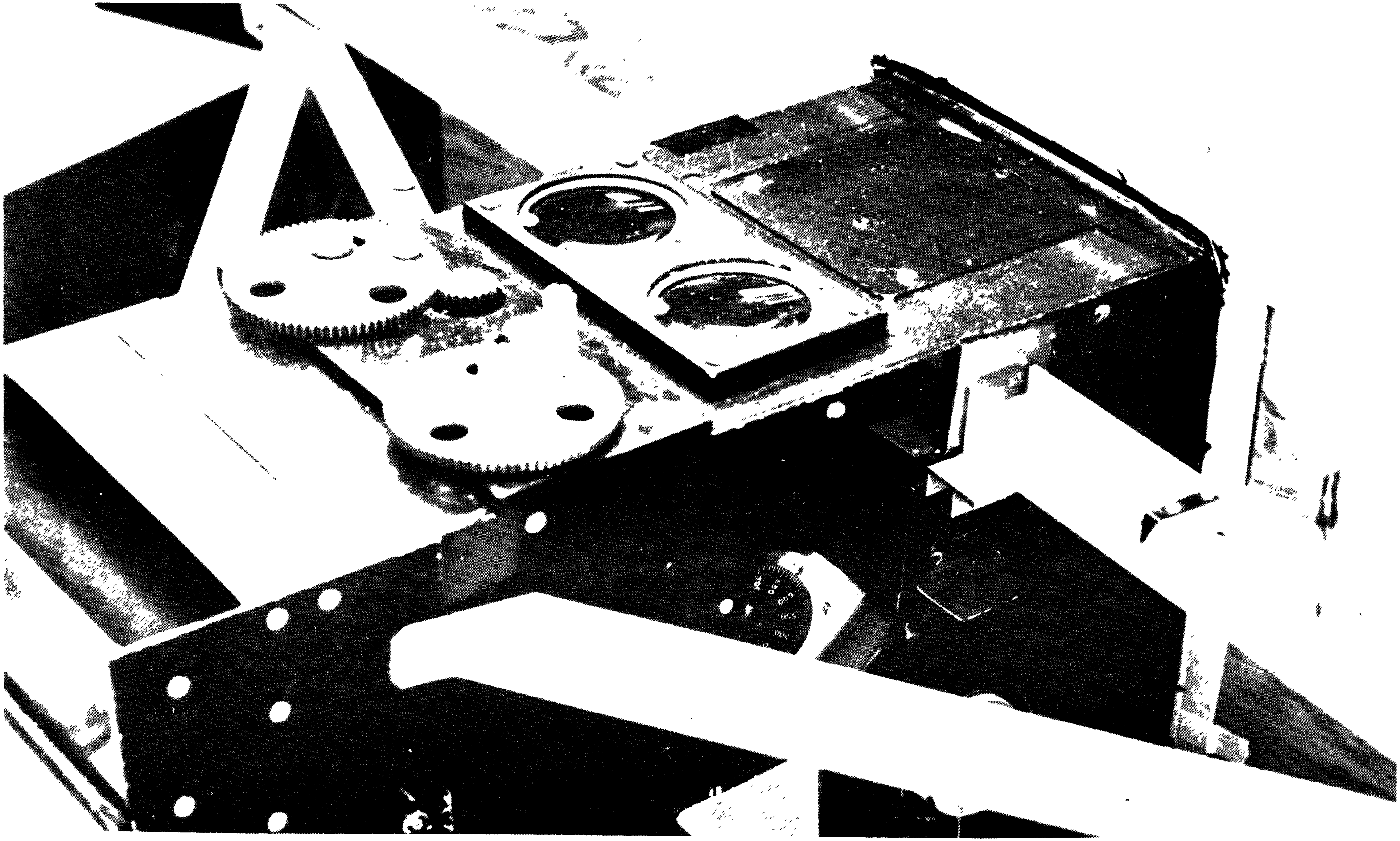

Figure 6.4. The dual-path monochromator, showing the slider arms supporting the desaturating source, neutral density wedge and wavelength controls.


Figure 6.5. Monochromator power, lamp and shutter timing controls.

In terms of the CIE Chromaticity Diagram (Figure 6.1), dual-path monochromator generates colors as follows: (1) a point on the border of the real color area is selected by setting the Farrand monochromator grating to the desired wavelength, and (2) movement from the border point toward the central white region is accomplished by sliding the miniature white light closer to the beam splitter, thereby increasing the proportion of white in the mixture and thus decreasing the purity.

SUBJECTS. Six subjects were used in the pilot study. All were tested with the Dvoring Psuedo-Isochromatic Plates (Dvorine, 1953) resulting in five classifications of "normal" color vision and one classification of "severe protanoid." All six subjects were males with ages ranging from 23 to 33.

METHOD.

Stimulus Selection. All colors used in the pilot study were at a luminance of 0.1 ft-L. Figure 6.6 shows these colors on the CIE Chromaticity Diagram. The point $W_0$ in Figure 6.6 is not a color shown to the subjects. It is the chromaticity of the white CM-20 miniature lights as measured at the bulb (color temperature=2260°K, coordinates: x=.499, y=.415).

Referring to Figure 6.6, stimuli $G_{11}$ through $G_{14}$ were selected by the following process:

1. The prue spectrum color at 484 nm was chosen as the dominant wavelength.
2. A straight line was drawn from this point to the $W_0$ point on the Chromaticity Diagram (see dashed line in Figure 6.6).
3. Point $G_{11}$ was chosen as the color whose dominant wavelength is 484 nm and whose purity (with respect to $W_0$) is .75.
4. Point $G_{14}$ was chosen as the color whose dominant wavelength is 484 nm and which falls just within the SAE white region.
5. Points $G_{12}$ and $G_{13}$ were chosen to be equally distributed between $G_{14}$ and $G_{11}$.

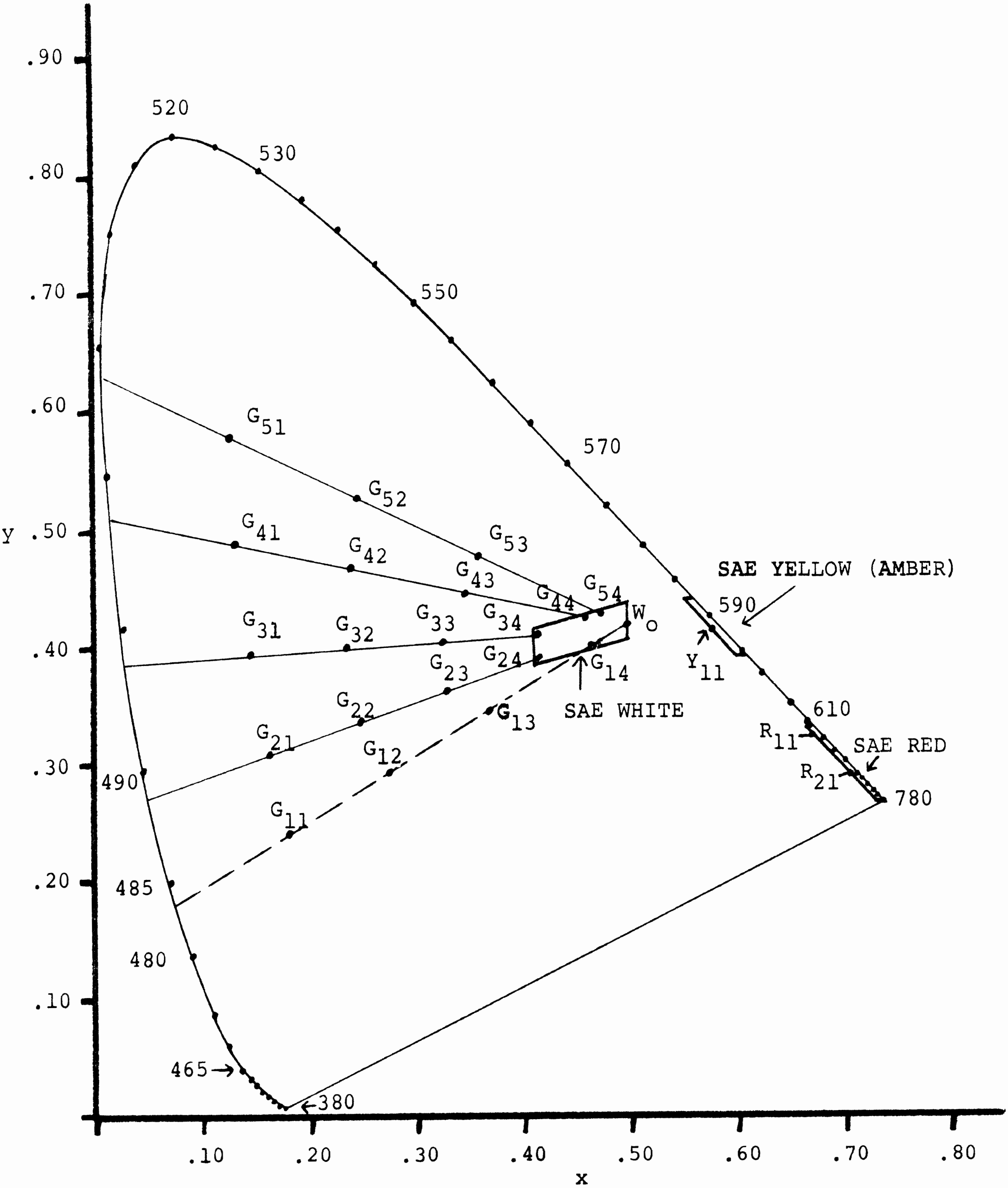


Figure 6.6. Pilot study stimuli on the CIE chromaticity diagram.

The reason these four points lie on the same straight line has to do with the definition of purity. As used in the present paper, purity means "excitation purity." The excitation purity of a sample color is always specified with respect to a particular "reference white." The way to determine excitation purity for the sample color on the Chromaticity Diagram is to draw a straight line from the reference white point through the sample color point to the border of the real color area. The point where this line intersects the border gives the dominant wavelength of the sample color. The purity is the ratio of the distance (along this line) between the white point and the sample point divided by the distance between the white point and the border. Thus, to say that $G_{11}$ has a purity of .75 with respect to $W_0$ is to say that the distance between $W_0$ and $G_{11}$ is 75% of the distance between $W_0$ and the border along the straight line through $W_0$ and $G_{11}$. In other words, $G_{11}$, $G_{12}$, $G_{13}$ and $G_{14}$ are colors of the same dominant wavelength (484 nm), but of different purities with respect to $W_0$.

By using various dominant wavelengths and purities, the remaining stimuli were chosen through essentially the same process. Table 6.2 shows the stimulus code name, dominant wavelength, excitation purity, and chromaticity coordinates for each stimulus color plotted in Figure 6.6. The stimulus code name can be interpreted as follows: (1) the capital letter indicates the color name of the dominant wavelength in the stimulus--G=green, Y=yellow, and R=red; (2) the first subscript refers to the particular dominant wavelength of that color name; and (3) the second subscript indicates the relative purity at that dominant wavelength. In general, the Gs were chosen to sample various greens merging into the SAE white region, the Rs were picked to sample the SAE red area, and Y was chosen to represent SAE yellow.

TABLE 6.2. Pilot Study Stimuli.

| Stimulus Code Name | Dominant Wavelength | Excitation* Purity (%) | CIE Chromaticity Coordinates |
|---|---|---|---|
| $G_{11}$ | 484 nm | 75 | x = .180, y = .242 |
| $G_{12}$ | 484 nm | 53 | x = .273, y = .293 |
| $G_{13}$ | 484 nm | 31 | x = .367, y = .344 |
| $G_{14}$ | 484 nm | 08 | x = .465, y = .397 |
| $G_{21}$ | 489 nm | 75 | x = .162, y = .309 |
| $G_{22}$ | 489 nm | 56 | x = .248, y = .336 |
| $G_{23}$ | 489 nm | 38 | x = .328, y = .361 |
| $G_{24}$ | 489 nm | 19 | x = .414, y = .388 |
| $G_{31}$ | 494 nm | 75 | x = .145, y = .395 |
| $G_{32}$ | 494 nm | 56 | x = .235, y = .400 |
| $G_{33}$ | 494 nm | 37 | x = .324, y = .405 |
| $G_{34}$ | 494 nm | 18 | x = .414, y = .410 |
| $G_{41}$ | 499 nm | 75 | x = .132, y = .488 |
| $G_{42}$ | 499 nm | 53 | x = .240, y = .467 |
| $G_{43}$ | 499 nm | 31 | x = .347, y = .445 |
| $G_{44}$ | 499 nm | 08 | x = .460, y = .423 |
| $G_{51}$ | 504 nm | 75 | x = .128, y = .578 |
| $G_{52}$ | 504 nm | 51 | x = .247, y = .526 |
| $G_{53}$ | 504 nm | 28 | x = .360, y = .476 |
| $G_{54}$ | 504 nm | 05 | x = .474, y = .426 |
| $Y_{11}$ | 592 nm | 89 | x = .577, y = .413 |
| $R_{11}$ | 617 nm | 91 | x = .668, y = .324 |
| $R_{21}$ | 650 nm | 90 | x = .704, y = .288 |

*With respect to $W_0$ (See Figure 3D.6).

Once the stimuli were chosen they were arranged in pairs, the intent being to have subjects make comparisons between the members of a pair. The color pairs were generated according to expected color confusions with a few cases of a color paired with itself to serve as reliability indicators. By this process, 38 pairs were formed and they were subsequently arranged in three random sequences to form three stimulus lists, a given pair appearing only once in a list. Table 6.3 shows the stimulus pairs. (Note that the pairs in column $G_{33}$ appeared only in list 1, while those in column $G_{34}$ appeared in all three lists.) Subjects 1, 2, and 4 were given only list 1; subject 3 received lists 1 and 2; and subjects 5 and 6 were given lists 1, 2, and 3. (Subject 6 was the protanoid.)

Stimulus Presentation and Responses. When viewing colors, subjects were enclosed in a hood which was painted flat black on the inside. Subjects viewed two color spots at eye level on a black surround, 10 ins. in front of their faces. A double-bulb fluorescent desk lamp was kept on in the room when not viewing colors, but was turned off during trials so the subjects would view the colors in the dark.

In the pilot study a single trial consisted of simultaneously presenting the two colors of a pair for a three second interval, and then having the subject respond. Subjects responded on each trial by first stating whether the two colors in the pair looked the "same or different" and then by naming the colors. If on any trial the subject responded "different" and then gave the same color name to both stimuli, he was asked to explain the difference. Responses were recorded by hand on prepared response sheets.

RESULTS AND DISCUSSION. The color names given by the subjects for each stimulus are shown in Tables 6.4 and 6.5. Table 6.4 shows the names used by the trichromats and Table 6.5

TABLE 6.3. Pilot Study Color Pairs.

| | $G_{11}$ | $G_{14}$ | $G_{24}$ | $G_{33}$* | $G_{34}$† | $G_{44}$ | $G_{54}$ | $Y_{11}$ | $R_{11}$ | $R_{21}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $G_{11}$ | x | x | | | | | | | | |
| $G_{12}$ | | x | | | | | | | | |
| $G_{13}$ | | x | | | | | | | | |
| $G_{14}$ | | x | | | | | | | | |
| $G_{21}$ | | | x | | | | | | | |
| $G_{22}$ | | | x | | | | | | | |
| $G_{23}$ | | | x | | | | | | | |
| $G_{31}$ | | | | x | x | | | | | |
| $G_{32}$ | | | | x | x | | | | | |
| $G_{33}$ | | | | x | x | | | | | |
| $G_{34}$ | | | | x | x | | | | | |
| $G_{41}$ | | | | | | x | | | | |
| $G_{42}$ | | | | | | x | | | | |
| $G_{43}$ | | | | | | x | | | | |
| $G_{51}$ | | | | | | | x | x | x | x |
| $G_{52}$ | | | | | | | x | x | x | x |
| $G_{53}$ | | | | | | | x | x | x | x |
| $G_{54}$ | | | | | | | x | | | |
| $Y_{11}$ | | | | | | | x | x | x | x |
| $R_{11}$ | | | | | | x | x | | x | |
| $R_{21}$ | | | | | | x | x | | | x |

*Pairs in column $G_{33}$ occurred only in List 1.
†Pairs in column $G_{34}$ occurred only in Lists 2 and 3.
xIndicates the stimulus of that row paired with the one of that column.

shows the ones used by the protanoid. Entries in both tables are in percent and the symbols for the color names are: R=red, R-Y=red to yellow, Y(A)=yellow or amber, Y-G=yellow to green, G=green, G-B=green to blue, and B=blue. Figures 6.7 and 6.8 are adapted from Tables 6.4 and 6.5, respectively, and show the predominant color names used for each stimulus on the CIE Chromaticity Diagram.

The color-naming data show a marked difference between the trichromats and the protanoid. The protanoid saw a much more restricted set of colors, since he rarely responded other than "red" or "green." Another interesting feature about the response of the protanoid is that he sometimes called the same stimulus green or red, depending on what it was paired with. For example, he called $G_{54}$ green whenever it was paired with $Y_{11}$, $R_{11}$, or $R_{21}$; but he called it red several times when it was paired with $G_{51}$, $G_{52}$, or $G_{53}$. This is thought to be for two reasons. First, previous experiences have forced him to use different names for colors that appeared to be identical. Thus, he is rather poor at absolute discrimination (naming). Second, in order to make discriminations at all, he usually has to rely on either context or brightness differences. In the experimental setting there are no contextual cues, and since his brightness response across wavelengths differs from that of trichromats, he was able to see brightness differences between stimuli that did not exist for the trichromatic subjects. (The Pritchard photometer measures luminance as if it were a trichromatic human eye. Since dichromats and trichromats have different brightness responses across the spectrum, in this experiment the brightness of the stimuli was made constant only for trichromats.) Thus, what often happened in the protanoid's color naming was a "green" response for the color that looked brighter, or conversely a "red" response for the color that looked darker.

Responses which the subjects gave when describing the differences and similarities between paired colors are shown in

TABLE 6.4. Color Names Given by the Trichromats for the Pilot Study Stimuli.

| Stimulus | Color Name | | | | | | |
|---|---|---|---|---|---|---|---|
| | R | R-Y | Y(A) | Y-G | G | G-B | B |
| $R_{21}$ | 100.0* | | | | | | |
| $R_{11}$ | 98.4 | 1.6 | | | | | |
| $Y_{11}$ | 1.6 | | 98.4 | | | | |
| $G_{54}$ | | | 96.9 | 3.1 | | | |
| $G_{44}$ | | | 95.0 | 5.0 | | | |
| $G_{34}$ | | | 100.0 | | | | |
| $G_{24}$ | | | 95.8 | 4.2 | | | |
| $G_{14}$ | | 2.5 | 97.5 | | | | |
| $G_{53}$ | | | 18.7 | 28.1 | 43.8 | | 9.4 |
| $G_{43}$ | | | | 37.5 | 50.0 | | 12.5 |
| $G_{33}$ | | | 21.4 | 35.7 | 28.6 | | 14.3 |
| $G_{23}$ | | | 62.5 | 25.0 | 12.5 | | |
| $G_{13}$ | | | 100.0 | | | | |
| $G_{52}$ | | | | | 87.5 | 3.1 | 9.4 |
| $G_{42}$ | | | | 12.5 | 75.0 | | 12.5 |
| $G_{32}$ | | | | 25.0 | 62.5 | | 12.5 |
| $G_{22}$ | | | | 25.0 | 62.5 | | 12.5 |
| $G_{12}$ | | | 12.5 | 37.5 | 25.0 | | 25.0 |
| $G_{51}$ | | | | | 71.9 | 21.9 | 6.2 |
| $G_{41}$ | | | | | 75.0 | 25.0 | |
| $G_{31}$ | | | | | 62.5 | 25.0 | 12.5 |
| $G_{21}$ | | | | | 75.0 | 12.5 | 12.5 |
| $G_{11}$ | | | | 4.2 | 50.0 | 8.3 | 37.5 |

*Table entry=percent.

TABLE 6.5. Color Names Given by the Protanoid for the Pilot Study Stimuli.

| Stimulus | Color Name | | | | | | |
|---|---|---|---|---|---|---|---|
| | R | R-Y | Y(A) | Y-G | G | G-B | B |
| $R_{21}$ | 83.3* | | | | 16.7 | | |
| $R_{11}$ | 87.5 | | | | 12.5 | | |
| $Y_{11}$ | 95.8 | | | | 4.2 | | |
| $G_{54}$ | 20.8 | | | | 79.2 | | |
| $G_{44}$ | 26.7 | | | | 73.3 | | |
| $G_{34}$ | | | | | 100.0 | | |
| $G_{24}$ | | | | | 100.0 | | |
| $G_{14}$ | 6.7 | | | | 93.3 | | |
| $G_{53}$ | | | | | 100.0 | | |
| $G_{43}$ | | | | | 100.0 | | |
| $G_{33}$ | | | | | 100.0 | | |
| $G_{23}$ | | | | | 100.0 | | |
| $G_{13}$ | | | | | 100.0 | | |
| $G_{52}$ | | | | | 100.0 | | |
| $G_{42}$ | | | | | 100.0 | | |
| $G_{32}$ | | | | | 100.0 | | |
| $G_{22}$ | | | | | 100.0 | | |
| $G_{12}$ | | | | | 66.7 | 33.3 | |
| $G_{51}$ | | | | | 100.0 | | |
| $G_{41}$ | | | | | 100.0 | | |
| $G_{31}$ | | | | | 100.0 | | |
| $G_{21}$ | | | | | 66.7 | 33.3 | |
| $G_{11}$ | | | | | 44.5 | 33.3 | 22.2 |

*Table entry=percent.

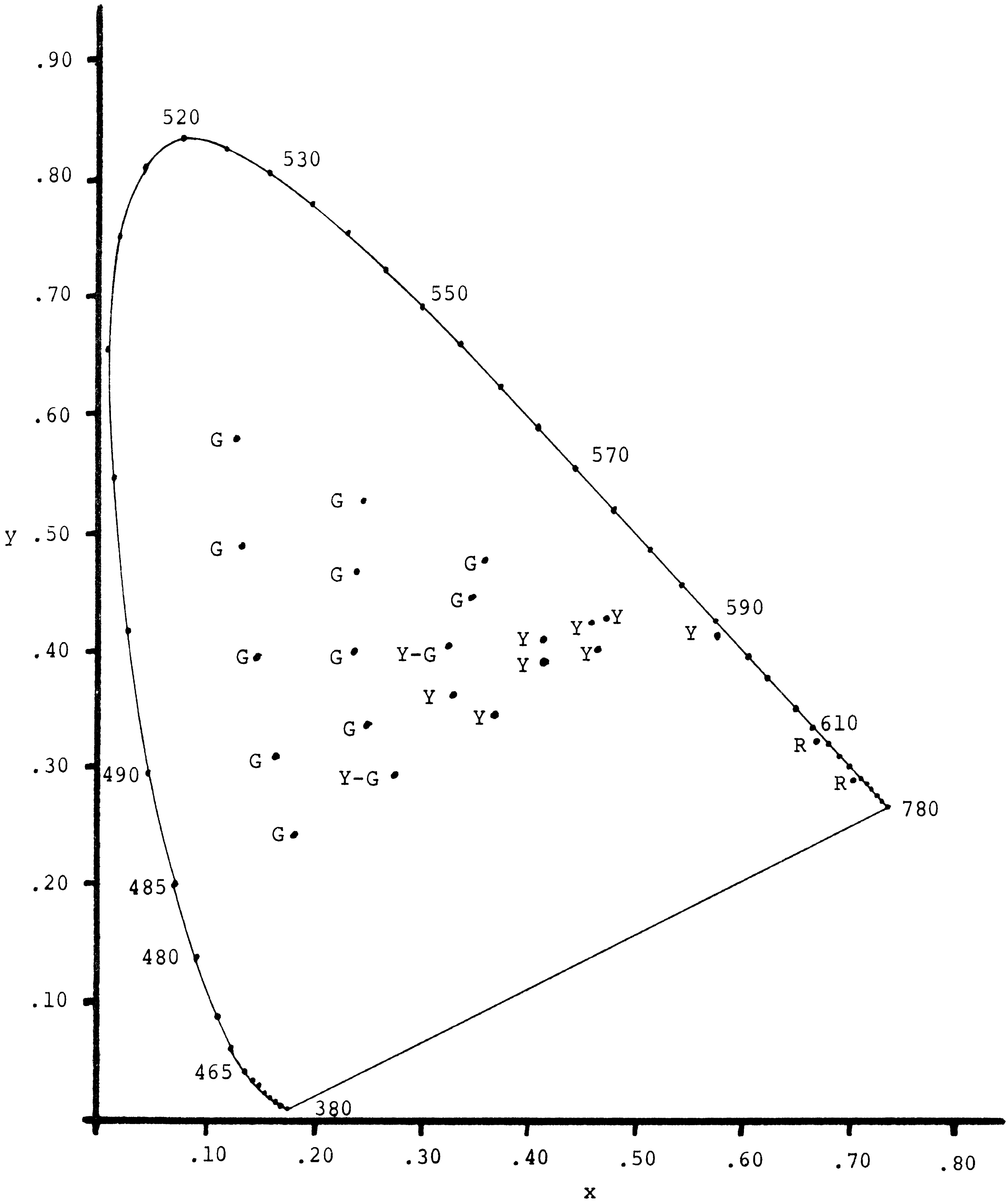


Figure 6.7. Predominant color names given by the trichromats for the pilot study stimuli.

