school speed zone and had been reduced by about 50 percent at the crossing that was within a school speed zone. Thus, the residual effect of enforcement was found to be greater at the crossing that was within a school speed zone.

Based on the results of this study, it was concluded that both school speed zones and enforcement enhance the speed-reduction effects of pedestrian presence and the normal crossing period at school crossings. However, to achieve an acceptable level of compliance, school speed zones must be enforced. Unless an adequate level of enforcement can be provided, a school speed zone should not be established. Although in this study everyday enforcement was required before an acceptable level of compliance was obtained, it seemed that, once the creditability of enforcement was established with the driving public, a lower level of enforcement would be required (e.g., one to two days per week).

Of course, a school speed zone is no different from any other form of traffic control in that, unless it is perceived by the driver as fulfilling a need, compliance will be poor. Therefore, school speed zones should be established only at those locations where pedestrian volumes are sufficient to convey this perception, which was assumed to be the case at the four crossings observed in this study.

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Visibility of Circular Traffic-Signal Indications

GERHART F. KING

An empirical determination of traffic signal visibility is presented. The study used subjects seated in stationary vehicles viewing standard, full-sized traffic-control signals at distances ranging from 370 to 1300 ft. Data, including response accuracy and response latency, were collected for both day and night ambient lighting conditions. It was found that currently used circular traffic-signal indications are generally adequate for nighttime service but their adequacy for daytime conditions is suspect. Signal visibility was found to be somewhat insensitive to signal lens size and illumination intensity for nighttime operations, which implies that even the dimmest signal tested (8-in lens with 67-W bulb) is above threshold visibility for all distances at night. The single most important factor affecting the visibility of traffic signals during the day is signal color. Green indications generally led to the poorest subject response, in terms of both response accuracy and response time, for the daytime observations. In relation to visibility considerations alone, the data obtained present strong support for the possibility of dimming all colors of 12-in signal indications at night.

A traffic control signal can be considered as an information-transmitting device that operates on the visual band. Its effectiveness at information transmission, and hence its effectiveness as a control device, can be determined on the basis of how well the device can be detected and how well the transmitted information can be perceived, interpreted, and responded to.

For any specific location and specific set of conditions, there is an optimum location at which the information should be received, information processing completed, and action initiated. If the vehicle is too close to the intersection when a red signal is first seen, a safe and comfortable stop may be impossible, and thus the potential for an accident may be increased and potential disobedience encouraged. On the other hand, signal indications that can be perceived from excessive distances serve to introduce potential confusion in the case of closely spaced intersections.

Traffic-control-signal installations should be designed so as to maximize the probability, given the expected distribution of the driver population, of the requisite control information being received at the optimum location by the largest possible number of drivers.

This paper contains a summary of an empirical study of the adequacy of currently used traffic-signal indications in inducing the required response on the part of motorists.

PREVIOUS RESEARCH

A comprehensive survey of the applicable literature has identified seven reports of previous studies of signal intensity requirements (see Table 1). The results of these studies, which varied widely, are summarized in Table 2.

Two of these studies used subjective judgments of conspicuity as a function of intensity, whereas the others used response latency and/or probability of detection. The two that used subjective judgment asked subjects to decide when a signal would be sufficiently conspicuous at a glance in traffic (1) or when it was bright enough to be unmistakable as a traffic signal and virtually impossible to miss (2). This approach suffers from all of the problems associated with category rating scales and more, since subjects were not rating signals but giving an absolute judgment. It is clear that subjects in such tasks use very different criteria as well as different dimensions in making their judgments (8). Jainski and Schmidt-Clausen's data (4) are based on a 50 percent level of color detection and extrapolated to a 90 percent level of conspicuity. The fact that the two sizes of stimuli used give such different values for the standard condition casts doubt on their procedure. Later research, on the subject of railroad crossing signals, has demonstrated a definite size effect (9). Boisson and Pages (3) examined the probability of detection for

Table 1. Research studies on signal intensity.