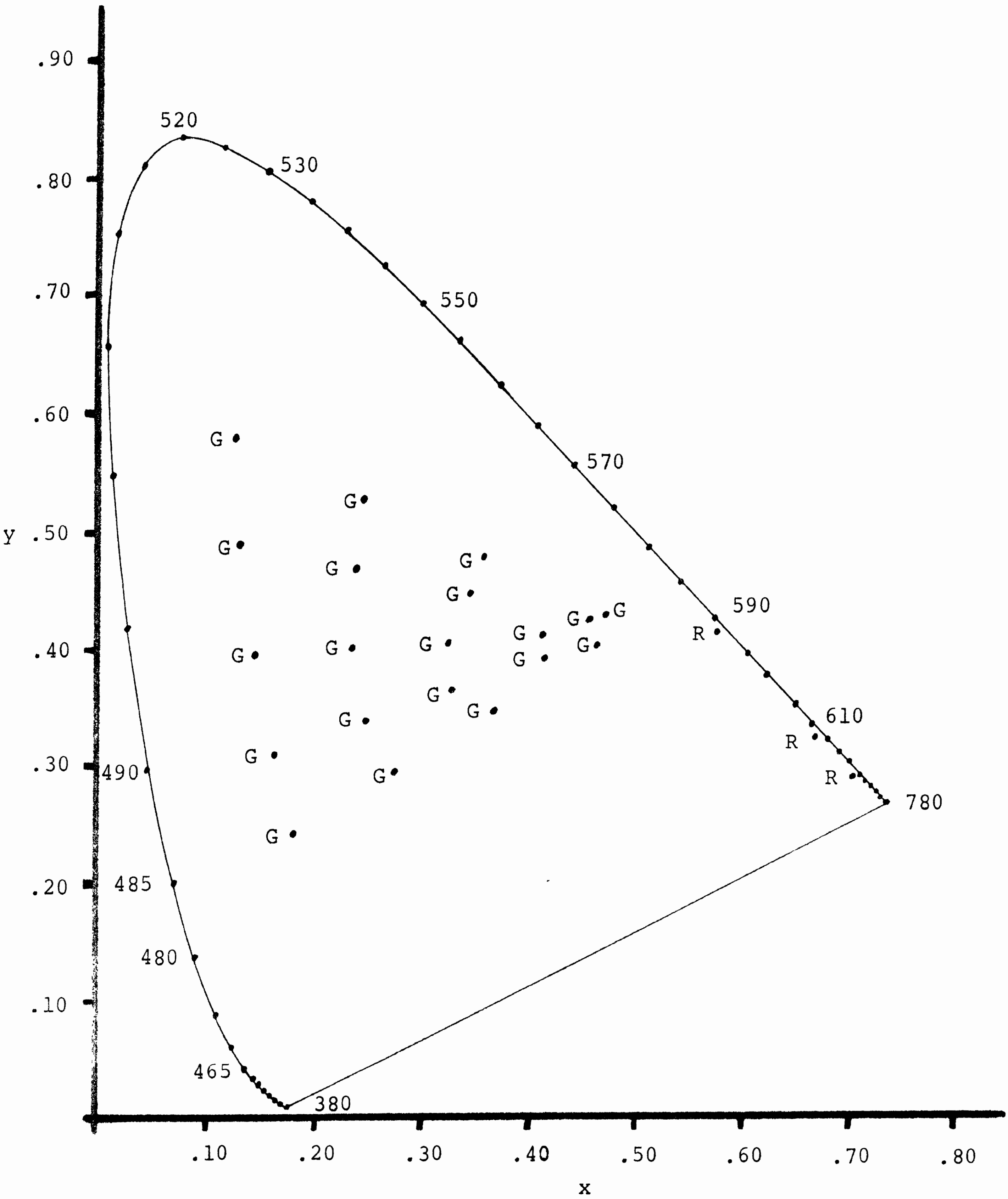


Figure 6.8. Predominant color names given by the protanoid for the pilot study stimuli.

Table 6.6. Numbers in the "chromatic difference" columns of the table are the percent of responses which were in terms of hue and/or saturation. Numbers in the "brightness or no difference" columns are the percent of responses which indicated either no difference was seen or a difference only in brightness was seen. (The protanoid described differences between colors in terms of brightness or hue, but never in terms of saturation. The trichromats on the other hand, used terms of hue or saturation, but never brightness in comparing the paired stimuli.) The first twelve pairs given in the table were always chromatically different for every subject, and the last eight pairs were never chromatically different for the protanoid. Considering responses from the protanoid, Table 6.6 indicates that SAE red is not distinct from SAE yellow. However, SAE red and yellow appear to be distinct from SAE white for the protanoid and the trichromats.

In Table 6.7 the same type of data are presented for the stimuli which were paired with themselves. In this table a low percent entry in the "chromatic difference" columns is desirable, since that would indicate high reliability in subject responses and in stimulus generation. Unfortunately, the obtained values are higher than desired, i.e., when the same color was presented to both slits on the ground glass screen, subjects perceived them as being different on several occasions.

Results from the pilot study identified the following problem areas which needed improvement before conducting the main study:

1. Subjects became overly bored and fatigued due to the slow pace of the experiment combined with an intermittent requirement for exact judgments.

2. Subjects used too many different color names and concentrated too heavily on irrelevant differences between colors, thus producing excessive variability in responses.

3. Color production was somewhat too variable.

TABLE 6.6. Differences Between Pilot Study Colors as Judged by the Trichromats and the Protanoid.

| Color Pair | Trichromat's Responses | | Protanoid's Responses | |
|---|---|---|---|---|
| | Chromatic Difference | Brightness or No Difference | Chromatic Difference | Brightness or No Difference |
| $G_{11} - G_{14}$ | 100.0* | | 100.0 | |
| $Y_{11} - G_{51}$ | 100.0 | | 100.0 | |
| $Y_{11} - G_{52}$ | 100.0 | | 100.0 | |
| $Y_{11} - G_{53}$ | 100.0 | | 100.0 | |
| $R_{11} - G_{51}$ | 100.0 | | 100.0 | |
| $R_{11} - G_{52}$ | 100.0 | | 100.0 | |
| $R_{11} - G_{53}$ | 100.0 | | 100.0 | |
| $R_{11} - G_{54}$ | 100.0 | | 100.0 | |
| $R_{11} - G_{44}$ | 100.0 | | 100.0 | |
| $R_{21} - G_{52}$ | 100.0 | | 100.0 | |
| $R_{21} - G_{54}$ | 100.0 | | 100.0 | |
| $R_{21} - G_{44}$ | 100.0 | | 100.0 | |
| $Y_{11} - G_{54}$ | 75.0 | 25.0 | 100.0 | |
| $G_{42} - G_{44}$ | 100.0 | | 66.7 | 33.3 |
| $G_{52} - G_{54}$ | 100.0 | | 66.7 | 33.3 |
| $R_{21} - G_{51}$ | 100.0 | | 66.7 | 33.3 |
| $R_{21} - G_{53}$ | 100.0 | | 66.7 | 33.3 |
| $G_{21} - G_{24}$ | 100.0 | | 33.3 | 66.7 |
| $G_{41} - G_{44}$ | 100.0 | | 33.3 | 66.7 |
| $G_{51} - G_{54}$ | 100.0 | | 33.3 | 66.7 |
| $G_{43} - G_{44}$ | 100.0 | | 33.3 | 66.7 |
| $R_{21} - Y_{11}$ | 100.0 | | 33.3 | 66.7 |
| $R_{11} - Y_{11}$ | 100.0 | | 33.3 | 66.7 |
| $G_{12} - G_{14}$ | 87.5 | 12.5 | 33.3 | 66.7 |
| $G_{53} - G_{54}$ | 87.5 | 12.5 | 33.3 | 66.7 |
| $G_{31} - G_{34}$ | 100.0 | | | 100.0 |
| $G_{22} - G_{24}$ | 100.0 | | | 100.0 |
| $G_{32} - G_{34}$ | 100.0 | | | 100.0 |
| $G_{31} - G_{33}$ | 100.0 | | | 100.0 |
| $G_{33} - G_{34}$ | 100.0 | | | 100.0 |
| $G_{13} - G_{14}$ | 50.0 | 50.0 | | 100.0 |
| $G_{23} - G_{24}$ | 50.0 | 50.0 | | 100.0 |
| $G_{32} - G_{33}$ | 40.0 | 60.0 | | 100.0 |

*Table entry=percent

TABLE 6.7. Reported Differences When Pilot Study Colors Were Paired With Themselves as Judged by the Trichromats and the Protanoids.

| Color Pair | Trichromat's Responses | | Protanoid's Responses | |
|---|---|---|---|---|
| | Chromatic Difference | Brightness or No Difference | Chromatic Difference | Brightness or No Difference |
| $G_{33}$ - $G_{33}$ | 80.0* | 20.0 | | 100.0 |
| $G_{11}$ - $G_{11}$ | 50.0 | 50.0 | 66.7 | 33.3 |
| $R_{21}$ - $R_{21}$ | 37.5 | 62.5 | 66.7 | 33.3 |
| $R_{11}$ - $R_{11}$ | 25.0 | 75.0 | 66.7 | 33.3 |
| $Y_{11}$ - $Y_{11}$ | 25.0 | 75.0 | | 100.0 |
| $G_{54}$ - $G_{54}$ | 25.0 | 75.0 | 33.3 | 66.7 |
| $G_{14}$ - $G_{14}$ | 12.5 | 87.5 | | 100.0 |
| $G_{34}$ - $G_{34}$ | | 100.0 | | 100.0 |

*Table entry=percent.

4. The chromaticity of the white desaturating lights (point $W_O$ in Figure 6.6) was too far toward the orange causing too little flexibility in selecting chromaticity points. Changes needed to correct for each of these problem areas are discussed at their appropriate places in the description of the main study which follows.

MAIN STUDY

EQUIPMENT. As explained in the discussion of the pilot study, the equipment in the two studies was essentially the same. However, some changes were made to counteract the problems identified by the pilot study.

In order to combat subject boredom and fatigue, waiting periods between color presentations were considerably reduced and the general pace of the experiment was quickened by using a tape recorder to record responses and by making mechanical alterations to the dual-path monochromator which allowed more rapid selection of control settings to produce the desired colors.

A reduction in the variability of color production was obtained by installing a different power supply for the desaturating lights. This power supply is the battery and charger as discussed under pilot study equipment. In addition, the stimulus situation was made less variable by the introduction of an adjustable chin rest and a desk lamp in the subject's hood. The chin rest was set for each subject so that the colors always appeared at eye level, 9.5 inches away. The desk lamp is a 15 watt incandescent with a flat black reflector. It was positioned between the subject and the viewing screen (without blocking the view) at a distance of 5 inches from the viewing screen, and was automatically operated by the dual-path monochromator control electronics in such a way that the lamp was off only when the subject was viewing colors.

The problem with the desaturating light chromaticity was resolved by incorporating color-temperature correcting filters, as mentioned in the equipment section of the pilot study.

SUBJECTS. Six subjects were used in the main study. All were tested with the Dvorine Pseudo-Isochromatic Plates (Dvorine, 1953) resulting in two classifications of "normal," two of "severe deuteranoid" and two of "severe protanoid" color vision. All subjects were males with ages ranging from 21 to 29.

METHOD.

Stimulus Selection. In the pilot study, a constant luminance (with respect to the trichromatic eye) was used for all colors. This allowed the protanope to make judgments based on luminance differences, since his eye response was different from the full-color vision eye response across wavelengths. Thus, in order to minimize such unwanted luminance differences in the main study, colors were generated such that the luminance was constant within vision types but not across vision types. Chromaticity of any given color was the same for all subjects, but the relative luminance of the pure color and the white in each mixture was adjusted to compensate for the eye response for each vision type. All colors were at a luminance of 0.3 ft-L for trichromatic subjects. For the deuteranoid types, the main adjustment to achieve equal luminance was a boost in the luminance of the reds; and for the protanoid types, the main adjustments were a boost in the reds and a boost in the desaturating white. (It is not reasonable to describe luminances in terms of "foot-Lamberts" for dichromatic eyes, since such luminance measures are defined in terms of full-color eyes.) In brief, the colors seen by a given subject were all of equal luminance; but those same colors would not have been of equal luminance to another subject, if he were of a different vision type. For all subjects, however, a given color had the same chromaticity.

By the same process described in the pilot study, 26 colors were chosen for the main study. They are shown along with the SAE color zones on the CIE Chromaticity Diagram in Figure 6.9. The point marked A within the SAE white region is not a color shown to the subjects. It is the chromaticity of CIE Source A white--the

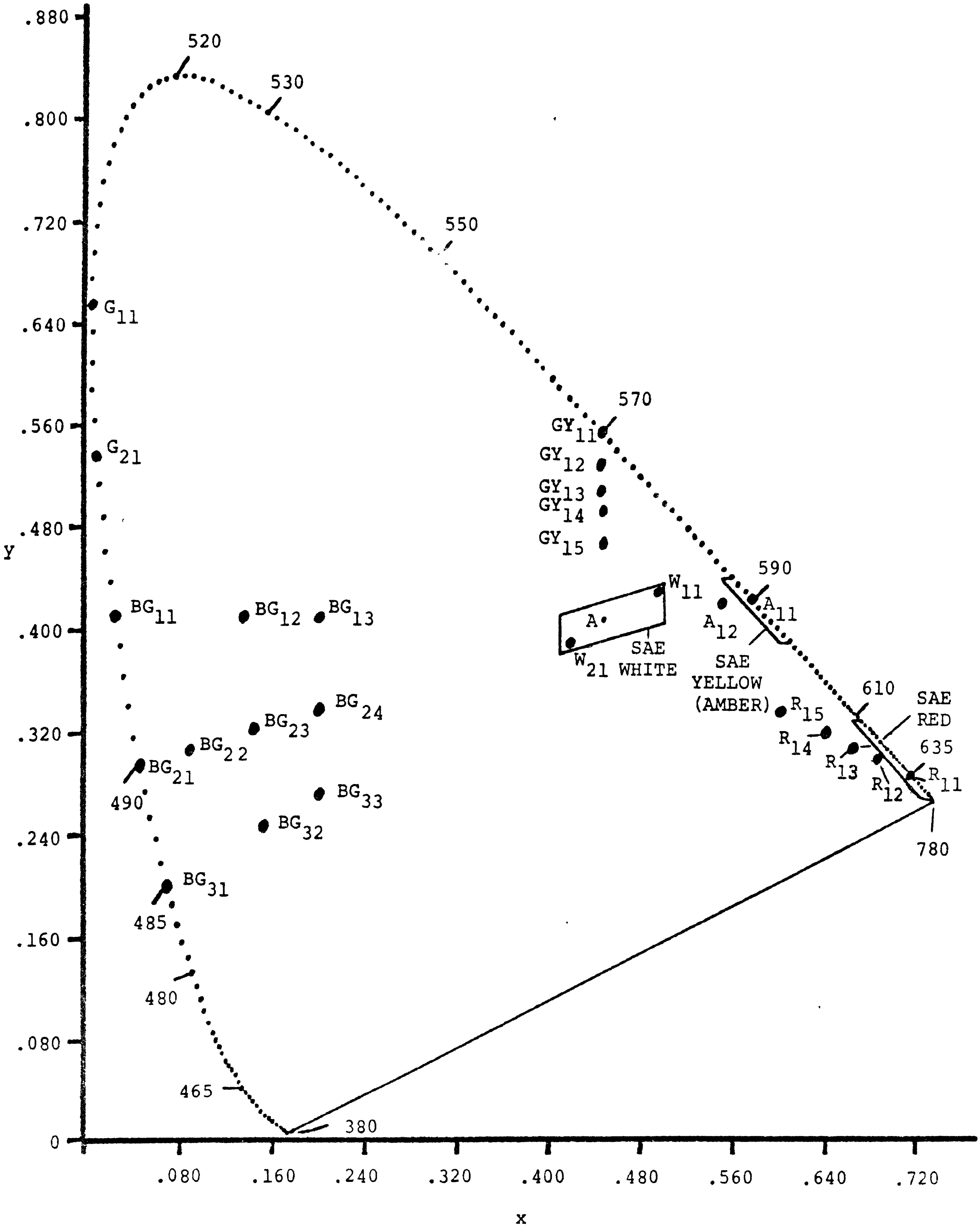


Figure 6.9. Main study stimuli on the CIE Chromaticity Diagram.

correlated color temperature to which the dual-path monochromator desaturating lights were moved by means of the color-temperature correcting filters (color temperature=2854°K, coordinates: x=.448, y=.407). By this means the problem in the pilot study of having the desaturating lights too far toward orange is avoided.

In Table 6.8 are listed the stimulus code name, dominant wavelength, excitation purity (with respect to Source A) and chromaticity coordinates for each stimulus color plotted in Figure 6.9. The stimulus code name can be interpreted as follows: (1) the capital letter indicates the color name of the dominant wavelength in the stimulus--R=red, A=amber, GY=greenish-yellow, W=white, G=green, and BG=blue-green; (2) the first subscript refers to the particular dominant wavelength within that color name; and (3) the second subscript refers to the excitation purity of the color at that dominant wavelength. For example, "$BG_{31}$" is a blue-green at dominant wavelength 3 (485nm) of the blue-greens and at purity level 1 (100%) of the blue-greens at 485nm.

Once the stimulus colors were chosen they were used to form 82 selected pairs of colors which are shown in Table 3.9. Pairs of colors, in turn, were used to generate four test lists. Each such list contained all 82 color pairs in random order with each pair appearing once per list.

The stimulus colors and color pairs were chosen to evaluate the present SAE color system with respect to the criteria stated in the Introduction, to explore means by which the present system could be modified to better satisfy those criteria, and to find a blue-green color set which could be added and still satisfy those criteria. In addition, some colors were paired with themselves to assess the reliability of the experimental procedures, and some color pairs were chosen to explore the implications of a dichromatic chromaticity coordinate system developed by Judd

TABLE 6.8. Main Study Stimuli.

| Stimulus Code Name | Dominant Wavelength | Excitation* Purity (%) | CIE Chromaticity Coordinates |
|---|---|---|---|
| $R_{11}$ | 635 nm | 100 | x = .714, y = .286 |
| $R_{12}$ | 635 nm | 89 | x = .686, y = .299 |
| $R_{13}$ | 635 nm | 81 | x = .664, y = .309 |
| $R_{14}$ | 635 nm | 72 | x = .640, y = .320 |
| $R_{15}$ | 635 nm | 58 | x = .602, y = .337 |
| $A_{11}$ | 590 nm | 100 | x = .575, y = .424 |
| $A_{12}$ | 590 nm | 80 | x = .550, y = .422 |
| $GY_{11}$ | 570 nm | 100 | x = .444, y = .558 |
| $GY_{12}$ | 570 nm | 81 | x = .445, y = .530 |
| $GY_{13}$ | 570 nm | 68 | x = .445, y = .510 |
| $GY_{14}$ | 570 nm | 57 | x = .446, y = .494 |
| $GY_{15}$ | 570 nm | 40 | x = .446, y = .468 |
| $W_{11}$ | 585 nm | 49 | x = .496, y = .431 |
| $W_{21}$ | 485 nm | 7 | x = .420, y = .391 |
| $G_{11}$ | 505 nm | 100 | x = .004, y = .655 |
| $G_{21}$ | 500 nm | 100 | x = .008, y = .538 |
| $BG_{11}$ | 495 nm | 100 | x = .023, y = .413 |
| $BG_{12}$ | 495 nm | 73 | x = .136, y = .411 |
| $BG_{13}$ | 495 nm | 58 | x = .200, y = .410 |
| $BG_{21}$ | 490 nm | 100 | x = .045, y = .295 |
| $BG_{22}$ | 490 nm | 89 | x = .088, y = .306 |
| $BG_{23}$ | 490 nm | 75 | x = .144, y = .322 |
| $BG_{24}$ | 490 nm | 62 | x = .200, y = .338 |
| $BG_{31}$ | 485 nm | 100 | x = .069, y = .201 |
| $BG_{32}$ | 485 nm | 78 | x = .152, y = .246 |
| $BG_{33}$ | 485 nm | 65 | x = .200, y = .272 |

*With respect to CIE Source A.

TABLE 6.9. Main Study Test List Color Pairs.

| | $R_{14}$ | $R_{11}$ | $A_{12}$ | $A_{11}$ | $GY_{14}$ | $GY_{13}$ | $GY_{12}$ | $GY_{11}$ | $W_{11}$ | $W_{21}$ | $G_{11}$ | $G_{21}$ | $BG_{13}$ | $BG_{12}$ | $BG_{11}$ | $BG_{24}$ | $BG_{23}$ | $BG_{22}$ | $BG_{21}$ | $BG_{33}$ | $BG_{32}$ | $BG_{31}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_{15}$ | | x* | x | | x | x | | | x | | x | | | | | | | | | | | |
| $R_{14}$ | x | | x | | x | x | x | | x | | | | | | | | | | | | | |
| $R_{13}$ | | x | x | x | x | x | x | | x | | | x | | | | | | | | | | |
| $R_{12}$ | | | x | x | x | x | x | x | x | | | | | | | | | | x | | | |
| $R_{11}$ | | | | x | x | x | x | x | | | | | | | | | | | | | x | |
| $A_{12}$ | | | | | | | | x | x | | x | | | | | | | x | | | | |
| $A_{11}$ | | | | x | | | | x | | x | | | | | | | x | | | | | |
| $GY_{15}$ | | | | | | | | x | x | | x | x | | x | | | | | | | | |
| $GY_{14}$ | | | | | | | | | x | | | | | | | | | | | | | |
| $GY_{13}$ | | | | | | x | | x | x | | | | | | | | | | | | | |
| $GY_{12}$ | | | | | | | | | | | | | | | x | | | | | | | |
| $GY_{11}$ | | | | | | | | | | | | | | | | | | | | | | x |
| $W_{21}$ | | | | | | | | | | x | x | x | x | x | | x | x | | | x | x | |
| $G_{11}$ | | | | | | | | | | | | | | | x | | | x | | | | |
| $G_{21}$ | | | | | | | | | | | | x | | | x | | | x | | | | |
| $BG_{13}$ | | | | | | | | | | | | | | | x | | | | | x | | x |
| $BG_{12}$ | | | | | | | | | | | | | | | x | | | | | | | |
| $BG_{11}$ | | | | | | | | | | | | | | | | | | | | x | | x |
| $BG_{24}$ | | | | | | | | | | | | | | | | | | | x | x | | x |
| $BG_{23}$ | | | | | | | | | | | | | | | | | x | | x | | | |
| $BG_{21}$ | | | | | | | | | | | | | | | | | | | | x | | x |
| $BG_{33}$ | | | | | | | | | | | | | | | | | | | | | | x |
| $BG_{32}$ | | | | | | | | | | | | | | | | | | | | | | x |

*x indicates the color of that row was paired with the one of that column.

(1948). Color choices and pairings were also based on the pilot study results. For example, blue-greens whose x-coordinates (CIE Chromaticity Diagram) were greater than .200 in the pilot study were often given names other than blue or green. Thus, in the main study $x \leq .200$ was used as the white limit for the blue-greens.

Stimulus Presentation and Responses. Unlike the pilot study, there were two color-observing conditions in the main study. In one case, two colors were presented simultaneously. In the other case, the two colors were presented sequentially. In the sequential case, five seconds elapsed between the termination of the first color and the onset of the second color. The left color spot (with respect to the subject) was always shown first in this condition. (In the remainder of this paper these two conditions are referred to as the "0 sec ISI" (Inter Stimulus Interval) condition and the "5 sec ISI" condition, respectively.)

Since the left-hand color was always shown first in the 5 sec ISI condition, color pairs had to be arranged so each color would appear equally often on the left and on the right. This was accomplished by interchanging the colors in every pair before generating the next test list. Thus, if a color pair presented a green to the subject's left and a red to his right in the first list, this same color pair would have the red on the subject's left and the green on his right in the second list, and so on. (The left-right interchange was also used for the 0 sec ISI condition.)

Subjects were instructed to respond on each trial first by giving a category name to each color and second by rating the similarity (to each other) of the two colors in the pair. When giving category names to the colors, subjects were allowed to select from only four such names. A color was a member of the "red" category, the "amber or yellow" category, the "blue or green" category, or the "white" category. When rating the similarity of the colors in a pair, subjects were instructed to say a whole number from one through five, with five meaning "the same or almost the same" and one meaning "not at all similar," to indicate how similar (i.e., confusable) they felt the colors were to each other. This method of responding was chosen to avoid the problem, found in the pilot study, of having too much variety in the color names used by the subjects and to provide more information on the confusability of the colors.

Under the 0 sec ISI condition a trial consisted of the following: the experimenter said "ready....go!," the desk lamp in the subject's hood went out (room lights were off at all times) and instantly two color spots appeared, 1 sec later the color spots went out and the desk lamp immediately came back on, and then the subject responded by saying two color category names and a similarity rating number.

The 5 sec ISI condition trial was the same, except the left-hand color came on alone for 1 sec and went off, the desk lamp came back on for 5 secs and went off, and then the right-hand color came on alone for 1 sec and went off.

A slight modification in this timing was necessary for the protanoid subjects. They were unable to sufficiently perceive the colors during the presentation interval of 1 sec. For these subjects the interval was increased to 1.5 sec.

Subjects were instructed to always name the color on their left first, to give a complete response on every trial, and to guess when necessary. The time allotted for responding was however long it took the experimenter to set the dual-path monochromator for the next trial. An average trial took 20 secs for both the 0 sec ISI and the 5 sec ISI conditions. (The 5 sec ISI condition took no longer because the experimenter was able to set the monochromator for the left-hand color of the next trial during the 5-sec wait.)

Each subject was run for two hours a day on three separate days. Because of the complex nature of the required responses, subjects were given an initial 40-minute practice and orientation session on their first day, and a nine-minute practice session at the start of the two following days. (Data were recorded but not analyzed from the practice sessions on days two and three.) Practice lists were constructed in the same fashion as the test lists, except that new color pairs were chosen which were different from those in the test lists and which were selected to show subjects the types of colors being used and the range of differences between colors to expect. The practice lists contained only 25 color pairs as shown in Table 6.10.

The 40-minute practice and orientation session on a subject's first day had three stages. First he was shown the initial ten color pairs on the practice list and instructed to make no verbal response, but to simply become acquainted with the sequence of events on a trial and the types of colors being presented. Then the color category names were explained to him and he was shown the next ten pairs on the list and instructed to give the names of the colors on each trial. Finally, the similarity rating scale was explained and he was instructed to respond with the color names and similarity number on each trial. He was then shown the entire practice list, starting over with the first color pair.

A rest period of ten minutes followed the 40-minute initial session, and then the first half of a test list was presented for 27 minutes. Another ten-minute rest period occurred followed by the remaining half of the test list for 27 minutes.

On the second day, a subject began with the nine-minute practice session in which he observed the entire practice list in one pass, giving complete responses on each trial. A ten-minute rest followed, then the first half of a test list for

TABLE 6.10. Main Study Practice List Color Pairs.

| | $R_{15}$ | $R_{14}$ | $R_{11}$ | $A_{12}$ | $A_{11}$ | $GY_{15}$ | $GY_{14}$ | $GY_{11}$ | $W_{11}$ | $G_{11}$ | $BG_{13}$ | $BG_{24}$ | $BG_{21}$ | $BG_{33}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_{13}$ | x | x | | | | | | | | | | | | |
| $R_{11}$ | | x | x | | | | | | | | | | | |
| $A_{12}$ | | | | x | | | | | | | | | | |
| $A_{11}$ | | | | x | | | | | | | | | | |
| $GY_{14}$ | | | | | | x | x | | | | | | | |
| $GY_{13}$ | | | | | | | x | | | | | | | |
| $GY_{11}$ | | | | | | | x | | | | | | | |
| $W_{21}$ | | | x | x | | | | | x | | | | | |
| $G_{11}$ | | | x | | | | | | | | | | | |
| $G_{21}$ | | | | | x | | | | | x | | | | |
| $BG_{12}$ | | | | | | | | | | | x | | | |
| $BG_{11}$ | | | | | | | | x | | | | | | |
| $BG_{24}$ | | | | | | | | | | | x | | | |
| $BG_{23}$ | | | | | | | | | | | | x | | |
| $BG_{22}$ | | | | | | | | | | | | x | | |
| $BG_{21}$ | | | | | x | | | | | | | | x | |
| $BG_{33}$ | | | | | | | | | | | | | | x |
| $BG_{31}$ | | | x | | | | | | | | | | | |

*x indicates the color of that row was paired with the color of that column.

27 minutes, then another ten-minute rest, then the second half of the test list, then another rest, and finally the first half of another test list.

The third day had the same timing as the second day, with the practice period being followed by the second half of the test list which ended the previous day's work. Table 6.11 summarizes the list sequence for each subject, the interstimulus interval associated with each list, and the time sequence for each day of running.

TABLE 6.11. Ordering Administration of Experimental Conditions in Main Study.

| | | Day 1 | | | Day 2 | | | | Day 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| List Type* = | | P | T | T | P | T | T | T | P | T | T | T |
| Subject Number (within vision type) | 1 | 1 | 1a† | 1b | 2 | 2a | 2b | 3a | 3 | 3b | 4a | 4b |
| | 2 | 1 | 1 | 3a | 2 | 4a | 4b | 1a | 3 | 1b | 2a | 2b |
| Interstimulus Interval (sec) | | 0 | 0 | 0 | 0 | 5 | 5 | 0 | 0 | 0 | 5 | 5 |
| Administration Time (min) | Lists | 40 | 27 | 27 | 9 | 27 | 27 | 27 | 9 | 27 | 27 | 27 |
| | Rests | ▲ 10 | ▲ 10 | | ▲ 10 | ▲ 10 | ▲ 10 | | ▲ 10 | ▲ 10 | ▲ 10 | |

*P=Practice List, T=Test List.
†1a=first half of Test List 1, 1b=second half of Test List 1, etc.

The frequent rest periods in the main study were given to help counteract the subject fatigue and boredom encountered in the pilot study. Practice sessions in the main study were needed not only because of the complexity of the responses, but also to help reduce the problem of subject response variability as found in the pilot study. In addition, this problem was reduced by having the four color category names and the similarity rating scale typed on two, white, 4 in. x 6 in. index cards and placed in the subject's hood where they would be seen whenever the desk lamp was on.

RESULTS AND DISCUSSION. Each subject saw every color pair four times (twice with a 0 sec ISI and twice with a 5 sec ISI). This gave a total of 1968 observations on color pairs and 3936 observations on individual colors. (Since not all possible color pairs were used, the individual colors did not appear equally often. $W_{21}$, for example, appeared 44 times to each subject, while $BG_{32}$ appeared only 12 times.)

Analysis of Color-Naming Data. Table 6.12 shows the distribution of color names given to each color with the data pooled across test lists and subjects within vision type. From the table it is seen that the pure red ($R_{11}$) was always called "red" by both the trichromats and the deuteranoids and nearly always called "red" by the protanoids. As this red was progressively desaturated ($R_{12}$ through $R_{15}$) the trichromats continued to say "red," while the deuteranoids began to say "amber or yellow" progressively more often, and the protanoids began to say "blue or green" and "white" progressively more often. At the level of the least pure red ($R_{15}$), the protanoids said "red" only about half the time with most of the remainder of their responses divided about equally between "white" and "blue or green."

The two ambers ($A_{12}$ and $A_{11}$) were always called "amber or yellow" by the trichromats; but they were sometimes called "red,"

TABLE 6.12. Color Names Given for the Main Study Stimuli.

| | Trichromats | | | | Deuteranoids | | | | Protanoids | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R* | A or Y | B or G | W | R | A or Y | B or G | W | R | A or Y | B or G | W |
| $R_{15}$ | 100[†] | | | | 95.8 | 4.2 | | | 56.2 | 4.2 | 18.8 | 20.8 |
| $R_{14}$ | 98.2 | 1.8 | | | 96.4 | 3.6 | | | 87.5 | | 5.4 | 7.1 |
| $R_{13}$ | 100 | | | | 96.9 | 3.1 | | | 93.7 | | 4.7 | 1.6 |
| $R_{12}$ | 100 | | | | 98.4 | 1.6 | | | 98.4 | | 1.6 | |
| $R_{11}$ | 100 | | | | 100 | | | | 96.9 | 3.1 | | |
| $A_{12}$ | | 100 | | | 1.6 | 95.3 | 3.1 | | 54.7 | 21.9 | 23.4 | |
| $A_{11}$ | | 100 | | | 6.2 | 89.1 | 4.7 | | 53.1 | 31.3 | 15.6 | |
| $GY_{15}$ | | 15.0 | 70.0 | 15.0 | 2.5 | 82.5 | 5.0 | 10.0 | 50.0 | | 47.5 | 2.5 |
| $GY_{14}$ | | 8.3 | 89.6 | 2.1 | 4.2 | 83.3 | 8.3 | 4.2 | 50.0 | | 50.0 | |
| $GY_{13}$ | | 1.4 | 95.8 | 2.8 | 2.8 | 84.7 | 11.1 | 1.4 | 50.0 | | 50.0 | |
| $GY_{12}$ | | | 97.5 | 2.5 | | 90.0 | 10.0 | | 50.0 | | 50.0 | |
| $GY_{11}$ | | | 100 | | | 83.9 | 16.1 | | 51.8 | 1.8 | 46.4 | |
| $W_{11}$ | | 87.5 | 4.7 | 7.8 | 3.1 | 81.3 | 7.8 | 7.8 | 48.4 | 3.1 | 42.2 | 6.3 |
| $W_{21}$ | 1.1 | | | 98.9 | 1.1 | 15.9 | 9.1 | 73.9 | 43.2 | | 38.6 | 18.2 |
| $G_{11}$ | | | 100 | | | 2.1 | 97.9 | | 2.1 | | 97.9 | |
| $G_{21}$ | | | 100 | | | | 100 | | | | 100 | |
| $BG_{13}$ | | | 100 | | 3.1 | 6.3 | 62.5 | 28.1 | 3.1 | | 96.9 | |
| $BG_{12}$ | | | 100 | | | | 95.8 | 4.2 | | | 100 | |
| $BG_{11}$ | | | 100 | | | | 100 | | | | 100 | |
| $BG_{24}$ | | | 100 | | | | 78.1 | 21.9 | 3.1 | | 96.9 | |
| $BG_{23}$ | | | 100 | | | | 97.5 | 2.5 | | | 100 | |
| $BG_{22}$ | | | 100 | | | | 100 | | | | 100 | |
| $BG_{21}$ | | | 100 | | | | 100 | | | | 100 | |
| $BG_{33}$ | | | 100 | | | | 85.4 | 14.6 | | | 100 | |
| $BG_{32}$ | | | 100 | | | | 91.7 | 8.3 | | | 100 | |
| $BG_{31}$ | | | 100 | | | | 100 | | | | 100 | |

*R=Red, A or Y=Amber or Yellow, B or G=Blue or Green, and W=White.
[†]Cell entry equals percent.

and even "blue or green" by the deuteranoids; and were called "red" by the protanoids about half the time.

The table also shows that pure greenish-yellow ($GY_{11}$) was always called "blue or green" by the trichromats. As this color was made less pure ($GY_{12}$ through $GY_{15}$) trichromats called it "amber or yellow" and "white" increasingly more often. In contrast, deuteranoids usually called pure greenish-yellow "amber or yellow" but often called it "blue or green" as well. When some white was mixed with this color (producing $GY_{12}$ and $GY_{13}$) deuteranoids called it "amber or yellow" an even greater percentage of the time. Further desaturation of the color produced a declining percentage of "amber or yellow" and "blue or green" calls and an increasing percentage of "red" and "white" calls. Protanoids showed yet another pattern of naming the greenish yellows. Their responses were almost evenly divided between "red" and "blue or green" for all the greenish yellows, regardless of their purity.

The two whites were called several names by the subjects. The white at the orange limit of SAE white ($W_{11}$) was called "amber or yellow" most of the time by the trichromats and deuteranoids, but was called "red" about half the time and "blue or green" about half the time by the protanoids. On the other hand, the white at the blue limit of SAE white ($W_{21}$) was nearly always called "white" by the trichromats. It was called "white" by the deuteranoids most of the time, but was also frequently called "amber or yellow" by them. Protanoids called this white "red" about half the time, "blue or green" somewhat less often, and "white" the rest of the time.

With the exception of $G_{11}$, the pure greens and blue-greens were always called "blue or green" by all subjects. Desaturating these colors had no effect on the naming responses of the trichromats and only a slight effect on the naming responses of the protanoids. (Protanoids occasionally said "red" when viewing $BG_{13}$ and $BG_{24}$--two of the least pure blue-greens.) Deuteranoids, however, increasingly more often said "white" as the blue-greens were progressively desaturated, and they also occasionally said "red" and "amber or yellow" when viewing the desaturated blue-greens.

Two general trends show in the color-naming data. One is that the more white is mixed with a color, the greater the variety of names used to describe that color, i.e., the less pure a color, the less consistently it is named. The other trend is that the closer a color is to the extremes of the visible spectrum (deep in the red or deep in the blue), the more consistently it is named.

The information in Table 6.12 is presented in a condensed form as bar graphs in Figures 6.10, 6.11, and 6.12. In these figures the names of the stimuli are shown across the top and correspond to the major vertical groupings. Just below these are shown the vision types as vertical sub-groupings. Along the sides of these figures are shown the color category names which subjects had to use when describing the colors. The color category names correspond to the major horizontal groupings of the figures. Within each color category group, the horizontal sub-groupings represent five unequal percentage levels. The height of a given column of x's shows what percent of the time a given stimulus was called the corresponding color category name by the indicated vision-type subjects. For example, Figure 6.10 shows that the stimulus $R_{15}$ was called "red" from 26 to 74 percent of the time, "amber or yellow" from 1 to 5 percent of the time, "blue or green" from 6 to 25 percent of the time, and "white" from 6 to 25 percent of the time by the protanoid subjects. The figure also shows that the same stimulus was called "red" from 95 to 100 percent of the time, and never called the other category names by the trichromatic subjects.

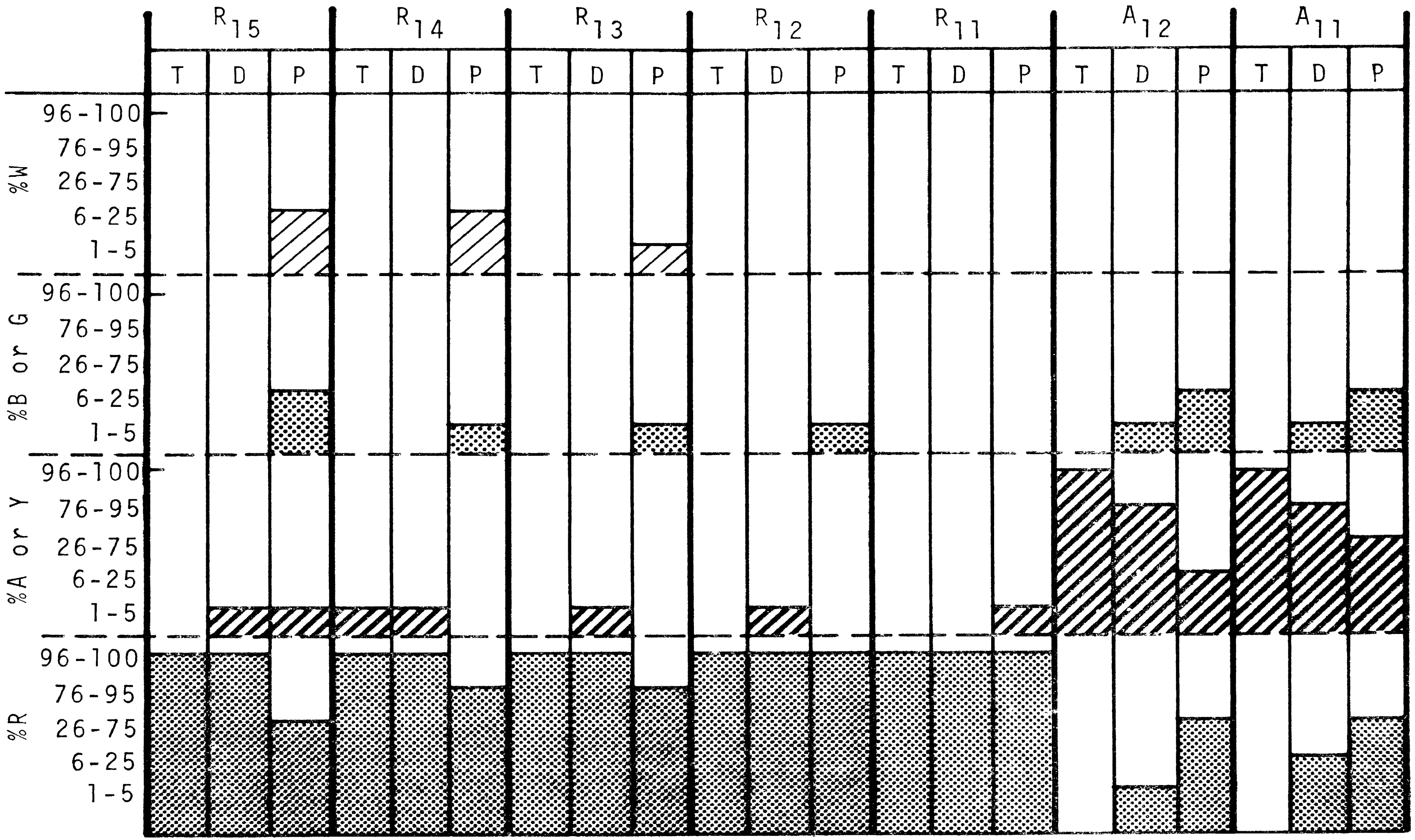


Figure 6.10. Main study distribution of color names given to reds and ambers as a function of vision type. (T=Trichromat, D=Deuteranoid, P=Protanoid)

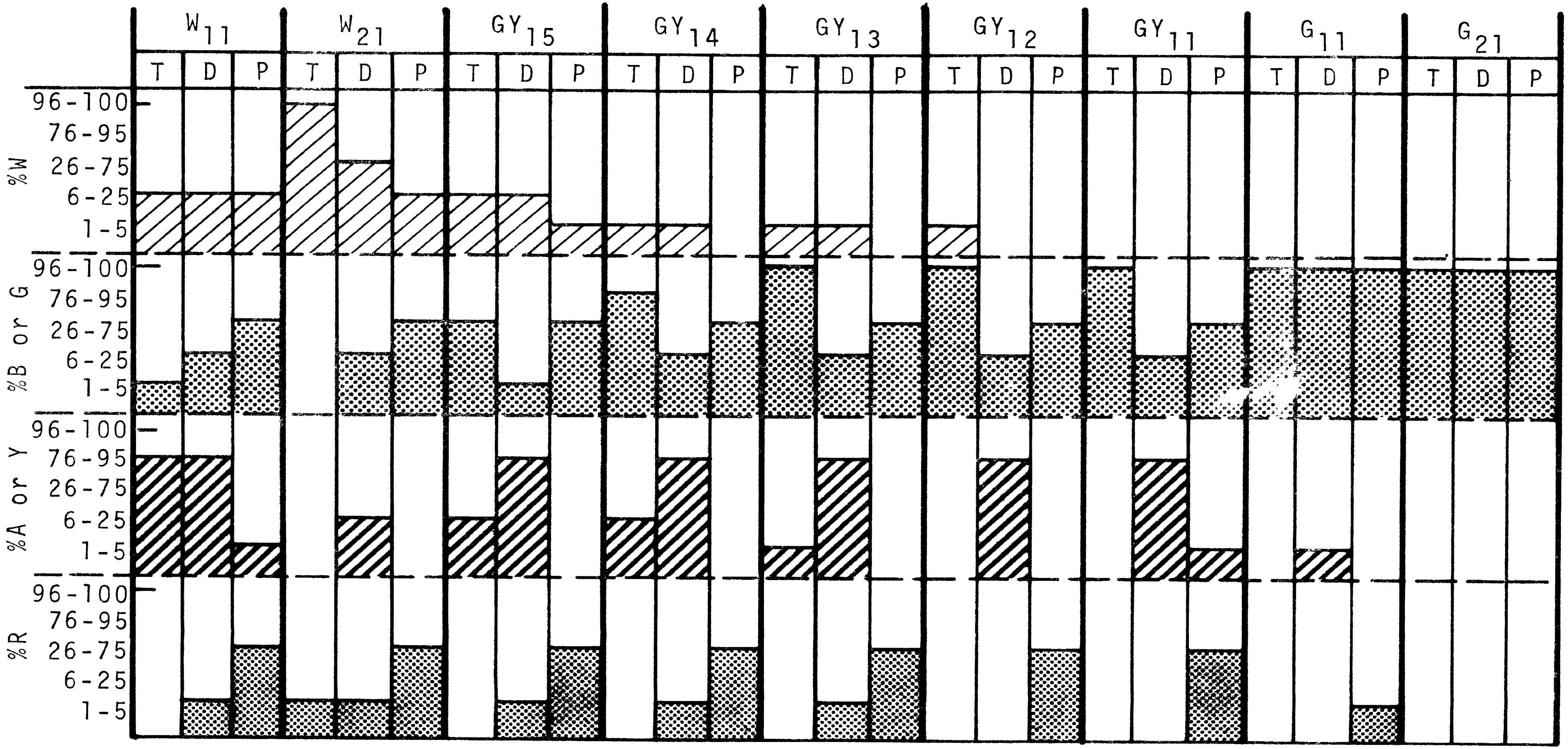


Figure 6.11. Main study distribution of color names given to whites, greenish-yellows, and greens as a function of vision type. (T=Trichromat, D=Deuteranoid, P=Protanoid)

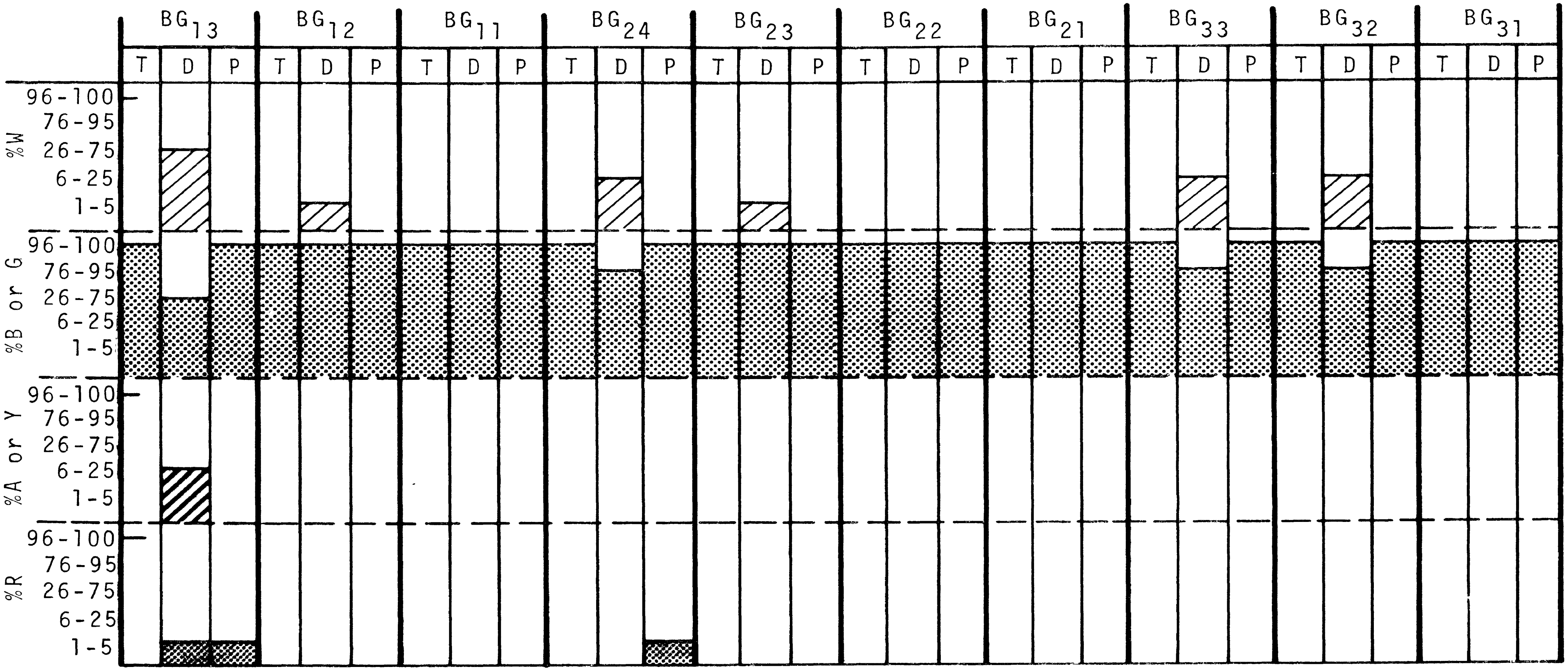


Figure 6.12. Main study distribution of color names given to blue-greens as a function of vision type. (T=Trichromat, D=Deuteranoid, P=Protanoid)

For purposes of vehicle rear lighting, desirable colors are those with stable names, that is, colors which are called the same name by subjects under a variety of viewing conditions. In order to assess the stability of the color names, a color-naming consistency (CNC) score was devised. This score is calculated for a given color by counting the number of times it is called "red" ($N_R$), the number of times it is called "amber or yellow" ($N_A$), the number of times it is called "blue or green" ($N_B$), and the number of times it is called "white" ($N_W$). The statistic is then computed according to the following equation:

$$\text{CNC Score} = \frac{N_R^2 + N_A^2 + N_B^2 + N_W^2}{(N_R + N_A + N_B + N_W)^2}$$

Thus, if a color were called "red" five times and not called any other name, its CNC score would be:

$$\frac{5^2 + 0^2 + 0^2 + 0^2}{(5 + 0 + 0 + 0)^2} = \frac{25}{25} = 1.00$$

On the other hand, if this color were called "red" twice and the other three names once each, its CNC score would be:

$$\frac{2^2 + 1^2 + 1^2 + 1^2}{(2 + 1 + 1 + 1)^2} = \frac{7}{25} = 0.28$$

Notice, this statistic does not indicate which color name is used; rather, it indicates how many different color names are used.