Researcher	Year	Size of Indication	Colors Included	Distance (ft)	Background Luminance (ft-L)	Type of Study[a]	Response Measure
Adrian (1)	1963	200 mm	Red, green	120	0.1-3000	Real signals	Subjective
Rutley, Christie, and Fisher (2)	1965	200 mm	Red, yellow, green	450-1200	0.1-3000	Real signals	Subjective
Boissin and Pages (3)	1964	11.3 and 35.7 mm	Red	66	420	Simulated signals, tracking task added	Reaction time, probability of detection
Jainski and Schmidt-Clausen (4)	1967	1°, 2 min	Red, yellow, green, black, white	6.6	10^{-8}-3000	Simulated signals	Fifty percent color detection
Cole and Brown (5)	1966	8 min	Red	6.6	1500	Simulated signals, tracking task added	Reaction time, probability of detection
Cole and Brown (6)	1968	4.1-16.5 min	Red	13	600	Simulated signals, tracking task added	Minimum reaction time, minimum reaction time plus 0.1 s
		5.5 min	Red	13	1.5-2250	Simulated signals, tracking task added	Minimum reaction time, minimum reaction time plus 0.1 s
Fisher (7)	1969	200 mm	Red, yellow, green	150	1370-5750	Real signals	Probability of detection

[a]All studies were static except that by Rutley, Christie, and Fisher (2), who used a nondriving observer.

Table 2. Results of studies of signal intensity.

Researcher	Required Intensity[a] (cd)	Required Intensity Ratio[b] Green	Yellow	Notes
Adrian (1)	1900	1.0	-	
Rutley, Christie and Fisher (2)	35	1.7	3.5	
Boissin and Pages (3)	200	-	-	
Jainski and Schmidt-Clausen	8	2.5	3.1	Based on 2-min data
	250	1.0	2.5	Based on 1° data
Cole and Brown (5)	160	-	-	
Cole and Brown (6)	70-120	-	-	Based on minimum reaction time plus 0.1 s
	250			Based on minimum reaction time
Fisher (7)	200[c]			

[a]Signal intensity required by observer at 330 ft with background luminance of 2900 ft-L.
[b]Red is 1.0.
[c]Maximum value of proposed intensity distribution.

all response times of 1 s or less. Cole and Brown (5,6) used two criteria for determining necessary signal intensity, both based on response time: (a) a "lenient" criterion of the intensity that yields response times 0.1 s over the minimum reaction time observed and (b) the more conservative criterion of the lowest intensity that gives the minimum reaction time.

However, these latter studies used only a single red signal. Thus, not only is the stimulus much less complex than normal, but also subjects made a detection response rather than the recognition response that they would have to make if other colors were included. The inclusion of other colors would have been expected to increase response times; in fact, Cole and Brown report increased times in a study that did include three colors, but they do not actually report the data from this study. In addition, all of these latter studies used simulated signals and the subjects observed from distances very near the display. This very restricted, homogeneous field of vision with a single fixed stimulus should also greatly reduce response time.

It should be mentioned that Boisson and Pages and Cole and Brown used a tracking task as a distractor. However, Fisher (7) argues that the primary function of these tasks has been merely to place the signal slightly out of foveal vision.

Finally, the three studies that included yellow and green signals yield varying estimates of the ratio of intensities of these signals compared with the red signal, although they do indicate that the yellow signal needs to be more intense than the green. These are also the three studies with the most suspect response measures.

The study being reported on here was designed in response to these apparent shortcomings and contradictions in the existing state of the art.

EXPERIMENTAL DESIGN

The experimental design was based on a complete factorial combination of all included variables: ambient lighting, viewing distance, and lens type, color, and lateral offset.

The experimental design included both between and within subject factors. Each of two ambient environments was assigned to each of two groups of subjects. The different ambient conditions required testing at different times of the day.

There were 45 stimuli defined by type, color, and offset location of a signal lens; these stimuli were presented in random order.

Subjects were tested at one distance at a time. In other words, while signal type, signal color, and offset were randomly varied, viewing distance was systematically ordered.