CNC scores were calculated for each color under each unique combination of subjects and other experimental variables. These data were subjected to an analysis of variance, the results of which are shown in Table 6.13. In the table, the variable "vision type" refers to whether a subject was protanoid, deuteranoid, or trichromatic, and "color" refers to the 26 colors presented. The variable "comparison" needs an explanation. This variable has three categories: category 1 includes only those colors which were presented at the subject's left during 5 sec ISI trials; category 2 includes only the colors presented at his right during 5 sec ISI trials; and category 3 includes colors presented on both sides during 0 sec ISI trials. Colors in category 1 had to be remembered for five seconds and then compared with a second color just prior to being named aloud. Colors in category 2 had to be compared, just prior to being named aloud, with the memory of a color presented five seconds earlier. Colors in category 3 were compared with a simultaneously presented color just prior to being named. Thus, this variable represents different conditions of comparison between colors. The "practice" variable has two categories. For a given set of conditions, category 1 is the first time a color was presented to a subject as a member of a particular color pair and category 2 is the second time as a member of the same color pair. (The two occurrences of a color pair under the same conditions occurred at least one day apart. See Table 6.11.)

Inspection of Table 6.13 shows two significant main effects and two significant interactions. The significant three-way interaction between color, comparison and vision type is too complex to allow a detailed discussion, especially since the variable "color" has 26 levels. However, some idea of the interaction can be gained by inspection of Tables 6.14 and 6.15. In Table 6.14, the colors are grouped by their commonly used names and a mean CNC score is used to represent the entire group. The table shows that trichromats consistently named most of the colors, but somewhat inconsistently named the greenish-yellows and whites when two colors were viewed simultaneously (compari-

TABLE 6.13. Main Study Analysis of Variance on Color Naming Consistency.

| Source | SS | df | MS | F | % Total Variance |
|---|---|---|---|---|---|
| Between Groups | | | | | |
| Vision Type (E) | .8566 | 2 | .4283 | 4.01 | 4.2 |
| Error Term | .3205 | 3 | .1068 | | 1.6 |
| Within Groups | | | | | |
| Color (A) | 2.3466 | 25 | .0939 | 2.43** | 11.5 |
| A x E | 2.9301 | 50 | .0586 | 1.52 | 14.3 |
| Error Term | 2.9000 | 75 | .0387 | | 14.2 |
| Comparison (B) | .4351 | 2 | .2175 | 18.8** | 2.1 |
| B x E | .1788 | 4 | .0447 | 3.86 | 0.9 |
| Error Term | .0694 | 6 | .0116 | | 0.3 |
| A x B | 1.0020 | 50 | .0200 | 1.41 | 4.9 |
| A x B x E | 2.0081 | 100 | .0201 | 1.41* | 9.8 |
| Error Term | 2.1374 | 150 | .0142 | | 10.4 |
| Practice (C) | .0008 | 1 | .0008 | 0.09 | 0.0 |
| C x E | .0048 | 2 | .0024 | 0.28 | 0.0 |
| Error Term | .0256 | 3 | .0085 | | 0.1 |
| A x C | .6691 | 25 | .0268 | 2.63** | 3.3 |
| A x C x E | .6327 | 50 | .0127 | 1.24 | 3.1 |
| Error Term | .7634 | 75 | .0102 | | 3.7 |
| B x C | .0134 | 2 | .0067 | 0.53 | 0.1 |
| B x C x E | .0351 | 4 | .0088 | 0.69 | 0.2 |
| Error Term | .0762 | 6 | .0127 | | 0.4 |
| A x B x C | .4116 | 50 | .0082 | 0.75 | 2.0 |
| A x B x C x E | .9844 | 100 | .0098 | 0.89 | 4.8 |
| Error Term | 1.6510 | 150 | .0110 | | 8.1 |
| Total | 20.4526 | 935 | | | 100.0 |

*$p \leq .05$
**$p \leq .01$

TABLE 6.14. Main Study Mean CNC Score as a Function of Vision Type and Comparison Category for Each Color Group.

| | Trichromats | | | Deuteranoids | | | Protanoids | | |
|---|---|---|---|---|---|---|---|---|---|
| | Comparison Category | | | Comparison Category | | | Comparison Category | | |
| Color Group* | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Reds | 1.00 | .98 | 1.00 | .94 | .96 | .98 | .93 | .94 | .86 |
| Ambers | 1.00 | 1.00 | 1.00 | .95 | .88 | .87 | .75 | .91 | .70 |
| Greenish-Yellows | .93 | .98 | .82 | .92 | .85 | .72 | 1.00 | .98 | .98 |
| Whites | .91 | 1.00 | .85 | .92 | .85 | .65 | .85 | .90 | .78 |
| Blue-Greens | 1.00 | 1.00 | 1.00 | .97 | .91 | .89 | 1.00 | .98 | .99 |

*Reds=$R_{11}$-$R_{15}$, Ambers=$A_{11}$ & $A_{12}$, Greenish-Yellows=$GY_{11}$-$GY_{15}$, Whites=$W_{11}$ & $W_{21}$, and Blue-Greens=$G_{11}$, $G_{21}$, $BG_{11}$-$BG_{13}$, $BG_{21}$-$BG_{24}$, $BG_{31}$-$BG_{33}$.

TABLE 6.15. Main Study Mean CNC Score as a Function of Vision Type and Comparison Category for Two Levels of Color Purity.

| | Trichromats | | | Deuteranoids | | | Protanoids | | |
|---|---|---|---|---|---|---|---|---|---|
| | Comparison Category | | | Comparison Category | | | Comparison Category | | |
| Color Purity* | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Pure | 1.00 | 1.00 | 1.00 | .96 | .94 | .95 | .96 | .99 | .94 |
| Least Pure | .95 | 1.00 | .90 | .92 | .80 | .74 | .90 | .91 | .87 |

*Pure=$R_{11}$, $A_{11}$, $GY_{11}$, $G_{11}$, $G_{21}$, $BG_{11}$, $BG_{21}$, and $BG_{31}$.
Least Pure=$R_{15}$, $A_{12}$, $GY_{15}$, $W_{11}$, $W_{21}$, $BG_{13}$, $BG_{24}$, and $BG_{33}$.

son category 3). Deuteranoids in general were least consistent in their color naming responses. They showed some decrement in performance for the greenish-yellows and whites when those colors were being compared to the memory of a color seen 5 sec previously (comparison category 2). Furthermore, they were least consistent in naming the greenish-yellows and whites on those trials when two colors were simultaneously viewed (comparison category 3). The protanoids were least consistent in naming the ambers and whites either when two colors were simultaneously viewed (comparison category 3), or when the color being named had been seen 5 sec previously (comparison category 1).

Table 6.15 shows another aspect of the three-way interaction. In this table, 16 of the stimulus colors are grouped by their purity. A mean CNC score is used to represent the 8 pure colors, and the 8 most desaturated colors. The table shows that the pure colors were fairly consistently named by all subjects. The least pure colors, however, showed varying decrements across the comparison categories for the three vision types. The least consistent naming performance was given by the deuteranoids when they were viewing two simultaneously presented colors.

The significant two-way interaction between color and practice is shown in Table 6.16. The most obvious trend in the table is that, on the whole, the more pure a color, the smaller the change over practice in how consistently it was named.

One of the significant main effects shown in the analysis of variance was comparison. The mean CNC score for category 1 (colors at subject's left, 5 sec ISI) was 0.96; for category 2 (colors at subject's right, 5 sec ISI) was 0.95; and for category 3 (both sides combined, 0 sec ISI) was 0.91. The Newman-Keuls procedure (Winer, 1962, p. 85) was used to test these means and showed that comparison category 3 was significantly smaller than

TABLE 6.16. Main Study Interaction of Color and Practice in Naming Consistency.

| Color | Overall Mean CNC Score | Mean CNC Score Early in Practice | Mean CNC Score Late in Practice | Change with Practice |
|---|---|---|---|---|
| $R_{15}$ | .91 | .86 | .96 | + .10 |
| $R_{14}$ | .93 | .89 | .98 | + .09 |
| $R_{13}$ | .96 | .93 | .99 | + .06 |
| $R_{12}$ | .98 | .98 | .99 | + .01 |
| $R_{11}$ | .99 | 1.00 | .97 | - .03 |
| $A_{12}$ | .90 | .94 | .86 | - .08 |
| $A_{11}$ | .89 | .89 | .90 | + .01 |
| $GY_{15}$ | .85 | .87 | .82 | - .05 |
| $GY_{14}$ | .91 | .87 | .94 | + .07 |
| $GY_{13}$ | .92 | .92 | .93 | + .01 |
| $GY_{12}$ | .95 | .95 | .96 | + .01 |
| $GY_{11}$ | .91 | .94 | .88 | - .06 |
| $W_{11}$ | .85 | .88 | .81 | - .07 |
| $W_{21}$ | .87 | .82 | .92 | + .10 |
| $G_{11}$ | .98 | .98 | .98 | .00 |
| $G_{21}$ | 1.00 | 1.00 | 1.00 | .00 |
| $BG_{13}$ | .87 | .92 | .81 | - .11 |
| $BG_{12}$ | .99 | 1.00 | .98 | - .02 |
| $BG_{11}$ | 1.00 | 1.00 | 1.00 | .00 |
| $BG_{24}$ | .94 | .98 | .90 | - .08 |
| $BG_{23}$ | .99 | 1.00 | .98 | - .02 |
| $BG_{22}$ | 1.00 | 1.00 | 1.00 | .00 |
| $BG_{21}$ | 1.00 | 1.00 | 1.00 | .00 |
| $BG_{33}$ | .92 | .91 | .93 | + .02 |
| $BG_{32}$ | .98 | .98 | .98 | .00 |
| $BG_{31}$ | 1.00 | 1.00 | 1.00 | .00 |

category 1 ($q_{3,6}$ = 8.23, $\alpha$<.01), category 3 was also significantly smaller than category 2 ($q_{2,6}$ = 6.49, $\alpha$<.01), and categories 1 and 2 were not different from each other ($q_{2,6}$ = 1.74). In other words, this main effect was primarily due to a difference between the 5 sec ISI case and the 0 sec ISI case--the difference between naming a color after viewing two colors sequentially and naming a color after viewing them simultaneously. Combining the scores for comparison categories 1 and 2 shows that subjects named colors more consistently under the 5 sec ISI condition (mean CNC score = 0.96) than they did under the 0 sec ISI condition (mean score = 0.91).

The remaining significant main effect in the analysis of variance was color. Table 6.16 shows the overall mean CNC score for each color. In general, the greens and blue-greens were named the most consistently, the reds next most consistently, the ambers and greenish-yellows next, and the whites were named least consistently. However, the Newman-Keuls procedure failed to show any significant differences between the colors at the $\alpha$<.01 level, even though the F-ratio (a more powerful test) was significant.

The overall mean CNC score for trichromats was 0.98. Deuteranoids had an overall mean score of 0.90, and protanoids had a mean of 0.95. These means were not statistically different from each other, however, as indicated in Table 6.13. Practice was also a nonsignificant variable. The overall mean CNC score early in practice was 0.94, while the mean score late in practice was also 0.94.

In Table 6.13 the relative effect of each variable is shown in the column titled "% Total Variance." Numbers in this column indicate the percentage of experiment-wide data variance attributable to the corresponding main effects, interactions, or error terms. Thus, we see that even though "comparison" was a statistically significant main effect, it accounted for only 2.1% of the data variance, and was therefore not a practically significant main effect. Similarly, the color x practice interaction accounted for only 3.3% of the data variance, and was therfore not of great practical significance.

Color was statistically significant and accounted for 11.5% of the data variance. In addition, the significant color x comparison x vision type interaction accounted for 9.8% of the data variance. These two variables together indicate a reasonable selection of experimental stimuli, since the subjects responded differentially to the various colors under the various conditions of naming.

Analysis of Similarity-Rating Data. Turning our attention now to pairs of colors, Table 6.17 shows the results from an analysis of variance based on the similarity ratings. (Recall the subjects had to rate the similarity of the two colors in a pair on a 5-point scale, with "5" meaning "the same or nearly the same.") The variables "vision type" and "practice" are the same as in the previous analysis of variance. "Color pairs" refers to the 82 pairs of colors which made up the test lists, and "interstimulus interval" refers to the 0 sec ISI and 5 sec ISI conditions discussed previously.

The overall mean similarity ratings given by the trichromats, deuteranoids, and protanoids were 2.5, 2.7, and 3.6, respectively. These means were not significantly different from each other. Practice and interstimulus interval were also nonsignificant effects. The overall mean similarity rating given early in practice was 3.0, and late in practice was 2.9. The overall mean similarity rating on trials with 0 sec ISI was 2.8, and on trials with 5 sec ISI was 3.0.

In Table 6.17 the only significant main effect was color pair, and the only significant interactions were color pair x vision type

TABLE 6.17. Main Study Analysis of Variance on Color Similarity Ratings.

| Source | SS | df | MS | F | % Total Variance |
|---|---|---|---|---|---|
| Between Groups | | | | | |
| Vision Type(E) | 426.31 | 2 | 213.16 | 2.77 | 9.7 |
| Error Term | 230.71 | 3 | 76.90 | | 5.2 |
| Within Groups | | | | | |
| Color Pair(A) | 2040.29 | 81 | 25.19 | 12.67** | 46.4 |
| A x E | 439.10 | 162 | 2.71 | 1.36* | 10.0 |
| Error Term | 483.04 | 243 | 1.99 | | 11.0 |
| Interstimulus Interval(B) | 21.15 | 1 | 21.15 | 4.29 | 0.5 |
| B x E | 9.41 | 2 | 4.71 | 0.95 | 0.2 |
| Error Term | 14.78 | 3 | 4.93 | | 0.3 |
| A x B | 61.69 | 81 | 0.76 | 1.52* | 1.4 |
| A x B x E | 99.50 | 162 | 0.61 | 1.23 | 2.3 |
| Error Term | 121.46 | 243 | 0.50 | | 2.8 |
| Practice(C) | 5.50 | 1 | 5.50 | 1.83 | 0.1 |
| C x E | 1.25 | 2 | 0.63 | 0.21 | 0.0 |
| Error Term | 9.02 | 3 | 3.01 | | 0.2 |
| A x C | 30.67 | 81 | 0.38 | 0.80 | 0.7 |
| A x C x E | 70.83 | 162 | 0.44 | 0.93 | 1.6 |
| Error Term | 114.73 | 243 | 0.47 | | 2.6 |
| B x C | 3.93 | 1 | 3.93 | 1.12 | 0.1 |
| B x C x E | 0.28 | 2 | 0.14 | 0.04 | 0.0 |
| Error Term | 10.56 | 3 | 3.52 | | 0.2 |
| A x B x C | 27.56 | 81 | 0.34 | 0.69 | 0.6 |
| A x B x C x E | 59.97 | 162 | 0.37 | 0.75 | 1.4 |
| Error Term | 119.68 | 243 | 0.49 | | 2.7 |
| Total | 4401.42 | 1967 | | | 100.0 |

*$p \leq .05$
**$p \leq .01$

and color pair x interstimulus interval. Since all three significant effects involve the 82-level color pair variable, a detailed exploration of the nature of these effects is not feasible. However, two observations can be made. One is that although the color pair x interstimulus interval interaction was statistically significant, it accounted for only 1.4% of the data variance and is therefore not of practical significance. The other observation is that the significant main effect of color pair and the significant interaction of color pair x vision type reinforce the previously stated contention that a reasonable selection of experimental stimuli was made, since the subjective similarity between colors varied as a function of colors and observers.

The mean similarity ratings for each color pair are shown in Tables 6.18, 6.19 and 6.20 as judged by the trichromats, deuteranoids and protanoids, respectively. In these tables, the mean similarity ratings were obtained by combining the data across subjects within vision type and across all four occurrences of each color pair.

Those colors which were paired with themselves as check items ($R_{14}$, $A_{11}$, $GY_{13}$, $W_{21}$, $G_{21}$, and $BG_{23}$) received an overall combined mean similarity rating of 4.9, indicating that the equipment and subjects were generally consistent.

In Table 6.21 the colors are combined into five major groups with the mean similarity ratings between these groups shown for trichromats. The same information is shown for the deuteranoids and protanoids in Tables 6.22 and 6.23, respectively. For all three vision types, the least similar color groups are reds and blue-greens, and in addition for the protanoids, the ambers and blue-greens. The whites and greenish-yellows are the most similar color groups for all three vision types, with the ambers and greenish-yellows also the most similar for protanoids and deuteranoids.

TABLE 6.18. Main Study Mean Similarity Ratings* for Color Pairs as Judged by Trichromats.

| Color 2 \ Color 1 | $R_{14}$ | $R_{11}$ | $A_{12}$ | $A_{11}$ | $GY_{14}$ | $GY_{13}$ | $GY_{12}$ | $GY_{11}$ | $W_{11}$ | $W_{21}$ | $G_{11}$ | $G_{21}$ | $BG_{12}$ | $BG_{11}$ | $BG_{23}$ | $BG_{21}$ | $BG_{33}$ | $BG_{31}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_{15}$ | | 2.4 | 2.0 | | 1.6 | 1.6 | | | 2.1 | | 1.4 | | | | | | | |
| $R_{14}$ | 4.9 | | 2.0 | | 1.6 | 1.6 | 1.5 | | 1.8 | | | | | | | | | |
| $R_{13}$ | | 4.1 | 2.1 | 2.0 | 1.3 | 1.4 | 1.3 | | 1.8 | | | 1.3 | | | | | | |
| $R_{12}$ | | | 1.9 | 1.8 | 1.6 | 1.8 | 1.5 | 1.5 | 1.5 | | | | | | | 1.1 | | |
| $R_{11}$ | | | | 1.9 | 1.3 | 1.3 | 1.4 | 1.1 | | | | | | | | | | |
| $A_{12}$ | | | | | | | | 2.4 | 3.3 | | 1.5 | | | | | | | |
| $A_{11}$ | | | | 5.0 | | | | 2.0 | | 2.0 | | | | | | | | |
| $GY_{15}$ | | | | | | | | 3.4 | 3.6 | | 2.0 | 1.6 | 1.9 | | | | | |
| $GY_{14}$ | | | | | | | | | 3.1 | | | | | | | | | |
| $GY_{13}$ | | | | | | 5.0 | | 4.8 | 3.3 | | | | | | | | | |
| $GY_{11}$ | | | | | | | | | | | | | | | | | | 1.6 |
| $W_{21}$ | | | | | | | | | | 4.9 | 1.9 | 1.6 | 1.8 | | | | | |
| $G_{21}$ | | | | | | | | | | | | 4.9 | | | | | | |
| $BG_{13}$ | | | | | | | | | | 2.1 | | | | 4.0 | | | 3.5 | 2.9 |
| $BG_{11}$ | | | | | | | 2.3 | | | | 4.9 | 5.0 | 4.1 | | | | 2.8 | 3.9 |
| $BG_{24}$ | | | | | | | | | | 2.0 | | | | | | 3.4 | 4.5 | 3.1 |
| $BG_{23}$ | | | | 1.5 | | | | | | 1.8 | | | | | 4.5 | 4.3 | | |
| $BG_{22}$ | | | 1.5 | | | | | | | | 3.3 | 3.5 | | | | | | |
| $BG_{21}$ | | | | | | | | | | | | | | | | | 3.0 | 4.4 |
| $BG_{33}$ | | | | | | | | | | 2.1 | | | | | | | | 3.3 |
| $BG_{32}$ | | 1.1 | | | | | | | | 2.0 | | | | | | | | 3.9 |

*Similarity rating scale: "1"=color 1 "not at all similar" to color 2; "5"=color 1 "the same or nearly the same" as color 2; "2", "3", or "4"=intermediate similarity.

TABLE 6.19. Main Study Mean Similarity Ratings* for Color Pairs as Judged by Deuteranoids.

| Color 2 \ Color 1 | $R_{14}$ | $R_{11}$ | $A_{12}$ | $A_{11}$ | $GY_{14}$ | $GY_{13}$ | $GY_{12}$ | $GY_{11}$ | $W_{11}$ | $W_{21}$ | $G_{11}$ | $G_{21}$ | $BG_{12}$ | $BG_{11}$ | $BG_{23}$ | $BG_{21}$ | $BG_{33}$ | $BG_{31}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_{15}$ | | 3.5 | 2.0 | | 2.4 | 2.4 | | | 2.0 | | 1.3 | | | | | | | |
| $R_{14}$ | 5.0 | | 1.5 | | 1.5 | 2.0 | 1.8 | | 1.5 | | | | | | | | | |
| $R_{13}$ | | 4.0 | 1.3 | 1.8 | 1.5 | 1.5 | 1.8 | | 1.3 | | | 1.0 | | | | | | |
| $R_{12}$ | | | 1.3 | 1.5 | 1.3 | 1.3 | 1.3 | 1.0 | 1.3 | | | | | | | 1.0 | | |
| $R_{11}$ | | | | 1.5 | 1.3 | 1.5 | 1.3 | 1.0 | | | | | | | | | | |
| $\overline{A}_{12}$ | | | | | | | | 4.5 | 3.8 | | 1.5 | | | | | | | |
| $A_{11}$ | | | | 4.8 | | | | 4.5 | | 1.8 | | | | | | | | |
| $\overline{GY}_{15}$ | | | | | | | | 3.5 | 4.3 | | 2.0 | 2.8 | 1.5 | | | | | |
| $GY_{14}$ | | | | | | | | | 5.0 | | | | | | | | | |
| $GY_{13}$ | | | | | | 4.5 | | 5.0 | 4.0 | | | | | | | | | |
| $GY_{11}$ | | | | | | | | | | | | | | | | | | 1.0 |
| $W_{21}$ | | | | | | | | | | 5.0 | 2.5 | 2.3 | 2.3 | | | | | |
| $G_{21}$ | | | | | | | | | | | | 5.0 | | | | | | |
| $\overline{BG}_{13}$ | | | | | | | | | | 3.5 | | | | 3.8 | | | 3.8 | 2.0 |
| $BG_{11}$ | | | | | | | 1.8 | | | | 3.3 | 4.0 | 3.0 | | | | 3.3 | 3.3 |
| $\overline{BG}_{24}$ | | | | | | | | | | 2.5 | | | | | | 2.0 | 1.5 | 2.3 |
| $BG_{23}$ | | | | 1.3 | | | | | | 2.0 | | | | | 5.0 | 4.0 | | |
| $BG_{22}$ | | | 2.0 | | | | | | | | 2.3 | 2.8 | | | | | | |
| $BG_{21}$ | | | | | | | | | | | | | | | | | 3.3 | 4.3 |
| $\overline{BG}_{33}$ | | | | | | | | | | 2.8 | | | | | | | | 2.5 |
| $BG_{32}$ | | 1.3 | | | | | | | | 1.0 | | | | | | | | 3.5 |

*Similarity rating scale: "1"=color 1 "not at all similar" to color 2; "5"=color 1 "the same or nearly the same" as color 2; "2", "3", or "4"=intermediate similarity.

TABLE 6.20. Main Study Mean Similarity Ratings* for Color Pairs as Judged by Protanoids.

| Color 2 | Color 1: $R_{14}$ | $R_{11}$ | $A_{12}$ | $A_{11}$ | $GY_{14}$ | $GY_{13}$ | $GY_{12}$ | $GY_{11}$ | $W_{11}$ | $W_{21}$ | $G_{11}$ | $G_{21}$ | $BG_{12}$ | $BG_{11}$ | $BG_{23}$ | $BG_{21}$ | $BG_{33}$ | $BG_{31}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_{15}$ | | 2.1 | 3.1 | | 3.9 | 3.3 | | | 4.5 | | 3.5 | | | | | | | |
| $R_{14}$ | 4.9 | | 3.1 | | 3.6 | 3.4 | 3.1 | | 4.1 | | | | | | | | | |
| $R_{13}$ | | 2.8 | 3.4 | 2.9 | 3.8 | 3.1 | 3.1 | | 3.6 | | | 2.4 | | | | | | |
| $R_{12}$ | | | 3.5 | 3.8 | 3.1 | 2.8 | 2.9 | 2.8 | 3.4 | | | | | | | 1.9 | | |
| $R_{11}$ | | | | 3.0 | 2.4 | 2.6 | 2.5 | 2.8 | | | | | | | | | | |
| $A_{12}$ | | | | | | | | 4.5 | 3.8 | | 2.9 | | | | | | | |
| $A_{11}$ | | | | 4.6 | | | | 4.8 | | 2.4 | | | | | | | | |
| $GY_{15}$ | | | | | | | | 3.4 | 5.0 | | 4.2 | 3.5 | 3.4 | | | | | |
| $GY_{14}$ | | | | | | | | | 4.8 | | | | | | | | | |
| $GY_{13}$ | | | | | | 5.0 | | 4.4 | 4.1 | | | | | | | | | |
| $GY_{11}$ | | | | | | | | | | | | | | | | | | 1.8 |
| $W_{21}$ | | | | | | | | | | 5.0 | 3.8 | 4.0 | 4.0 | | | | | |
| $G_{21}$ | | | | | | | | | | | | 5.0 | | | | | | |
| $BG_{13}$ | | | | | | | | | | 4.5 | | | | 4.8 | | | 4.3 | 2.9 |
| $BG_{11}$ | | | | | | | 2.4 | | | | 3.9 | 4.3 | 4.6 | | | | 4.0 | 3.5 |
| $BG_{24}$ | | | | | | | | | | 4.3 | | | | | | 4.4 | 4.8 | 4.1 |
| $BG_{23}$ | | | | 2.0 | | | | | | 3.4 | | | | | 5.0 | 4.6 | | |
| $BG_{22}$ | | | 2.1 | | | | | | | | 2.9 | 3.4 | | | | | | |
| $BG_{21}$ | | | | | | | | | | | | | | | | | 4.6 | 4.4 |
| $BG_{33}$ | | | | | | | | | | 2.6 | | | | | | | | 4.5 |
| $BG_{32}$ | | 1.8 | | | | | | | | 2.5 | | | | | | | | 4.5 |

*Similarity rating scale: "1"=color 1 "not at all similar" to color 2; "5"=color 1 "the same or nearly the same" as color 2; "2", "3", or "4"=intermediate similarity.

TABLE 6.21. Main Study Mean Similarity Ratings Between Color Groups for Trichromats.

| Color Group | Ambers | Greenish-Yellows | Whites | Blue-Greens |
|---|---|---|---|---|
| Reds* | 2.0 | 1.5 | 1.8 | 1.2 |
| Ambers | | 2.2 | 2.6 | 1.5 |
| Greenish-Yellows | | | 3.3 | 1.9 |
| Whites | | | | 1.9 |

*Reds=$R_{11}$-$R_{15}$; Ambers=$A_{11}$, $A_{12}$; Greenish-Yellows=$GY_{11}$-$GY_{15}$; Whites=$W_{11}$, $W_{21}$; Blue-Greens=$G_{11}$, $G_{21}$, $BG_{11}$-$BG_{13}$, $BG_{21}$-$BG_{24}$, and $BG_{31}$-$BG_{33}$.

TABLE 6.22. Main Study Mean Similarity Ratings Between Color Groups for Deuteranoids.

| Color Group | Ambers | Greenish-Yellows | Whites | Blue-Greens |
|---|---|---|---|---|
| Reds* | 1.6 | 1.6 | 1.5 | 1.1 |
| Ambers | | 4.5 | 2.8 | 1.6 |
| Greenish-Yellows | | | 4.4 | 1.8 |
| Whites | | | | 2.4 |

*Reds=$R_{11}$-$R_{15}$; Ambers=$A_{11}$, $A_{12}$; Greenish-Yellows=$GY_{11}$-$GY_{15}$; Whites=$W_{11}$, $W_{21}$; Blue-Greens=$G_{11}$, $G_{21}$, $BG_{11}$-$BG_{13}$, $BG_{21}$-$BG_{24}$, and $BG_{31}$-$BG_{33}$.

TABLE 6.23. Main Study Mean Similarity Ratings Between Color Groups for Protanoids.

| Color Group | Ambers | Greenish-Yellows | Whites | Blue-Greens |
|---|---|---|---|---|
| Reds* | 3.3 | 3.1 | 3.9 | 2.4 |
| Ambers | | 4.6 | 3.1 | 2.3 |
| Greenish-Yellows | | | 4.6 | 3.1 |
| Whites | | | | 3.6 |

*Reds=$R_{11}$-$R_{15}$; Ambers=$A_{11}$, $A_{12}$; Greenish-Yellows=$GY_{11}$-$GY_{15}$; Whites=$W_{11}$, $W_{21}$; Blue-Greens=$G_{11}$, $G_{21}$, $BG_{11}$-$BG_{13}$, $BG_{21}$-$BG_{24}$, and $BG_{31}$-$BG_{33}$.

Correlations Between Similarity Ratings and Distances Between Colors. The distance between the two colors in a pair was calculated for each color pair and then correlated with the given similarity ratings for each color pair. The distance was calculated separately for each of five "dimensions," defined as follows:

1. UV=the geometric distance between the chromaticity points of two colors when they are plotted in the 1960 CIE-Uniform Chromaticity Scale (1960 CIE-UCS). This chromaticity diagram is a transformation of the 1931 CIE diagram in which distances between points are based on perceived (psychological) differences. Chromaticity coordinates in this system are u and v, and the transformation from the 1931 system is $u=\frac{4x}{-2x+12y+3}$, $v=\frac{6y}{-2x+12y+3}$.

2. WD=the distance between the chromaticity points of two colors when they are expressed in terms of the dichromatic coordinates for deuteranopic observers proposed by Judd (1948). The dichromatic coordinates for deuteranopic observers are $w_d$ and $k_d$, and the transformation from the 1931 CIE system is $w_d=\frac{y}{1-x}$, $k_d=1-w_d$. The distance is calculated by taking the absolute difference between the $w_d$ values for the two colors. (Since $w_d+k_d=1$, only $w_d$ values need be used.)

3. WP=the distance for protanopic observers, analogous to the WD distance. The coordinates in this system are $w_p$ and $k_p$, and the transformation from the 1931 CIE system is $w_p=\frac{-0.561x+1.258y+0.101}{-1.561x+0.258y+1.101}$, $k_p=1-w_p$. The distance is calculated by taking the absolute difference between the $w_p$ values for the two colors. (Since $w_p+k_p=1$, only $w_p$ values need be used.)

4. PE=the distance between the two colors in terms of excitation purity ($P_e$) with respect to Source A. The distance is calculated by taking the absolute difference between the $P_e$ values for the two colors.

5. LD=the distance between two colors in terms of dominant wavelength ($\lambda_D$). The distance is calculated by taking the absolute difference between the $\lambda_D$ values for the two colors.

Table 6.24 shows the correlations between subjects' similarity ratings and the distance measures explained above. Only data from the 0 sec ISI condition was used for these correlations, since this is the condition where the two colors were presented simultaneously. (The distance between one color which is immediately visible and another color which has been remembered for five seconds as is the case for the 5 sec ISI condition, is a less representative index of the confusability of the two colors.) The various distance measures in Table 6.24 are not independent. Their intercorrelations are shown in Table 6.25.

The trichromats' similarity ratings show the highest correlations with UV and LD. (UV and LD are correlated .84 as shown in Table 6.25.) Thus, the similarity ratings given by the trichromats are related to the geometric distances between colors as plotted on the 1960 CIE-UCS chromaticity diagram.

Deuteranoids also show their highest correlations to be with UV and LD, while the protanoids show two different correlation patterns. The similarity ratings given by protanoid subject number 1 correlate best with WP and nearly as well with WD. Ratings from the other protanoid subject correlate best with UV and LD, but WP and WD were not much different.

It was expected that trichromats would correlate best with UV, deuteranoids best with WD, and protanoids best with WP, since UV, WD and WP represent their three color spaces, respectively. The fact that the deuteranoids did not show this pattern could be due to several factors.

One possibility is that subjects were not consistently using the similarity rating scale, but the generally high correlations

TABLE 6.24. Main Study Correlations Between Similarity Ratings and Distances Between Colors for the 0 sec ISI Condition.

| Vision Type | Subject Number | Distance Measure | | | | |
|---|---|---|---|---|---|---|
| | | UV | WD | WP | PE | LD |
| Trichromat | 1 | -.80* | -.25 | -.28 | -.19 | -.70 |
| | 2 | -.72 | -.25 | -.30 | -.28 | -.64 |
| Deuteranoid | 1 | -.69 | -.37 | -.39 | -.09 | -.60 |
| | 2 | -.69 | -.24 | -.27 | -.24 | -.61 |
| Protanoid | 1 | -.27 | -.67 | -.70 | -.33 | -.28 |
| | 2 | -.56 | -.40 | -.50 | +.01 | -.57 |

*Correlations are negative because the greater the distance between colors, the lower the similarity rating.

TABLE 6.25. Main Study Intercorrelations Between Distance Measures.

| Distance Measure | WD | WP | PE | LD |
|---|---|---|---|---|
| UV | .32 | .29 | .09 | .84 |
| WD | | .92 | .19 | .47 |
| WP | | | .07 | .48 |
| PE | | | | -.06 |

with UV indicate the reverse. Another possibility is that because WD and WP are not based on psychological distances, while UV is, the correlations with UV are higher. A third possibility is that not all of the color-blind subjects were true dichromats.

The Dvorine Pseudo-Isochromatic Plates used to classify subjects may not distinguish between severely anomalous trichromats and true dichromats. Thus, the deuteranoid subjects may have been true deuteranopes (dichromats), or they may have been severely deuteranomalous trichromats (near-dichromats). If these subjects were, in fact, near-dichromats, then they would exhibit some features of both trichromatic and dichromatic vision. (Since they were at least severely anomalous, the preponderant vision characteristics would be dichromatic, however.) This would possibly lead to such a mixture of correlations as obtained in Table 6.24.

The analogous situation would hold for the protanoid subjects, with one exception. Protanoid subject number 1 was independently diagnosed as a true protanope by means of special equipment at the Department of Ophthalmology, University of Michigan. (He was the only such subject available at the time the experiment was conducted.) This subject was the one who showed the expected pattern in Table 6.24. His highest correlation was with WP, with the next highest being WD, and he showed relatively low correlations with UV and LD.

CONCLUSIONS AND RECOMMENDATIONS

SAE COLOR SYSTEM. In the present experiment, SAE red is represented by $R_{11}$, SAE amber is represented by $A_{11}$, and SAE white is represented by both $W_{21}$ and $W_{11}$. Table 6.26 presents the mean CNC (Color Naming Consistency) scores for these colors as a function of the three vision types.

TABLE 6.26. Main Study Mean CNC Scores for SAE Colors as a Function of Vision Type.

| Vision Type | SAE RED | SAE Amber | SAE White | |
|---|---|---|---|---|
| | $R_{11}$ | $A_{11}$ | $W_{11}$ | $W_{21}$ |
| Trichromats | 1.00 | 1.00 | .87 | .97 |
| Deuteranoids | 1.00 | .86 | .83 | .79 |
| Protanoids | .96 | .81 | .85 | .85 |

As shown in the table, $R_{11}$ is consistently named by both trichromats and deuteranoids, and nearly as consistently named by the protanoids. Referring back to Table 6.12, we see that $R_{11}$ was always called "red" by the trichromats and deuteranoids, while the protanoids nearly always called it "red" with an occasional "amber or yellow." Thus, SAE red is a stable color in the sense that it is consistently named.

Table 6.26 shows that $A_{11}$ was consistently named only by the trichromats. Furthermore, Table 6.12 shows that $A_{11}$ was called "red" 53% of the time by the protanoids. SAE amber, therefore, is not a stable color for deuteranoids or protanoids and it is more likely to be called "red" than "amber or yellow" by the protanoids.

The two SAE whites were generally not consistently named. $W_{11}$ (at the orange border of SAE white) was called "amber or yellow" most of the time by trichromats and deuteranoids. The protanoids divided their responses about equally between "red" and "blue or green." $W_{21}$ (at the blue border of SAE white) on the other hand was consistently named "white" by the trichromats. The deuteranoids called it "white" 74% of the time, and the protanoids again split their responses fairly evenly between "red" and "blue or green." However, the protanoids called $W_{21}$ "white"

18% of the time to 6% for $W_{11}$. Thus, SAE white is generally not a stable color in the naming sense, but the bluer end of SAE white appears to be more stable and to be called "white" a greater percentage of the time.

To summarize, in terms of the naming data SAE red is the only "good" color in the SAE system for all subjects, SAE amber is "good" only for trichromats, and SAE white is generally not "good" for any of the subjects. However, the bluish SAE whites are "good" for trichromats and are better than the orange SAE whites for the color-blind subjects.

The SAE colors can also be evaluated in terms of the similarity rating data. Referring back to Table 6.18, trichromats gave a mean similarity rating of 1.9 for SAE red and SAE amber. Although SAE red and white were not directly compared in the experiment, the pattern of ratings for SAE white and the desaturated SAE red leads to the expectation that SAE red and white would receive a similarity rating from the trichromats of no greater than 1.5. SAE amber and $W_{21}$ (at the blue border of SAE white) received a mean similarity rating of 2.0 from the trichromats, but SAE amber was not directly compared to $W_{11}$ (at the orange border of SAE white). However, $A_{12}$, which is just slightly outside the SAE amber region toward white, was compared with $W_{11}$ and received a mean rating of 3.3. Thus, trichromats can be expected to rate SAE amber and $W_{11}$ at no more than 3.3, and no less than 2.0.

Using the same approach with Table 6.19, the deuteranoids gave a mean similarity rating of 1.5 to SAE amber and SAE red, an estimated rating of no more than 1.3 to SAE white and SAE red, and a minimum rating of 1.8 to SAE amber and white, with the estimated maximum amber to white rating at 3.8.

Similarly, Table 6.20 shows that protanoids gave a mean rating of 3.0 to SAE red and amber, an estimated rating of no more than 3.4 to SAE red and white, and a minimum rating of 2.4, with the estimated maximum at 3.8, to SAE amber and white.

In summary, for both deuteranoids and trichromats the SAE colors are as follows: 1) red and white are the least similar and few confusions would be expected, 2) red and amber are more similar and somewhat more confusions would be expected, and 3) amber and white are the most similar and would be confused the most of the set. For the protanoids, all pairs of SAE colors seem equally confusable and many more confusions would be expected than for the other vision types.

In general, then, the weak points in the SAE color system are the ambers and whites. The whites at the orange border of SAE white are not consistently named and they are too similar to the ambers for at least protanoids. The ambers are not consistently named by color-blind observers and are too similar to the reds for protanoids.

If the subjects in the present study were in fact near-dichromats, then the situation would show the same pattern, but would be more extreme for true dichromats. SAE ambers, reds, and whites would all be called "red" more frequently, and the similarity between them would increase. For example, inspection of the data from the known protanope of the present study revealed that he always called SAE amber "red" and nearly always called $W_{11}$ "red" $W_{21}$ was an improvement over $W_{11}$ in that he called it "white" approximately 14% of the time. Furthermore, this subject gave a mean similarity rating of 4.3 to red and amber, an estimated maximum rating of 4.3 to red and white, and a minimum rating of 3.0 with an estimated maximum of 4.5 to amber and white.

MODIFICATIONS TO THE SAE COLOR SYSTEM. Several possible modifications to the SAE system were considered in the experiment. One modification is to use a desaturated amber ($A_{12}$) in place of SAE amber. Inspection of Table 6.18 leads to the expectation that such an amber would be just as similar to SAE red as is SAE amber, and would be more similar to SAE white than is SAE amber as far as trichromats are concerned. Tables 6.19 and 6.20 show essentially the same result for deuteranoids and protanoids. Thus, the substitution of a desaturated amber would be of no benefit.

Another modification is to use a desaturated red ($R_{12}$-$R_{15}$) in place of SAE red. Table 6.18 shows that, for trichromats, such a red would be more similar to SAE white than is the present SAE red, and it might be more similar to SAE amber as well. Essentially the same result is predicted for deuteranoids and protanoids (Tables 6.19 and 6.20). However, it appears that the most desaturated reds ($R_{13}$-$R_{15}$) would be less similar to SAE amber than is the present SAE red for the protanoids. Unfortunately these reds also would be expected to be very similar to SAE white for the protanoids. Thus, it appears that the substitution of a desaturated red would also be of no benefit to the color-blind observers.

A third modification is to replace SAE amber with a greenish-yellow ($GY_{11}$ and $GY_{12}$). Table 6.18 shows that for trichromats, greenish-yellow contrasted with SAE amber would be rated as less similar to SAE red and equally or less similar to SAE white. Tables 6.19 and 6.20 show the same result would be expected for protanoids and deuteranoids. Thus, moving SAE amber into the greenish-yellow region would give some benefit to all three vision types, though least to the protanoid.

If in fact the subjects in the present experiment were not true dichromats, the above conclusions would have to be altered only slightly to apply to true dichromats. In order to explore this topic in more detail we need to digress briefly to a discussion of the dichromatic coordinate system proposed by Judd (1948), as mentioned earlier.

Recall that in Judd's system, the chromaticity coordinates in the 1931 CIE chromaticity diagram for deuteranopic observers are $w_d$ and $k_d$. These are defined as follows: $w_d=\frac{y}{1-x}$ and $w_d+k_d=1$. The first equation, when put in straight-line form, yields $y=-w_d x+w_d$. When this equation is plotted on the 1931 CIE chromaticity diagram, the result is a family of straight lines, all of which intersect at the point x=1, y=0. Four such lines and their intersection point are shown in Figure 6.13 as the solid lines on the CIE chromaticity diagram.

Similarly, recall that in Judd's system the two chromaticity coordinates for protanopic observers are as follows: $w_p=\frac{-0.561x+1.258y+9.101}{-1.561x+0.258y+1.101}$ and $w_p+k_p=1$. By the same process as above, the first equation when plotted on the 1931 CIE chromaticity diagram, results in a family of straight lines which intersect at the point x=.747, y=.253. Three such lines and their intersection point are shown in Figure 6.13 as dashed lines.

In this dichromatic coordinate system, any two colors which have the same $w_d$ value should appear to be identical to a deuteranopic observer when luminance is held constant; and any two colors having the same $w_p$ value should appear to be identical to a protanopic observer when luminance remains constant. Thus, in Figure 6.13, all points on the same deuteranopic line should appear to be identical to a deuteranopic observer when luminance is held constant. Analogously, a protanopic observer should be unable to distinguish between any colors on the same protanopic line, if they have the same luminance.

At the border of the chromaticity diagram in Figure 6.13, the protanopic lines are spaced according to the hue discrimination capabilities of protanopic observers, and the deuteranopic lines are spaced according to the hue discrimination capabilities of deuteranopic observers as determined by Pitt (Wright, 1947, Fig. 204). For example, the distance from 516nm to 520nm at

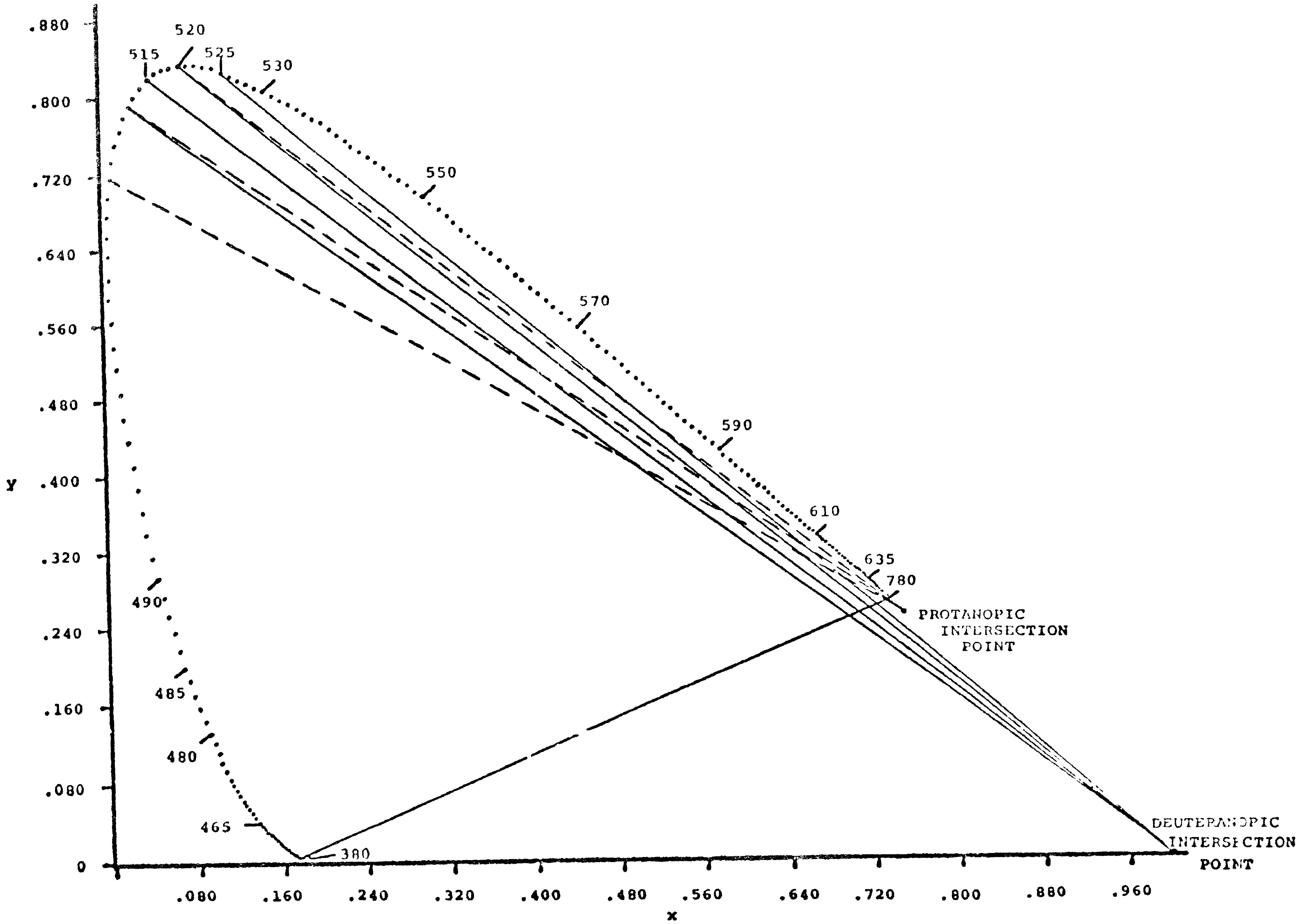


Figure 6.13. Main study: Some protanopic and deuteranopic confusion zones on the CIE chromaticity diagram.

the border of the chromaticity diagram represents the least change in wavelength necessary for a deuteranopic observer to report a change in hue, starting with a pure color at 516nm. Therefore, the zones between adjacent deuteranopic lines in the diagram are confusion zones for deuteranopic observers. Colors whose chromaticity points fall within the same zone should look the same to a deuteranope when luminance is held constant, and colors which are separated by at least a zone should look different to a deuteranope. In the same fashion, the zones between adjacent protanopic lines are confusion zones for protanopic observers, and colors should be at least one zone apart to look different to protanopes.

Spacing of the dichromatic lines in Figure 6.13 shows that in the portion of the chromaticity diagram containing SAE red, amber and white, deuteranopic observers have better discrimination than do protanopic observers. (If the process used to generate these lines is continued to include the entire chromaticity diagram, the same situation is shown to be true throughout the visible spectrum.) Furthermore, Figure 6.13 shows that if one color is located at the right border of the diagram (such as SAE red or SAE amber), then a second color should be located in a direction toward the left border for both deuteranopes and protanopes in order to be out of the confusion zone of the first color.

Getting back to our earlier question of the implications resulting if the subjects in the present study were not all true dichromats, Figure 6.13 indicates we can use the known protanope as a "worst case" situation. Modifications to SAE red, amber or white which are beneficial to the protanope should also be beneficial to deuteranopes and the anomalous trichromats.

As shown in the correlational analysis, similarity ratings given by the known protanope correlated -.70 with the absolute differences between $w_p$ values of colors. From this analysis we can predict the protanope's similarity rating for any two colors by the following regression equation: $x' = -3.9 + 4.44$, where y=the absolute difference in $w_p$ values for the two colors, $x'$=the predicted similarity rating, and the standard error of estimate for this equation $= \pm 0.57$.

With respect to those colors involved in the proposed modifications to the SAE color system, Table 6.27 presents both obtained and predicted (from the above equation) similarity ratings for the known protanope. As concluded previously, the substitution of desaturated amber ($A_{12}$) for SAE amber ($A_{11}$) would be of no benefit. The desaturated amber would be essentially just as confusable with SAE red ($R_{11}$) and would probably be more similar to SAE white ($W_{11}$ and $W_{21}$).

Also as concluded previously, the substitution of desaturated red ($R_{12}$-$R_{15}$) for SAE ($R_{11}$) would be of no benefit. As the reds become more desaturated, they grow less similar to SAE amber, but they also become more similar to SAE white.

As previously concluded, replacing SAE amber with greenish-yellow ($GY_{11}$ and $GY_{12}$) would not benefit the protanope. Greenish-yellow would be just as similar to SAE red and white as is SAE amber. However, it can be concluded that the replacement of SAE amber with greenish-yellow probably would not help true dichromats, but would benefit trichromatic and anomalous trichromatic observers.

A final modification to the SAE system, not discussed previously, is to move SAE white toward blue, or at least restrict SAE white to the bluer half of the present zone. If SAE white were redefined so that the orange limit was where the blue limit is presently located, then Table 6.27 shows that the protanope would rate white as noticeably less similar to both SAE red and

TABLE 6.27. Main Study Mean Similarity Ratings* for Selected Color Pairs as Judged by the Protanope in the 0 Sec ISI Condition.

| Color 2 | Color 1: $R_{15}$ | $R_{14}$ | $R_{13}$ | $R_{12}$ | $R_{11}$ | $W_{11}$ | $W_{21}$ |
|---|---|---|---|---|---|---|---|
| $A_{12}$ | 4.0 | 4.0 | 3.8 | 5.0 | 4.1† | 4.5 | 3.4† |
| $A_{11}$ | 3.5† | 3.6† | 3.5 | 4.0 | 4.3 | 3.8† | 3.0 |
| $GY_{15}$ | 4.1† | 4.2† | 4.3† | 4.4† | 3.8† | 5.0 | 3.7† |
| $GY_{14}$ | 3.8 | 4.3 | 4.8 | 4.8 | 3.8 | 4.5 | 3.5† |
| $GY_{13}$ | 4.0 | 4.0 | 4.0 | 4.5 | 4.3 | 3.8 | 3.4† |
| $GY_{12}$ | 3.7† | 3.8 | 4.0 | 4.5 | 4.0 | 4.0† | 3.3† |
| $GY_{11}$ | 3.5† | 3.6† | 3.7† | 4.5 | 4.5 | 3.8† | 3.1† |
| $W_{11}$ | 4.8 | 4.5 | 4.3 | 4.8 | 3.8† | | |
| $W_{21}$ | 4.0† | 3.9† | 3.8† | 3.6† | 3.1† | | |

*Similarity rating scale: "1"=color 1 "not at all similar" to color 2; "5"=color 1 "the same or nearly the same" as color 2; "2," "3," or "4"=intermediate similarity.

†Estimated value - see text.

amber. Taking into account ratings from all the subjects (Tables 6.18, 6.19 and 6.20), and considering that $A_{12}$, is just slightly out of the SAE amber region toward white, the comparison of ratings for $A_{12}$ and $W_{11}$ versus $A_{11}$ and $W_{21}$ shows that all observers would rate the "new" white as noticeably less similar to SAE red and amber.

DEFINITIONS OF NEW COLOR ZONES.

Greenish-Yellow. If greenish-yellow were substituted for

SAE amber, then the simplest way to define it (based on the colors used in the present experiment) is to move the color zone from amber and center it around $GY_{11}$ (570nm). The resulting zone is defined as follows:

red limit: $y \geq 0.5$

green limit: $y \leq 0.58$

White limit: $x+y \geq 0.99$

Figure 6.14 shows the proposed greenish-yellow zone on the 1931 CIE chromaticity diagram.

Reduced SAE White. If SAE whites are restricted to the bluer portion of the present zone, then the reduced SAE white is defined as follows.

blue limit: $x \geq 0.41$

yellow limit: $x \leq 0.45$

green limit: $y \leq 0.25x+0.31$

Purple limit: $y \geq 0.25x+0.28$

Figure 6.14 shows the reduced SAE white zone on the 1931 CIE chromaticity diagram.

Blue-Green. The most likely confusions with blue-greens will be SAE whites. To locate the blue-greens far enough from the SAE white (or reduced SAE white) we will again use the protanope as the "worst case." We will also assume that a similarity rating of 3.5 or higher between blue-green and the nearest SAE white would be undesirable.

Using the same regression equation previously used, two colors whose $w_p$ values differ by no more than 0.24 are predicted to receive a similarity rating of 3.5 or higher from the protanope. $W_{21}$, which represents the nearest SAE white, has a $w_p$ value of 0.65. Therefore, no blue-green should have a $w_p$ value greater than 0.41. Substituting this value in the equation which defines $w_p$ in terms of the trichromatic chromaticity

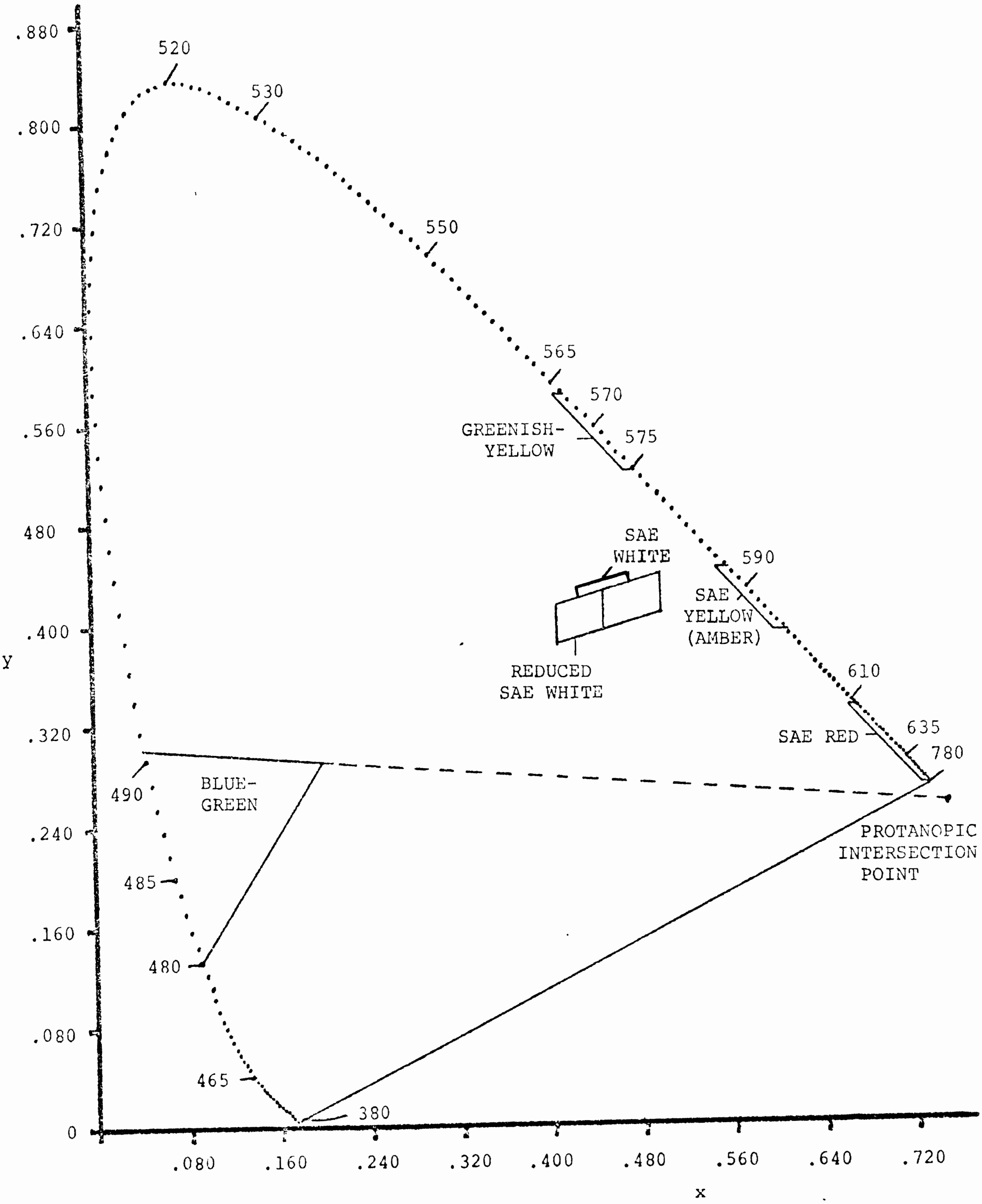


Figure 6.14. Main study: present SAE color zones and proposed new zones on the CIE chromaticity diagram.

coordinates gives the equation for the green limit of the proposed blue-green zone as $y \leq -0.07x+0.30$. This green limit is shown plotted on the 1931 CIE chromaticity diagram in Figure 6.14. The dashed line in the figure shows that the green limit line passes through the protanopic intersection point as it should, since it represents a specified $w_p$ value.

In a similar fashion, the purple limit for the blue-green zone can be estimated by using the results of the correlational analysis for trichromatic subject number 1. In this case the purpose is to restrict the size of the blue-green zone so that colors within the zone do not appear too dissimilar to each other, and in this sense the trichromat is the "worst case."

As shown in the correlational analysis, trichromatic subject 1 gave similarity ratings which correlated -0.80 with the geometric distance between colors when they were plotted on the 1960 CIE UCS chromaticity diagram. From this analysis we can predict the trichromat's similarity rating for any two colors by the following regression equation: $x' = -8.02y+4.26$, where $y$=the geometric distance between the colors in the CIE-UCS diagram, $x'$=the predicted similarity rating, and the standard error of estimate for this equation is ±0.73.

This time we will consider a similarity rating of 3.5 or higher as desirable. Accordingly, two colors which are no more than 0.10 units apart in the CIE-UCS diagram are predicted to receive a similarity rating of 3.5 or higher from the trichromat. Using $BG_{21}$ as the reference point; determining the equation of a straight line on the 1960 CIE-UCS diagram which closely approximates the locus of points no more than 0.10 units from $BG_{21}$; and converting this equation into the 1931 CIE diagram gives the following purple limit for the blue-green zone: $y \geq 1.45x$. Figure 6.14 shows this limit on the 1930 CIE chromaticity diagram.

## PROPOSED COLOR SYSTEMS

SYSTEM 1. The present SAE system with the blue-green zone added constitute system 1. With this system, it is expected that dichromatic observers will make numerous confusions between SAE red, SAE amber and SAE white; particularly between red and amber. Anomalous trichromatic observers are also expected to confuse red, amber and white; but confusions between amber and white are expected to be more numerous. Trichromats are expected to make some confusions between amber and white.

SYSTEM 2. System 2 is the same as system 1, except the reduced SAE white is substituted for the present SAE white. This system should reduce the confusions between amber and white, and between red and white for all observers.

An even greater improvement would result if SAE white were moved further toward blue. However, this would require lamps which burn at higher color temperatures. It would also require the blue-green zone to be moved deeper into the blue--the distance moved depending on how far SAE white were moved.

SYSTEM 3. SAE red, greenish-yellow, reduced SAE white, and blue-green make up system 3. This system is expected to be an improvement over system 2 for trichromats and anomalous trichromats with respect to red-amber confusions and white-amber confusions.

## SUMMARY

A blue-green color zone was determined which could be added to the present SAE colors and result in few confusions due to the added color. It was also shown that the present system could be improved by restricting SAE whites to the bluer portion of the present white zone or by moving SAE white further toward blue. Some improvement was also indicated by substituting a greenish-yellow in place of SAE amber. These conclusions were shown to apply to color-blind as well as color-normal observers.

The proposed color systems need to be tested in daylight conditions to examine the effects of sunlight on the confusability and visibility of the colors, since the present experiment applies primarily to nighttime conditions.

## RECOMMENDATIONS AND CONCLUSIONS

### SOME RECOMMENDATIONS DERIVED FROM REVIEW OF U.S. AND FOREIGN STANDARDS

The review of the present U.S. lighting equipment standards and some of the comparisons that have been made between these standards and those in existence in foreign countries, should provide a reasonably concise and complete reference source. Such information, should prove useful to lighting equipment engineers as well as those in agencies concerned with the setting of vehicle lighting standards, whose work will be facilitated by providing this information in the same cover. From the standpoint of research, these reviews have been useful in highlighting elements of the standards which may not be compatible with good practice for safety, or because of incompatibilities between U.S. standards and those existing in other countries having large vehicle populations. The reviews have also been used to suggest elements of standards existing outside the United States that warrant consideration for implementation in vehicle marking and signaling systems.

Various of the problems associated with the present marking and signaling standards have been discussed in the appropriate sections of the report, but some of the more important ones require some further discussion.

1. Area of Presence (tail) lamps. There is no specific minimum area requirement for rear presence lamps on vehicles in the U.S. standard, other than that a minimum of two square inches of lens surface must be visible at a horizontal angle of 45 degrees. Since U.S. practice is to combine presence and turn/stop functions in the same lamp this may appear to pose no problem, since there is a minimum area requirement for the lamps performing the stop and turn signal functions. However, some

European and other vehicles do not combine the presence lamp with other functions and could thereby meet the visibility requirement, as defined above, with quite small lamps. There does not appear to be anything detrimental that can be associated with presence lamps of small area. On the contrary, there appear to be some potential advantages, not only in that small lamps occupy less space on the vehicle, but the lens surface will be at a higher luminance, for a given candela lamp output, than for a larger lamp thus providing an increase in the apparent brightness of small presence lamps. This may also be advantageous to offset the effect of dirt accumulation on the surface of the lens, whose visibility will be less reduced for a lamp of higher luminance than for a larger lamp of the same candlepower which necessarily will have a reduced intensity per unit area of lens surface. (These alleged advantages are not applicable to stop or turn signal lamps, which have considerably higher intensities than presence lamps, and in those cases small lamp areas increase the probability of causing discomfort glare.)

Potentially detracting from the advantages accruing in apparent brightness of presence lamps of small areas, may be difficulties associated with identifying the lights they would present to a following vehicle driver as those eminating from another vehicle. This question would require further resolution, as it is important that vehicles can be readily identified at night by the light configuration which they present as compared to lights from other objects that are not a part of the traffic.

2. <u>Location of Rear Turn Signal Lamps on Truck Tractors</u>. Double-faced turn signal lamps, to satisfy the front and rear turn signal indication, can be used on truck tractors. Thus, whereas stop signal lamps must be mounted at the rear of the vehicle, the rear turn signal indication is given by a lamp normally mounted on the front fenders. Such a location may be

difficult to see from the driver's position of a following vehicle. It would be considered useful to evaluate the visibility of such lamps, particularly mounted on the right side of the tractor in case vehicle structures obscure its visibility to a following driver. Should that be the case a revision of the present standard would appear reasonable.

3. Effect of Brake Application Incapacitating Hazard Warning Indication. On those vehicles where the turn and the stop signal is given by the same lamp, as is common on U.S. vehicles, the hazard warning (four-way flashing) will be overridden by the steady-burning stop lamps. There is also a side effect of this on the side marker lamps, on those vehicles where they are made to flash out of phase with the turn signal lamps, which will result in the side marker lamps being turned off when the brake pedal is depressed and the hazard warning system has been activated.

It appears reasonable that the hazard warning system should override the action of the stop lamp switch and allow the lamps to flash, in the same way that the turn signal switch overrides the stop lamp switch on the turning side.

4. Clearance Lamps on Truck/Tractors Indicate Cab Width Rather Than Vehicle Width. It is presently permitted to mount clearance lamps on truck/tractors on top of the cab area. Since the purpose of clearance lamps are to indicate the width of large vehicles such a mounting does not fulfill this requirement, except in the case where the cab extends over the full width of the vehicle, which is not the usual situation. It would appear more useful to indicate the width of the vehicle by insuring that clearance lamps are mounted close to the edges of truck/tractors, at their widest point.

5. Rear Side Marker Lamps of Truck/Tractors. Truck/tractors are not required to have rear side marker lamps, or for that matter rear clearance, rear identification and rear side reflex

reflectors. Each of these appears to be important, if drivers of vehicles approaching from the rear are to identify the truck. In particular, the rear side marker lamp omission appears to pose a particular hazard, such as in those instances where a tractor is backing onto a road in which case its rear side will not be marked to approaching drivers. Either side marker lamps or, minimally, side reflex reflectors at the rear of tractors would appear to be a useful safety feature.

6. Side, Forward-Mounted Front Turn Signal Lamps. In some European countries vehicles must be equipped with side-mounted turn signal lamps, one on each side of the vehicle located at the front end. It would appear that such lamps could provide a useful function to eliminate blind spots of either the front or rear turn signals which now exist in many roadway situations. It is possible, that such side-mounted lamps could also fulfill the requirement of the turn signal indicator lamp, which could thereby be deleted. A previous study (Mortimer, 1970) has suggested intensity-area and location requirements for such signals.

7. Rear Retroreflector Performance. There are no minimum area requirements currently stipulated for rear, retroreflectors on vehicles. Intensity requirements for such reflectors are indicated, but they span a relatively narrow angular range, between ± 10 degrees vertically and ± 20 degrees horizontally. These requirements for retroreflectors mounted on the rear of vehicles require reconsideration. A recent study of rear-end collisions (Mortimer and Post, 1972) on country roads, city streets and limited access highways in Washtenaw County, Michigan has shown that parked vehicles are struck in the rear 3.8 times as often at night as in daytime on roads and streets, and 6 times as often on limited access highways. This relative overinvolvement of parked vehicles at night compared to daytime strongly suggests that the visibility of such vehicles is considerably reduced from daytime conditions. It is believed that this situation could be

alleviated by an improvement in the overall performance requirements of rear-mounted reflectors.

Based on the findings from the review of present U.S. and foreign standards, it is apparent that there are gaps in these data and instances where revisions to these standards or inclusion of additional requirements could lead to an improvement in the overall marking and signaling performance of vehicles.

SEPARATION OF LAMPS BY FUNCTION

Since the major thrust of the studies reported here and other studies that have been completed or are underway in the marking and signaling project, is to lead to recommendations for an improved marking and signaling system for automobiles and trucks, a brief review was conducted concerned with the effect of separation of lamps having different signaling functions. That review summarized a number of studies concerned with this problem, and clearly concluded that there appears to be a substantial benefit to this concept. These benefits were found to arise from a reduction in information processing time required to identify stop and turn signals on the rear of vehicles, by reducing response times to signals, as well as confusions in identifying the specific signal presented and a reduction in signals that are missed completely. Since measures of this type appear to be quite relevant to the evaluation of the performance of drivers in interpreting signals from vehicle rear lighting systems, and since the studies were conducted in a variety of simulation, static field test and driving conditions, there can be a considerable degree of security in extrapolating results of such studies to performance under normal driving conditions.

Thus, separation of lamps by functions appears to be a useful system design concept. There are numerous ways in which this can be done, and more work is required to provide information as to the most cost-effective approach that should be used. Studies of that type, including those concerned with the effect of commonly occurring malfunctions in the vehicle marking and signaling system, will be conducted in other phases of this research.

## SIGNAL IDENTIFICATION DISTANCE

The distance at which signals should be visible, or identifiable, has received considerable attention but lack of adequate evaluation. For example, most state vehicle codes indicate that stop and turn signals should be visible under day and night driving conditions at distances of not less than 100-500 feet. A substantial number of lighting tests have also been carried out by member companies of the Motor Vehicle Manufacturers Association (Automobile Manufacturers Association, 1966), in which intensity and other factors that affect the visibility of signal lamps have been evaluated, usually at distances not exceeding 500 feet. While such a distance might appear to be reasonable, it was determined that an analytical approach could be utilized to provide better insight for the establishment of visibility distances at which it would be desirable for signal lamps to be not only visible but also identifiable. The analysis conducted in this study has suggested that the distances used in those previous tests have been too small, and that more relevant distances are at least 1500 feet. Having established that the evaluation of intensity requirements and other variables that can affect signal system performance should be conducted at distances considerably larger than have been used before, a study was designed which incorporated viewing distances of up to 2000 feet.

## SIGNAL INTENSITY AND SYSTEM CONFIGURATION

The study conducted in this project concerned with signal system intensity requirements and some other variables, was unique in that the evaluations were carried out using complete conventional and experimental systems. This differed, for example, from a previous study (Mortimer, 1970), in which isolated lamps were used out of the context of a rear lighting system. Since it became apparent that the operational concept of a system influenced the ease of identification of the signals which it presents, it seemed reasonable to believe that similar considerations would have a bearing upon the intensities required by signal lamps of such systems to convey information. The study was concerned with the effect of a number of variables, such as viewing distance, edge-to-edge separation distance between lamps, system operating concept, presence and signal lamp intensities, upon the ability of drivers to identify and rate the brightness of signals presented by such systems under day, night, and night + glare conditions. Overall subjective ratings of the effectiveness of the systems in these various conditions were also obtained.

The findings of this study have shown that subjective impressions of the effectiveness of systems in providing signals, under varying conditions of viewing distance and intensities, etc., are fairly reliable indicators when compared with data derived by other means, such as by measurement of signals correctly identified. It appears that drivers can make estimates of system effectiveness, taking account of many of the variables involved, as shown by the results of this study. The overall effectiveness ratings correlated reasonably well with the objective measure taken, and thereby lends support to this technique which has been used extensively in previous evaluations (AMA, 1965; 1966; Mortimer, 1969).

Aside from providing this type of information on techniques that can be used for the evaluation of variables affecting rear lighting system performance, the major findings of the study relate to system operating parameters, in terms of their effect upon signal intensity requirements. There was good agreement found between this study and that conducted previously (Mortimer, 1970) in deriving maximum night intensities and minimum day intensities for stop signals, and minimum daytime intensities for turn signals.

The study also found that for a lamp flashing at about 1 cps the maximum intensity can be about 50% greater than for an equivalent steady-burning lamp at night, to provide the same level of discomfort glare. This means that turn signal lamp nighttime maximum intensities could be 1.5 times the intensity of a corresponding stop lamp, without increasing discomfort glare. This finding is particularly relevant for those rear lighting systems in which stop lamps are separated from the lamps providing the turn signal, since the findings of this study showed that in those systems, at large viewing distances, the turn signal tends to be missed. By increasing the turn signal intensity to be 1.5 times greater than for a steady-burning lamp, the probability of detecting the turn signal will be increased.

The most important finding of this study is that the intensities required to provide near optimum levels of signal identification and low degrees of discomfort glare, differ according to the systems' operating characteristics. Three basic system types were used in this study and each required a different set of minimum and maximum intensities in night and daytime conditions, to maximize their effectiveness.

It will have been noted (Table 5.46) that with the presently used system, in which all signals are combined into the same lamps, it will be difficult to obtain adequate stop signal identification at night unless intensities are used that exceed discomfort glare levels. This problem does not occur with the other two system configurations that were evaluated involving either red lamps with separation of stop lamps only, or color coding and functional separation of all lamps. The latitude allowed in the latter system between minimum and maximum nighttime intensities is larger than for any other configuration tested, suggesting a practical benefit in the implementation of effective nighttime signal intensities for this system concept utilizing color coding and functional separation. It will also be noted that, as found in previous studies (AMA Vehicle Lighting Committee Tests, 1958-64; Mortimer, 1970), greater minimum intensities are needed in the daytime than the maximum values at night which reasonably control discomfort glare. This finding holds for each of the three system types evaluated, and again shows that, for effectiveness in identification of signals and to control discomfort glare, it would be necessary to have different intensity minima and maxima applicable to night and daytime driving conditions.

The findings of this study have provided some new information which clearly indicates that intensity requirements are a function not only of variables such as lamp area, ambient lighting condition, viewing distance, etc., but also interact with the operational characteristics of the system. The results also show that systems that provide improved information processing for drivers, such as those that use some degree of functional separation or others that also utilize color coding, also increase the flexibility of the intensity requirements which they impose to provide effective levels of performance. These findings are, therefore, further evidence that improvements in overall rear lighting system effectiveness can be achieved using concepts of functional separation and color coding, and that these requirements on the intensities of signal lamps can be attained more readily for such systems than the one presently in use.

The output of this study has been prepared in the form of a set of guidelines for the intensities of signal lamps for systems incorporating the three operating concepts that were studied.

## A BLUE-GREEN ZONE FOR PRESENCE LIGHTS

The experiment concerned with hue identification and discrimination by normal and color-blind observers was initiated in order to obtain some better information, than presently available, on the bounds that should be placed on the chromaticity coordinate values for the filters of lamps in the vehicle marking and signaling system. While vehicles presently use marking and signaling lamps that are white, yellow or red, this study was also concerned with providing data on the spectral transmission of filters in green-blue region.

The study was limited to low ambient lighting, night driving conditions, since the objective was to find color zones for rear lights, which are primarily used at night. A dual-path monochromator was used, in a laboratory experiment. This technique allowed close control of the purity and dominant wavelength of the colors presented to the observers, which would be difficult to do in any other way. The objective was to find a basic set of colors that would be identifiable and not confused with each other or with white, by normal and color-blind observers.

The findings of this study have shown that SAE red and white are the least similar for deuteranoids and trichromats, while red and amber are more similar and confusions between them would be expected. Amber and white were rated most similar and would be confused more often than any other pairs of the SAE colors. However, the protanoid experienced a high frequency of confusions among red, amber and white. These findings are similar to those obtained under field test conditions (e.g. Mortimer, 1969a). That same study also raised the issue of potential problems with blue-green rear presence lamps, since these tended to be confused by dichromats with white lights. This would be a particularly undesirable aspect since it could lead to confusions between the appearance, at night, of the front and rear of vehicles. For this reason one of the major objectives of this study was to select a blue-green zone suitable for rear presence lamp filters.

The results of the study have been used to suggest new color zones for white, yellow and blue-green. These zones (shown in Figure 6 .14) retain the SAE red as presently specified. It is suggested, however, that the SAE yellow be changed to a color in the greenish-yellow region to provide a greater distinction from white and SAE red, which would benefit drivers with normal color vision and those with anomalous color vision defects. The remaining, approximately 2% of true dichromatic, preponderantly male, drivers would not be helped by this change and would continue to make some confusions between red, greenish-yellow and white. The least desirable aspect of this type of confusion would probably be that between the headlights and rear presence lamps of vehicles at night, although distinctions would be available to these drivers due to the substantial differences in the intensities of the lamps that would normally be directed towards them. The findings of this study have also shown that it is important that the colors in the red and yellow regions that are used be maximally pure, as even small increases in the relative proportion of white light reduces the color naming consistency scores obtained and increased confusions between them.

A blue-green zone was defined with the intent of minimizing confusions with the region of SAE white closest to the blue-green zone.

The responses of subjects to colors selected in the blue-green region were generally quite consistent in correctly naming them, with the most confusions being made by the deuteranoids who most often confused them with white. However, these effects were relatively minor if the purity exceeded 75% for these blue-green (Table 6 .12). The effect of reducing the purity of the blue-greens and thereby increasing their similarity to the SAE white is also shown by the similarity ratings, for each of the three vision types, in Tables 6.18-6.20. A blue zone was selected having a green limit described by a line passing through the protanopic intersection point to a point at 490.5 nm. The purple limit of the blue-green zone was selected so that the colors seen within the zone appear similar to each other.

These recommendations for the color zones of red, greenish-yellow, blue-green and the SAE white are shown in Figure 6.14. Some additional improvement in the discrimination of white from yellow could be obtained by reducing the yellow limit of SAE white. However, this is not practical since this limit is necessary due to the filament temperatures of presently used headlamps. In the event that quartz-halogen type bulbs should be used in headlamp systems, to replace the lower temperatures of present headlamps, then it may be feasible to reduce the orange limit of SAE white. However, this will also have the effect of moving the present SAE white-blue zone more toward the blue region, and would require a small reduction in the suggested blue-green zone that has been recommended based on the results of this study. The computational steps by which this could be accomplished, based on the data of this study, have been shown and could be used to make such changes.

Finally, it is important to note that the study of color identification and discrimination was conducted under low ambient lighting conditions, such as found in night driving. It would be appropriate to examine the recommendations for color filters based on these data to determine their effectiveness under daylight conditions. Such a study would be primarily concerned with the comparison of the SAE red and the greenish-yellow zone that has been suggested here as being suitable to replace the presently used SAE yellow, since neither headlamps nor rear presence lamps are normally used in the daytime.

## CONCLUSIONS

The findings of the studies that have been described in this report will be useful in structuring some of the further studies to be conducted in vehicle marking and signaling, and will assist in developing criteria for the intensities, separation distances and spectral transmission characteristics of lamps used for vehicle marking and signaling systems.

Appendices

# APPENDIX A.

# INSTRUCTIONS FOR TEST 5.

## Appendix A

### INSTRUCTIONS FOR TEST 5.

The following instructions were read to the subjects in the various conditions in which they participated:

Each of you should have a clip board with a number of data sheets attached to it. On the first data sheet please fill in your subject number which is as follows . Then fill in your name, age, the date which is , and indicate your sex by inserting the correct number. Record the session as number . You should have (10-day, 10-night + glare, 6-night) data sheets on your clipboard. Please number the pages successfully and also put your subject number on each page. Let me know if you have too many or too few pages. All set?

In this experiment we want you to image that you are driving down this road and that there is another car ahead of you, that you are following, in the same lane. From time to time you will see some lights which are mounted on a panel representing the rear of the car you are following. Imagine that these lights are the rear lights of the vehicle in front of you. The purpose of this experiment is to learn how well you can identify signals that are being shown on the back of the car ahead of you. The signals you see will be taillights, or as we shall refer to them, presence lights; stop lights, turn signal lights, or combinations of these. We want you to identify which signal lights are being given and to rate the brightness of each of the lights that you noticed in the appropriate columns on the data sheets. For example, if a stop light and a turn light were both presented you should rate the brightness of the stop lights by checking the appropriate column under "STOP" on the data sheet (i.e. check either "Too Dim," "Adequate," or "Too Bright"); you should then rate the brightness of the turn signal by checking the appropriate column under "TURN" (check only either "too dim," "adequate," or "too bright"). An adequately bright signal is one you feel would be easily seen and would attract your attention. If you are unable to see any lights during a trial presentation or should happen to be looking away during the presentation and miss seeing the lights, draw a horizontal line across the page in the row for that trial number. However, if you see a signal, but are unsure what the signal was, you should put down the best guess.

After each light presentation a buzzer will sound. When it sounds you should rate the brightness of each of the lights that you have observed; then press the button on your clipboard when you are ready, and watch for the next light presentation.

Be sure to fill in your ratings in successive trial slots. I will check with you frequently to make sure we are all on the same trial. The white cards on the clipboard should be used as a guide to make sure you place your check marks in the correct row. Does anyone not have a card? Are there any questions?

You will be given a demonstration of the turn, stop, (and presence) lights of each rear lighting and signaling system before the trials of that system are presented, so that you will know what the signals of that particular system look like. The systems differ to some degree in the manner in which various signals are displayed.

In addition to the brightness ratings that you will be asked to make at the end of each trial you will be also asked to make a rating of the overall effectiveness of that particular lighting system for which you will have just been making brightness ratings. The effectiveness of the system is the extent to which you judge it to be capable of giving good and clear signals. Rate the effectiveness by a 1 to indicate a very effective system, a 2 to show that you feel that the system is fair and that you are indifferent to it, and a 3 to indicate that you judge the system to be ineffective and would not like to see it on the rear of vehicles.

The system we will be observing for the next several minutes will be demonstrated now. For now, just observe the signals; do not write down anything (show signals). These are typical of signal presentations in this system. At night presence lights may or may not be presented.

I will now hand each of you an extra data sheet. The signals you have just seen will be presented again in random order. Please respond as if these were regular signals, and I will check your sheet to make sure you are responding in the correct manner. (Present signals, observe and collect data sheets.)

Remember, after each light presentation, when the buzzer has sounded you should immediately rate the brightness of each of the lights that you observed. Do not discuss any aspects of the experiment until it is completed. Please do not smoke during the experiment, and if you are wearing tinted glasses, please remove them. There will be rest periods during the test when you will have an opportunity to smoke and stretch your legs. If there are no more questions please watch the light board, and we will begin.

## APPENDIX B

PERCENT OF SIGNALS CORRECTLY IDENTIFIED, PERCENT ERRORS, AND SIGNALS RATED INADEQUATE(I) OR EXCESSIVE(E) IN BRIGHTNESS IF >15%, FOR EACH SYSTEM IN EACH CONDITION OF TEST 5.

TABLE B.1. Percent of Signals Correctly Identified, and Percent Errors by Type and Signals Rated Inadequate(I) or Excessive(E) in Brightness if >15%, are Shown for All Conditions for System 1.

System 1

| | | | DAY | | | | NIGHT - 4 CP | | | | NIGHT - 15 CP | | | | NIGHT GLARE - 4 CP | | | | NIGHT GLARE - 15 CP | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance | SI | Mode | %ID | Error | >15%I | >15%E | %ID | Error | >15%I | >15%E | %ID | Error | >15%I | >15%E | %ID | Error | >15%I | >15%E | %ID | Error | >15%I | >15%E |
| 250 | 80 | P | | | | | 97 | | | | 80 | | | P=17 | 97 | | P=23 | | 100 | | | |
| | | P+S | 93 | | S=60 | | 60 | P=34 | | | 69 | P=31 | | | 64 | P=35 | | | 58 | P=39 | | |
| | | P+T | 91 | | T=85 | | 89 | | T=34 | | 74 | S+T=20 | | | 87 | | P=26<br>T=23 | | 81 | | T=52 | |
| | | P+S+T | 94 | | S=65<br>T=81 | | 69 | P+T=29 | | | 49 | P+T=51 | | | 55 | P+T=42 | | | 55 | P+T=42 | | |
| | 185 | P | | | | | 91 | | P=26 | | 91 | | | P=17 | 100 | | P=45 | | 97 | | | |
| | | P+S | 99 | | S=32 | | 80 | | | | 69 | P=29 | | | 81 | | | | 81 | | | |
| | | P+T | 99 | | T=44 | | 91 | | P=20 | | 83 | | T=20 | | 90 | | P=35 | | 84 | | | |
| | | P+S+T | 97 | | S=28<br>T=32 | | 80 | | T=23 | | 69 | P+T=29 | | | 71 | P+T=23 | | | 68 | P+T=29 | | |
| | 425 | P | | | | | 91 | | P=17 | | 83 | | | | 90 | | P=32 | | 94 | | | |
| | | P+S | 93 | | | | 89 | | | S=29 | 95 | | | | 81 | | | | 74 | P=26 | | |
| | | P+T | 94 | | | | 89 | | P=29 | T=31 | 89 | | | T=34 | 81 | | P=23 | | 90 | | | |
| | | P+S+T | 97 | | | | 80 | | | S=26 | 80 | | T=23 | S=29<br>T=17 | 77 | P+T=19 | | | 74 | P+T=23 | | |
| | 1000 | P | | | | | 94 | | P=17 | | 86 | | | | 87 | | P=42 | | 90 | | | |
| | | P+S | 91 | | | S=29 | 94 | | | S=51 | 89 | | | S=43 | 78 | P=19 | | | 77 | P=19 | | |
| | | P+T | 97 | | | T=22 | 91 | | P=45 | T=57 | 86 | | | T=46 | 87 | | P=45 | T=48 | 84 | T=19 | | |
| | | P+S+T | 96 | | | S=28<br>T=22 | 92 | | | S=40<br>T=23 | 89 | | | S=49<br>T=23 | 84 | | | S=39<br>T=29 | 77 | | | |
| 1000 | 80 | P | | | | | 100 | | P=31 | | 77 | S=23 | | | 100 | | P=55 | | 91 | | P=27 | |
| | | P+S | 93 | | S=79 | | 69 | P=23 | | | 100 | | S=23 | | 55 | P=45 | | | 36 | P=64 | | |
| | | P+T | 86 | | T=86 | | 62 | N=15<br>S+T=15 | | | 69 | S+T=31 | | | 91 | | P=64<br>T=18 | | 91 | | | |
| | | P+S+T | 36 | N=21<br>S=36 | | | 85 | | T=31 | | 77 | P+T=23 | | | 64 | P+T=36 | | | 36 | P+T=55 | | |
| | 185 | P | | | | | 100 | | P=54 | | 92 | | | | 100 | | P=73 | | 91 | | P=18 | |
| | | P+S | 100 | | S=79 | | 100 | | S=23 | | 92 | | S=23 | | 82 | | S=18 | | 82 | | | |
| | | P+T | 100 | | T=86 | | 92 | | P=31 | | 100 | | T=23 | | 91 | | P=45 | | 73 | T= 9<br>P+S= 9<br>P+S+T= 9 | | |
| | | P+S+T | 100 | | S=79<br>T=71 | | 92 | | T=23 | | 85 | | T=31 | | 82 | | T=18 | | 82 | | T=36 | |
| | 425 | P | | | | | 100 | | P=23 | | 92 | | | | 100 | | P=73 | | 100 | | P=18 | |
| | | P+S | 93 | | S=50 | | 100 | | | | 100 | | | | 100 | | | S=27 | 91 | | | |
| | | P+T | 79 | S=21 | | | 92 | | P=46 | T=31 | 100 | | | | 91 | | P=73 | T=36 | 82 | | P=27 | |
| | | P+S+T | 93 | | S=43<br>T=50 | | 92 | | | S=23 | 100 | | | | 91 | | S=18 | S=18 | 91 | | | |
| | 1000 | P | | | | | 100 | | P=38 | | 92 | | | | 100 | | S=91 | | 100 | | P=36 | |
| | | P+S | 79 | S+T=21 | | | 100 | | | S=31 | 85 | | | S=38 | 82 | | | | 82 | | | S=27 |
| | | P+T | 93 | | | | 100 | | P=46 | T=46 | 85 | | | T=38 | 100 | | P=55 | T=45 | 91 | | P=27 | T=18 |
| | | P+S+T | 93 | | | | 100 | | | S=31 | 100 | | | S=46 | 100 | | | S=36 | 82 | | | S=36 |
| 2000 | 80 | P | | | | | 94 | | P=51 | | 69 | P+S=11 | | | 90 | | P=71 | | 71 | P+S=10 | | |
| | | P+S | 25 | N=49<br>T=18<br>S+T= 9 | | | 80 | | | | 74 | P=14 | | | 55 | P=42 | | | 55 | P=39 | | |
| | | P+T | 24 | N=71 | | | 86 | | P=34<br>T=23 | | 74 | P= 9<br>S+T= 9<br>P+S+T= 9 | | | 55 | P=19<br>T=13 | | | 74 | P=16 | | |
| | | P+S+T | 24 | N=47<br>T=24 | | | 89 | | T=49 | | 63 | P+T=34 | | | 42 | N=13<br>P+T=42 | | | 39 | P=19<br>P+T=32 | | |
| | 185 | P | | | | | 97 | | P=54 | | 80 | | | | 94 | | P=65 | | 90 | | P=35 | |
| | | P+S | 75 | N=18 | | | 94 | | | | 89 | | | | 68 | P=26 | | | 49 | P=48 | | |
| | | P+T | 85 | | T=78 | | 97 | | P=40 | T=17 | 71 | S+T= 9<br>P+S+T=14 | | | 90 | | P=74 | | 65 | T=10<br>S+T=13 | | |
| | | P+S+T | 56 | N=15<br>S=26 | | | 94 | | T=29 | | 80 | | T=26 | | 55 | T=10<br>P+T=35 | | | 35 | S=10<br>P+T=39 | | |
| | 425 | P | | | | | 94 | | P=57 | | 89 | | | | 94 | | P=77 | | 81 | | P=32 | |
| | | P+S | 96 | | S=41 | | 94 | | | S=29 | 94 | | | S=26 | 97 | | | | 77 | P=23 | | |
| | | P+T | 96 | | T=59 | | 94 | | P=54 | T=26 | 80 | | P=20 | T=20 | 64 | | P=67 | T=23 | 81 | | P=35 | |
| | | P+S+T | 87 | | S=41<br>T=40 | | 100 | | | S=23 | 100 | | T=17 | | 81 | | | | 84 | | | S=19 |
| | 1000 | P | | | | | 97 | | P=54 | | 97 | | P=20 | | 87 | | P=71 | | 81 | | P=39 | |
| | | P+S | 91 | | | | 100 | | | S=38 | 97 | | | S=29 | 71 | P=26 | | | 84 | | | S=16 |
| | | P+T | 97 | | | | 86 | | P=60 | T=46 | 91 | | P=31 | T=34 | 68 | T=19<br>S+T=10 | | | 74 | T=10<br>S+T=13 | | |
| | | P+S+T | 94 | | | | 94 | | | S=32<br>T=17 | 100 | | | S=40<br>T=20 | 90 | | | S=23 | 87 | | | S=23 |

TABLE B.2. Percent of Signals Correctly Identified, and Percent Errors by Type and Signals Rated Inadequate(I) or Excessive(E) in Brightness if >15%, are Shown for All Conditions for Systems 2 and 3.

## Systems 2 and 3, Day Condition Only

| | | | System 2 - 2" Sep [illegible] | | | System 3 - 2" Sep [illegible] | | | System 2 - 8" Sep [illegible] | | | System 3 - 8" Sep [illegible] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance | SI | Type | % | Error | I/E | % | Error | I/E | % | Error | I/E | % | Error | I/E 15%F |
| 250 | 80 | S | 99 | S=63 | | 97 | S=72 | | 96 | S=60 | | 94 | S=71 | |
| | | T | 99 | T=85 | | 97 | S=96 | | 99 | T=85 | | 97 | T=94 | |
| | | S+T | 97 | S=63 T=69 | | 91 | S=43 T=87 | | 97 | S=54 T=57 | | 99 | S=59 T=88 | |
| | 185 | S | 99 | S=28 | | 96 | S=40 | | 97 | S=40 | | 100 | S=21 | |
| | | T | 94 | T=47 | | 97 | T=84 | | 97 | T=46 | | 100 | T=79 | |
| | | S+T | 97 | S=24 T=29 | | 99 | S=35 T=76 | | 97 | S=26 T=22 | | 99 | S=22 T=63 | |
| | 425 | S | 100 | | | 100 | | | 97 | | | 96 | | |
| | | T | 100 | T=21 | | 97 | T=56 | | 99 | | | 100 | T=35 | |
| | | S+T | 100 | | | 97 | T=40 | | 99 | | | 100 | T=22 | |
| | 1000 | S | 96 | | S=22 | 100 | | S=32 | 94 | S=28 | | 100 | S=29 | |
| | | T | 97 | | T=19 | 99 | T=22 | | 96 | T=26 | | 97 | | |
| | | S+T | 99 | S=56 | T=40 | 99 | T=16 | S=38 T=19 | 97 | S=44 T=35 | | 99 | S=34 T=16 | |
| 1000 | 80 | S | 71 | N=21 | | 86 | S=71 | | 79 | N=21 | | 93 | S=71 | |
| | | T | 93 | T=86 | | 43 | N=29 S=29 | | 86 | T=79 | | 21 | N=71 | |
| | | S+T | 7 | N=14 S=71 | | 14 | N=14 S=71 | | 43 | N= 7 S=50 | | 14 | S=79 | |
| | 185 | S | 100 | S=50 | | 100 | S=57 | | 100 | S=86 | | 93 | S=79 | |
| | | T | 79 | N= 7 S= 7 S+T= 7 | | 100 | T=86 | | 100 | T=71 | | 93 | T=86 | |
| | | S+T | 64 | S=36 | | 43 | S=57 | | 79 | S=21 | | 43 | S=57 | |
| | 425 | S | 93 | S=57 | | 100 | S=36 | | 100 | S=29 | | 100 | S=50 | |
| | | T | 100 | T=71 | | 100 | T=50 | | 93 | T=21 | | 100 | T=71 | |
| | | S+T | 93 | S=36 T=64 | | 71 | S=29 | | 93 | S=21 T=43 | | 79 | S=21 | |
| | 1000 | S | 100 | | | 100 | | | 93 | | | 93 | | |
| | | T | 100 | | | 100 | | | 93 | T=29 | | 93 | T=36 | |
| | | S+T | 93 | T=29 | | 71 | S=29 | | 93 | T=21 | | 86 | | |
| 2000 | 80 | S | 32 | N=43 T=15 S+T=10 | | 29 | N=41 T=18 S+T=12 | | 54 | N=31 | | 43 | N=38 T=13 | |
| | | T | 15 | N=75 | | 6 | N=88 | | 22 | N=71 | | 6 | N=84 | |
| | | S+T | 22 | N=37 S=26 T=15 | | 7 | N=43 S=29 T=21 | | 15 | N=25 S=40 T=21 | | 12 | N=35 S=41 S+T=12 | |
| | 185 | S | 88 | S=78 | | 71 | N=15 S+T= 9 | | 88 | S=78 | | 82 | S=75 | |
| | | T | 79 | N=16 | | 35 | N=59 | | 75 | N=19 | | 40 | N=54 | |
| | | S+T | 19 | N= 9 S=66 | | 13 | N=13 S=69 | | 32 | S=62 | | 22 | N=12 S=66 | |
| | 425 | S | 90 | S=50 | | 88 | S=37 | | 96 | S=34 | | 96 | S=44 | |
| | | T | 96 | T=62 | | 79 | N=15 | | 97 | T=57 | | 78 | N=18 | |
| | | S+T | 40 | S=56 | | 16 | S=82 | | 62 | S=38 | | 37 | S=62 | |
| | 1000 | S | 93 | | | 96 | | | 97 | | | 93 | | |
| | | T | 94 | | | 94 | T=57 | | 97 | | | 94 | T=63 | |
| | | S+T | 37 | S=60 | | 31 | S=66 | | 74 | S=26 | | 51 | S=46 | |

TABLE B.3. Percent of Signals Correctly Identified, and Percent Errors by Type and Signals Rated Inadequate(I) or Excessive(E) in Brightness if >15%, are Shown for All Conditions for System 4.

System 4, Night Condition Only

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|
| 250 | 80 | P | 91 | P=17 | 91 | | 100 | P=31 | 100 | |
| | | P+S | 89 | P=26 S=17 | 97 | P=17 S=23 | 97 | P=26 S=17 | 94 | S=17 P=17 |
| | | P+T | 89 | P=37 T=34 | 91 | T=57 | 97 | P=31 S=31 | 97 | T=57 |
| | | P+S+T | 66 | P+T=11 S+T=14 | 63 | P+S=23 P+T= 9 | 97 | P=29 T=57 | 97 | T=74 P=17 |
| | 185 | P | 91 | P=31 | 83 | | 94 | P=34 | 94 | |
| | | P+S | 89 | P=46 S=17 | 91 | P=17 | 100 | P=29 S=26 | 100 | |
| | | P+T | 80 | P=26 | 86 | T=20 | 97 | P=26 | 100 | T=31 |
| | | P+S+T | 74 | S+T=17 | 77 | S+T=14 | 97 | P=46 T=23 S=31 | 97 | T=37 S=17 |
| | 425 | P | 97 | | 89 | | 100 | P=31 | 97 | |
| | | P+S | 69 | S=26 | 89 | P=34 S=29 | 97 | P=54 S=49 | 94 | P=23 S=40 |
| | | P+T | 89 | P=34 T=29 | 83 | T=20 | 100 | P=40 S=37 | 94 | T=23 |
| | | P+S+T | 57 | P+T= 9 S+T=31 | 66 | S+T=29 | 94 | P=43 S=43 T=17 | 94 | P=26 S=54 T=17 |
| | 1000 | P | 97 | P=37 | 97 | | 97 | P=34 | 97 | |
| | | P+S | 23 | P=14 S=57 | 63 | S=34 | 83 | P=49 S=51 | 89 | S=51 |
| | | P+T | 89 | P=51 T=43 | 94 | P=26 T=43 | 91 | P=40 T=46 | 86 | T=40 |
| | | P+S+T | 40 | S+T=51 | 60 | S+T=31 | 77 | S+T=20 | 91 | P=20 S=46 T=26 |
| 1000 | 80 | P | 100 | P=46 | 92 | | 100 | P=23 | 100 | |
| | | P+S | 46 | S=54 | 54 | S=46 | 77 | S=15 | 69 | S=31 |
| | | P+T | 92 | | 92 | T=69 | 92 | | 77 | S+T=15 |
| | | P+S+T | 8 | S=23 S+T=69 | 8 | P+S=15 S+T=77 | 69 | S+T=23 | 23 | P+S=31 S+T=31 |
| | 185 | P | 100 | P=46 | 92 | | 100 | | 92 | |
| | | P+S | 46 | S=54 | 46 | S=54 | 46 | S=46 | 69 | S=23 |
| | | P+T | 100 | P=31 | 92 | | 100 | | 92 | |
| | | P+S+T | 0 | S=23 S+T=69 | 8 | S=23 S+T=54 | 46 | S+T=54 | 54 | S+T=38 |
| | 425 | P | 92 | P=54 | 92 | | 100 | P=54 | 85 | |
| | | P+S | 23 | S=69 | 23 | S=77 | 38 | S=54 | 31 | S=69 |
| | | P+T | 92 | P=23 T=38 | 92 | | 92 | T=31 | 100 | |
| | | P+S+T | 0 | S=15 S+T=85 | 0 | S=31 S+T=69 | 38 | S+T=62 | 54 | S+T=38 |
| | 1000 | P | 100 | P=54 | 92 | | 100 | P=31 | 92 | |
| | | P+S | 8 | S=92 | 0 | S=92 | 0 | S=100 | 8 | S=92 |
| | | P+T | 92 | P=31 T=69 | 100 | T=38 | 100 | P=46 T=62 | 92 | T=31 |
| | | P+S+T | 0 | S+T=85 | 0 | S=15 S+T=85 | 8 | S+T=92 | 31 | S+T=62 |
| 2000 | 80 | P | 86 | P=54 | 80 | | 94 | P=46 | 71 | S=11 P+S=11 |
| | | P+S | 57 | P=11 S=31 | 49 | S=40 | 54 | S=40 | 51 | S=43 |
| | | P+T | 80 | P=26 | 71 | P+S+T=14 | 86 | P=54 T=23 | 66 | S+T=14 P+S+T=17 |
| | | P+S+T | 14 | S=17 P+S=20 S+T=29 | 14 | S=23 P+S=37 S+T=11 | 31 | S+T=43 | 23 | P+S=26 S+T=40 |
| | 185 | P | 94 | P=46 | 86 | | 97 | P=63 | 97 | P=20 |
| | | P+S | 37 | S=54 | 46 | S=37 | 57 | S=37 | 37 | S=60 |
| | | P+T | 91 | P=46 | 80 | P=17 | 97 | P=57 | 86 | |
| | | P+S+T | 20 | P+S=14 P+T=14 S+T=43 | 26 | S=23 S+T=37 | 26 | P+S=26 S+T=43 | 29 | S=17 S+T=40 |
| | 425 | P | 97 | P=54 | 86 | P=17 | 89 | P=49 | 94 | P=23 |
| | | P+S | 37 | S=57 | 37 | S=54 | 34 | S=57 | 43 | S=57 |
| | | P+T | 86 | P=57 T=29 | 69 | S+T=11 P+S+T=11 | 83 | P=60 T=20 | 80 | P=17 |
| | | P+S+T | 20 | P+S=14 S+T=54 | 20 | S=20 S+T=54 | 34 | S+T=54 | 31 | S+T=63 |
| | 1000 | P | 91 | P=31 | 77 | S=11 | 89 | P=60 | 83 | P=20 |
| | | P+S | 26 | S=74 | 26 | S=63 | 26 | S=69 | 23 | S=71 |
| | | P+T | 77 | T= 9 P+S+T= 9 | 71 | T=11 P+S+T=14 | 77 | P+S+T= 9 | 80 | P=37 T=20 |
| | | P+S+T | 23 | S+T=63 | 23 | S=14 S+T=54 | 14 | S+T=69 | 26 | S+T=66 |

TABLE B.4. Percent of Signals Correctly Identified, and Percent Errors by Type and Signals Rated Inadequate (I) or Excessive(E) in Brightness if >15%, are Shown for the Conditions with 2" Lamp Separation for System 5.

## System 5, 2" Lamp Separation

| | | | Night - 4cp | | | | Night - 15cp | | | | Night Glare - 4cp | | | | Night Glare - 15cp | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance | [illegible] | Mode | %ID | Error | >15% I | >15% E | %ID | Error | >15% I | >15% E | %ID | Error | >15% I | >15% E | %ID | Error | >15% I | >15% E |
| 250 | 80 | P | 97 | | | | 94 | | | P=43 | 100 | | P=26 | | 100 | | | |
| | | P+S | 91 | | P=26 S=17 | S=20 | 94 | | | | 97 | | P=26 | | 100 | | | |
| | | P+T | 94 | | T=17 | | 94 | | T=26 | P=31 | 100 | | P=16 | | 97 | | T=29 | |
| | | P+S+T | 94 | | P=37 T=43 | S=20 | 94 | | P=20 S=20 T=40 | S=17 | 100 | | P=42 T=32 | S=16 | 97 | | P=23 S=23 T=48 | |
| | 185 | P | 100 | | | | 100 | | | P=26 | 100 | | P=26 | | 94 | | | |
| | | P+S | 89 | | P=46 | S=29 | 93 | | | S=23 | 90 | | P=32 | S=19 | 94 | | | S=32 |
| | | P+T | 91 | | | T=20 | 97 | | | | 97 | | P=19 | | 90 | | | |
| | | P+S+T | 91 | | P=37 | S=26 | 94 | | T=20 | S=26 | 90 | | P=39 | S=19 | 97 | | P=16 T=16 | S=19 |
| | 425 | P | 100 | | P=17 | | 97 | | | P=23 | 100 | | | | 100 | | | |
| | | P+S | 83 | | P=40 | S=43 | 89 | | P=26 | S=46 | 94 | | P=52 | S=48 | 97 | | P=32 | S=42 |
| | | P+T | 94 | | | T=46 | 91 | | | T=43 | 97 | | P=16 | T=23 | 100 | | | T=29 |
| | | P+S+T | 86 | | P=54 | S=34 T=17 | 89 | | P=26 | S=46 | 97 | | P=55 | S=55 T=19 | 94 | | P=23 | S=35 T=16 |
| | 1000 | P | 100 | | P=23 | | 100 | | | P=29 | 100 | | P=35 | | 100 | | | |
| | | P+S | 77 | S=20 | | | 91 | | P=49 | S=77 | 81 | | P=68 | S=74 | 90 | | P=39 | S=45 |
| | | P+T | 94 | | P=29 | T=71 | 94 | | | T=69 | 90 | | P=23 | T=65 | 94 | | | T=68 |
| | | P+S+T | 54 | S+T=40 | | | 86 | | P=46 | S=60 T=29 | 58 | S+T=35 | | | 87 | | P=45 | S=68 T=42 |
| 1000 | 80 | P | 100 | | P=38 | | 92 | | | | 91 | | P=45 | | 100 | | P=18 | |
| | | P+S | 100 | | P=31 | | 92 | | | | 73 | . S=27 | | | 91 | | P=36 S=36 | |
| | | P+T | 92 | | T=31 | | 100 | | T=62 | | 91 | | P=27 T=18 | | 100 | | T=45 | |
| | | P+S+T | 85 | | P=23 T=77 | | 85 | | T=69 | | 45 | P+S= 9 S+T=45 | | | 82 | | P=36 S=45 T=72 | |
| | 185 | P | 92 | | P=46 | | 100 | | | | 91 | | P=64 | | 100 | | P=27 | |
| | | P+S | 85 | | P=23 | | 92 | | P=23 | | 45 | S=45 | | | 45 | S=55 | | |
| | | P+T | 100 | | | | 100 | | | | 91 | | P=27 | | 100 | | | |
| | | P+S+T | 62 | S+T=38 | | | 85 | | P=23 T=38 | S=23 | 18 | N= 9 S+T=73 | | | 36 | S= 9 S+T=55 | | |
| | 425 | P | 100 | | P=46 | | 77 | N=23 | | | 100 | | P=36 | | 91 | | P=18 | |
| | | P+S | 23 | S=69 | | | 46 | S=54 | | | 36 | P= 9 S=55 | | | 55 | S=36 S+T= 9 | | |
| | | P+T | 100 | | P=23 | T=62 | 100 | | | T=23 | 91 | | P=73 | T=27 | 100 | | P=27 | |
| | | P+S+T | 15 | S+T=77 | | | 38 | S+T=62 | | | 27 | S= 9 S+T=64 | | | 45 | S+T=55 | | |
| | 1000 | P | 100 | | P=31 | | 100 | | | | 100 | | P=55 | | 100 | | P=27 | |
| | | P+S | 8 | S=77 | | | 15 | S=77 | | | 9 | S=91 | | | 0 | S=100 | | |
| | | P+T | 100 | | P=23 | T=54 | 100 | | | T=69 | 100 | | P=73 | T=18 | 100 | | P=27 | T=18 |
| | | P+S+T | 0 | S+T=100 | | | 8 | S+T=92 | | | 0 | S+T=100 | | | 0 | S+T=100 | | |
| 2000 | 80 | P | 94 | | P=54 | | 97 | | | | 97 | | P=81 | | 94 | | P=32 | |
| | | P+S | 71 | S=29 | | | 69 | S=20 P+S+T=11 | | | 52 | S=45 | | | 58 | P=13 S=26 | | |
| | | P+T | 97 | | P=43 T=23 | | 97 | | T=29 | | 94 | | P=77 T=39 | | 94 | | P=32 T=58 | |
| | | P+S+T | 46 | S+T=48 | | | 60 | P+S=14 S+T=17 | | | 45 | S+T=39 | | | 52 | S=13 S+T=16 | | |
| | 185 | P | 97 | | P=51 | | 100 | | P=17 | | 94 | | P=84 | | 90 | | P=19 | |
| | | P+S | 43 | S=57 | | | 60 | S=37 | | | 45 | P=10 S=42 | | | 35 | S=45 | | |
| | | P+T | 97 | | P=43 | | 97 | | | | 94 | | P=74 | | 87 | | P=39 T=29 | |
| | | P+S+T | 40 | S+T=60 | | | 37 | S+T=51 | | | 26 | S+T=58 | | | 29 | S+T=48 | | |
| | 425 | P | 100 | | P=66 | | 100 | | | | 94 | | P=81 | | 94 | | P=29 | |
| | | P+S | 9 | S=89 | | | 23 | S=74 | | | 16 | S=77 | | | 13 | S=77 | | |
| | | P+T | 86 | | P=60 | T=20 | 97 | | P=26 | | 90 | | P=77 | | 87 | | P=45 | |
| | | P+S+T | 3 | S+T=91 | | | 11 | S+T=77 | | | 10 | S+T=80 | | | 13 | S+T=84 | | |
| | 1000 | P | 94 | | P=60 | | 97 | | P=20 | | 84 | | P=71 | | 94 | | P=32 | |
| | | P+S | 6 | S=89 | | | 0 | S=94 | | | 6 | S=84 | | | 3 | S=90 | | |
| | | P+T | 80 | | P=63 | T=43 | 91 | | P=34 | T=40 | 84 | | P=77 | T=32 | 84 | | P=45 | T=32 |
| | | P+S+T | 0 | S+T=94 | | | 0 | S+T=97 | | | 3 | S+T=87 | | | 3 | S+T=87 | | |

TABLE B.5. Percent of Signals Correctly Identified and Percent Errors by Type and Signals Rated Inadequate(I) or Excessive(E) in Brightness if >15%, are Shown for the Conditions With 8" Lamp Separation for System 5.

System 5, 8" Lamp Separation

| Distance | SI | Sig | Night - 4cp %CID | Night - 4cp Error / >15% I / >15% E | Night - 15 cp %CID | Night - 15 cp Error / >15% I / >15% E | Night Glare - 4cp %CID | Night Glare - 4cp Error / >15% I / >15% E | Night Glare - 15cp %CID | Night Glare - 15cp Error / >15% I / >15% E |
|---|---|---|---|---|---|---|---|---|---|---|
| 250 | 80 | P | 91 | P=17 | 100 | P=26 | 97 | P=39 | 100 | P=19 |
| | | P+S | 100 | | 100 | | 97 | P=19 | 97 | S=23 |
| | | P+T | 100 | | 100 | P=20 | 100 | P=23 | 100 | T=16 P=16 |
| | | P+S+T | 97 | P=20 T=23 | 97 | T=26 | 94 | T=32 | 97 | T=35 S=16 |
| | 185 | P | 100 | P=17 | 100 | P=31 | 100 | P=39 | 100 | P=23 |
| | | P+S | 97 | P=23 S=34 | 100 | S=34 | 97 | P=32 S=26 | 100 | S=23 |
| | | P+T | 91 | T=17 | 91 | | 100 | P=26 T=16 | 100 | |
| | | P+S+T | 97 | P=17 S=34 | 100 | S=23 | 100 | P=29 S=32 | 100 | S=45 |
| | 425 | P | 97 | | 100 | P=37 | 100 | P=39 | 100 | |
| | | P+S | 100 | P=31 S=54 | 100 | S=46 | 90 | P=32 S=42 | 94 | P=19 S=39 |
| | | P+T | 94 | T=46 | 100 | P=17 T=43 | 97 | P=26 T=23 | 100 | T=19 |
| | | P+S+T | 100 | P=37 S=46 T=31 | 100 | S=46 T=26 | 100 | P=29 S=45 | 100 | P=16 S=45 |
| | 1000 | P | 97 | | 97 | P=34 | 100 | P=39 | 100 | P=16 |
| | | P+S | 91 | P=40 S=74 | 100 | P=17 S=66 | 97 | P=45 S=61 | 100 | S=61 |
| | | P+T | 97 | T=86 | 97 | T=83 | 100 | P=19 T=65 | 100 | T=65 |
| | | P+S+T | 97 | P=51 S=77 T=60 | 100 | S=71 T=49 | 97 | P=39 S=65 T=39 | 97 | P=23 S=61 T=39 |
| 1000 | 80 | P | 100 | P=31 | 92 | | 100 | P=36 | 100 | |
| | | P+S | 100 | | 100 | | 82 | P=45 | 82 | P=27 |
| | | P+T | 100 | | 92 | T=31 | 91 | P=45 T=18 | 100 | P=18 T=27 |
| | | P+S+T | 85 | I=23 T=38 | 100 | T=62 | 82 | P=55 S=18 T=45 | 73 | S+T=27 |
| | 185 | P | 100 | P=38 | 100 | | 100 | P=45 | 100 | P=18 |
| | | P+S | 77 | S=15 | 92 | S=31 | 64 | S=27 P+T=9 | 82 | P=45 S=18 |
| | | P+T | 100 | T=46 | 100 | | 100 | P=36 | 91 | |
| | | P+S+T | 69 | S+T=31 | 100 | P=23 T=38 S=23 | 73 | S+T=27 | 73 | S+T=27 |
| | 425 | P | 100 | | 100 | | 91 | P=45 | 100 | P=18 |
| | | P+S | 46 | S=54 | 77 | S=23 | 27 | S=73 | 55 | S=45 |
| | | P+T | 100 | P=23 T=46 | 100 | T=46 | 100 | P=64 T=18 | 100 | P=36 |
| | | P+S+T | 31 | S+T=69 | 69 | S+T=23 | 27 | N=9 S+T=64 | 45 | S+T=55 |
| | 1000 | P | 100 | P=46 | 100 | | 100 | P=82 | 91 | |
| | | P+S | 8 | S=92 | 62 | S=38 | 0 | S=100 | 18 | S=82 |
| | | P+T | 100 | P=46 T=77 | 92 | T=62 | 91 | P=73 T=45 | 100 | P=18 T=45 |
| | | P+S+T | 8 | S+T=92 | 15 | S+T=85 | 0 | S+T=100 | 9 | S+T=91 |
| 2000 | 80 | P | 100 | P=66 | 97 | | 94 | P=84 | 97 | P=32 |
| | | P+S | 66 | S=31 | 74 | S=17 | 55 | S=35 | 68 | S=16 |
| | | P+T | 100 | P=54 | 97 | T=34 | 87 | P=71 T=39 | 94 | P=19 T=58 |
| | | P+S+T | 51 | S+T=46 | 66 | P+S=11 S+T=17 | 39 | P+S=10 S+T=45 | 68 | S=16 S+T=10 |
| | 185 | P | 91 | P=49 | 97 | | 94 | P=74 | 87 | P=29 |
| | | P+S | 43 | S=51 | 69 | S=26 | 26 | S=68 | 45 | S=48 |
| | | P+T | 94 | P=66 | 97 | P=17 | 90 | P=71 | 97 | P=29 T=26 |
| | | P+S+T | 34 | S=11 S+T=[illegible] | 50 | S+T=31 | 39 | S+T=55 | 45 | S+T=48 |
| | 425 | P | 97 | P=60 | 94 | P=20 | 97 | P=87 | 90 | |
| | | P+S | 37 | S=57 | 46 | S=46 | 16 | S=81 | 23 | S=74 |
| | | P+T | 89 | P=63 T=17 | 97 | P=20 T=29 | 94 | P=81 | 97 | P=23 |
| | | P+S+T | 29 | S+T=69 | 40 | S+T=57 | 16 | S+T=84 | 23 | S+T=77 |
| | 1000 | P | 100 | P=60 | 97 | P=17 | 94 | P=84 | 94 | P=32 |
| | | P+S | 0 | S=97 | 0 | S=97 | 0 | S=90 | 0 | S=94 |
| | | P+T | 83 | P=66 T=46 | 100 | P=34 T=43 | 87 | P=81 T=39 | 97 | P=71 T=23 |
| | | P+S+T | 3 | S+T=91 | 3 | S+T=97 | 0 | S+T=94 | 3 | S+T=97 |

# APPENDIX C.

## RECOMMENDED INTENSITY LIMITS AS A FUNCTION OF LAMP AREA (FROM MORTIMER, 1970) FOR STEADY BURNING SIGNALS

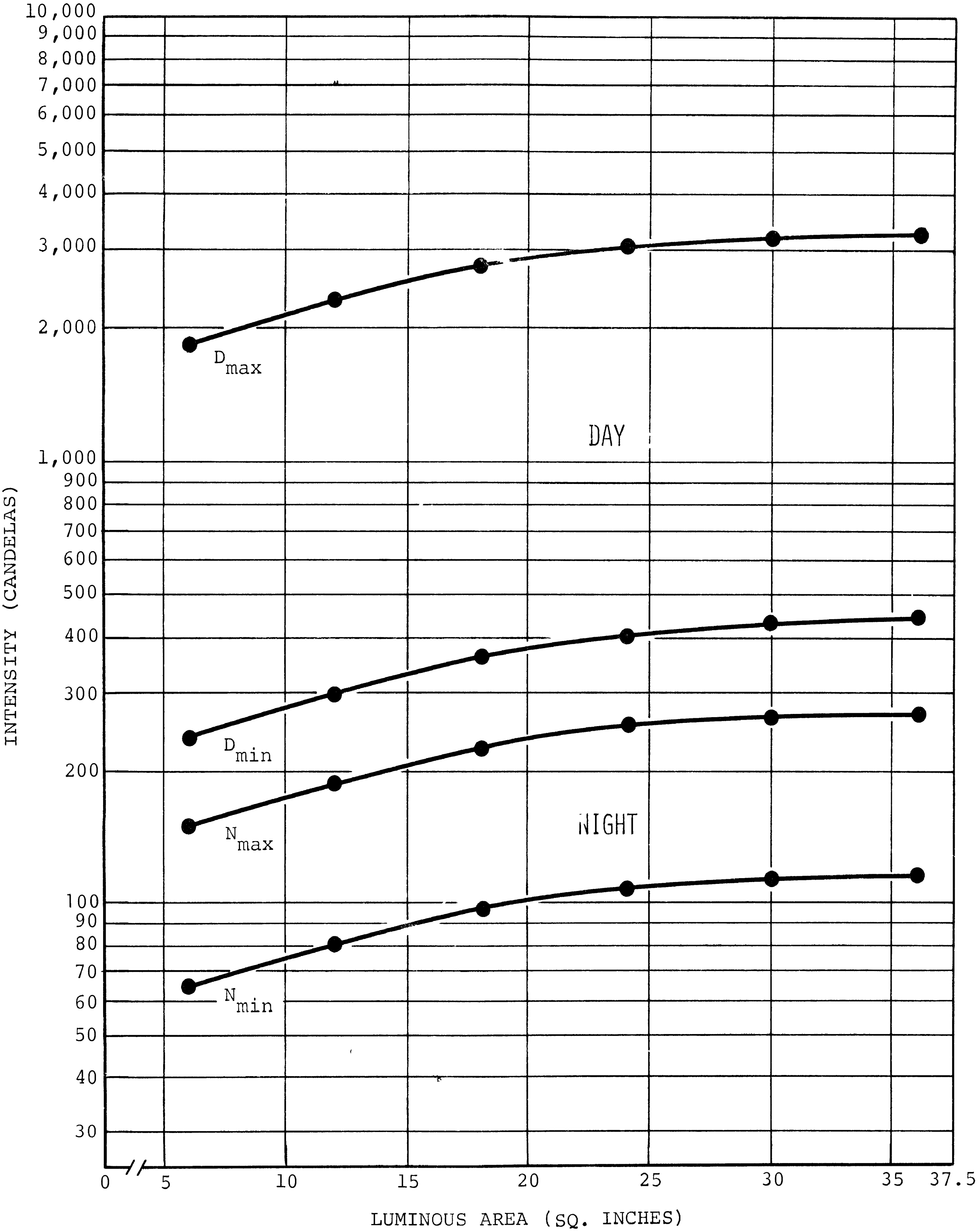


Figure C.1. Red, Day and Night Minimum and Maximum Intensity as a Function of Lamp Area

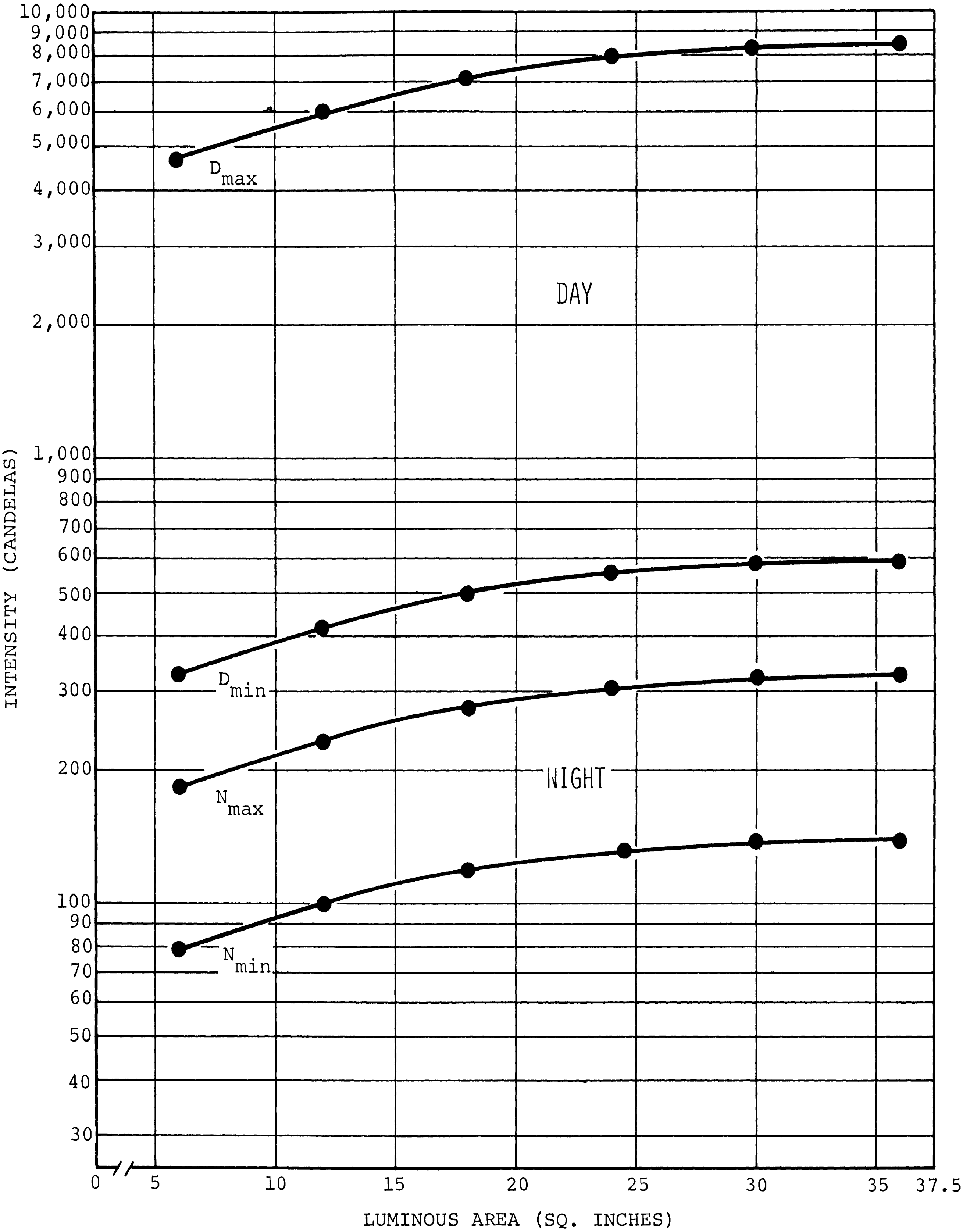


Figure C.2. Amber, Day and Night Minimum and Maximum Intensity as a Function of Lamp Area

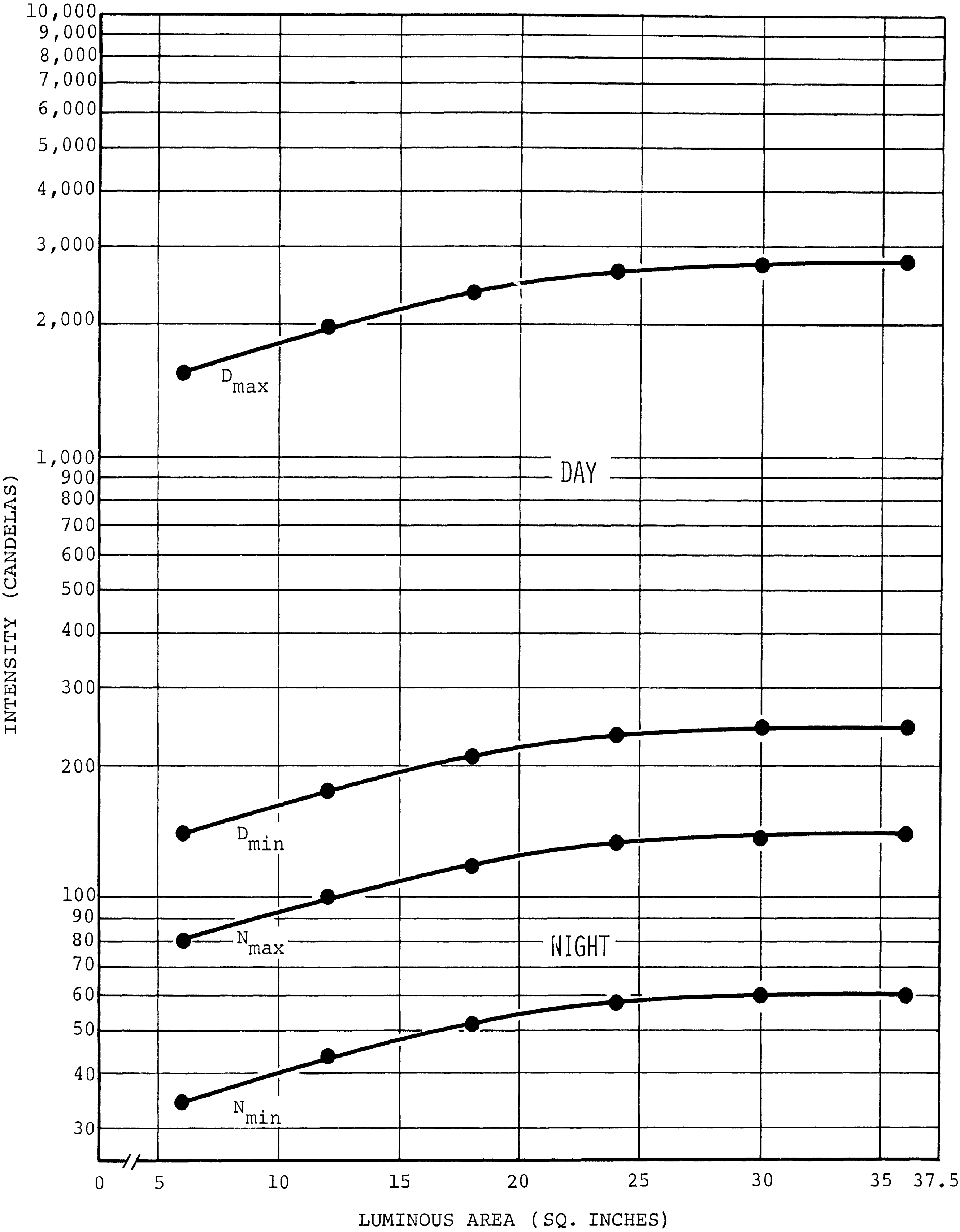


Figure C.3. Green-Blue, Day and Night Minimum and Maximum Intensity as a Function of Lamp Area

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