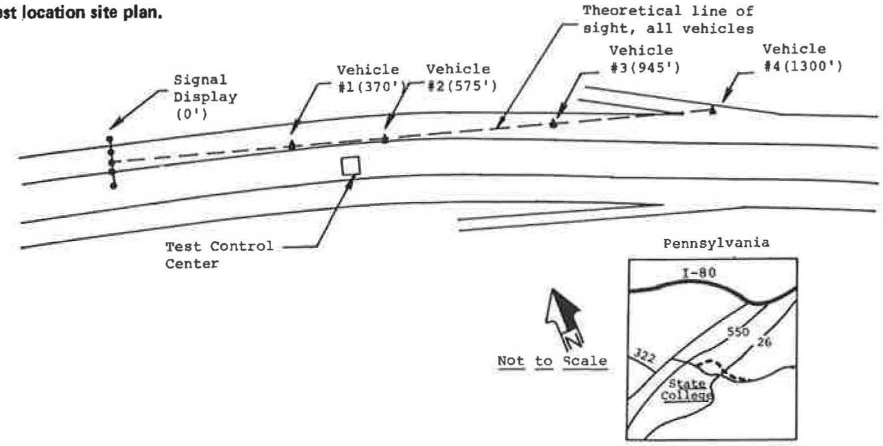
Experimental Variables

The number of levels of each variable and the description of each level are given below:

Variable	No. of Levels	Levels
Signal color	3	Red, yellow, green
Signal type	3	8-in lens, 67-W bulb; 12-in lens, 116-W bulb; 12-in lens, 150-W bulb
Offset	5	-50, -25, 0, 25, 50 ft
Distance	4	370, 575, 945, 1300 ft
Ambient illumination	2	Day, night
Sex	2	Male, female
Age	-	Continuous

Two dependent variables (response measures) were included in the experiment: (a) response latency, measured to the nearest 10 ms on a continuous scale from 50 to 5000 ms, and (b) correctness of response, expressed as a pass-fail dichotomy (data on the type of error made were collected and reduced but were not used in the analysis).

Figure 1. Test location site plan.



Subsidiary Task

To approximate the task loading involved in driving an automobile, subjects were asked to perform a subsidiary task. This task consisted of observing and reacting to a bank of lights placed immediately in front of the observer. Data on the performance of the subsidiary task were collected.

Test Statistics

The data collected for the two response measures were used to compute seven different test statistics: (a) mean response time (correct responses only), (b) standard deviation of response time (correct responses only), (c) standard score of response time (i.e., response time corrected for individual differences in average response time), (d) 90th percentile response time (correct responses only), (e) proportion of correct responses, (f) proportion of maximum-time responses (maximum time was set at 5 s), and (g) proportion of adequate responses (an adequate response was defined as a correct response of less than 1.5 s by a subject with a "passing" grade on the subsidiary task).

This paper discusses two of these test statistics: mean response time and proportion of adequate responses. A full presentation and discussion of all seven test statistics can be found in the project report (10).

DATA COLLECTION

Data were collected between October 29 and December 5, 1979. An unopened section of freeway designed to serve as a bypass around State College, Pennsylvania, was used as the experiment site. Figure 1 shows a plan view of the test site, including the orientation of the signal display and the location of the test vehicles.

Signal Display

A total of five assemblies, each containing nine signal indications, were used. Panel C, the center panel, was located at a lateral offset of 10 ft to the right of the sight line. The remaining four panels were located at 25 and 50 ft on each side of the central panel along a line perpendicular to the line of sight. Each type of signal indication occurred three times in each assembly, once for each of the three standard signal colors. Signal colors were displayed in their standard order (red, yellow, green from top to bottom). Indication types were randomized within each panel except that 8- and 12-in indications were not mixed in any vertical array. The signal heads were mounted at the normal mounting height for over-the-road indications and aligned in accordance with standard Pennsylvania Department of Transportation practices.

In relation to the geometrical and optical aspects of signal viewing, these maximum offsets do not represent a critical case. With one exception, the farthest left array at the closest viewing distance, all viewing angles fall well within the range of foveal vision. These angles are also such that no major fall-off in signal intensity can be expected according to the published specifications of the signal equipment used. Furthermore, the angles are so small that their effect, if any, is likely to be diluted by variations in alignment due to normal practices in field signal alignment.

The offset variable was added to the experimental plan primarily to add complexity to the task faced by the subjects and to enforce a scan pattern on them. Major effects of offset as a variable affecting signal visibility were not anticipated. The analysis presented in this paper therefore collapsed the data for the offset variable.

Subsidiary Task Display

A series of eight pairs of 7.5-W lamps (one white and one orange per pair) were mounted on a 16-ft-long aluminum channel and displayed in front of each test vehicle. The aluminum channels were supported 4 ft above the ground. These subsidiary lights were turned on and off in a pseudorandom manner, and one orange lamp was lighted for every eight white lamps.

Data-Collection Equipment

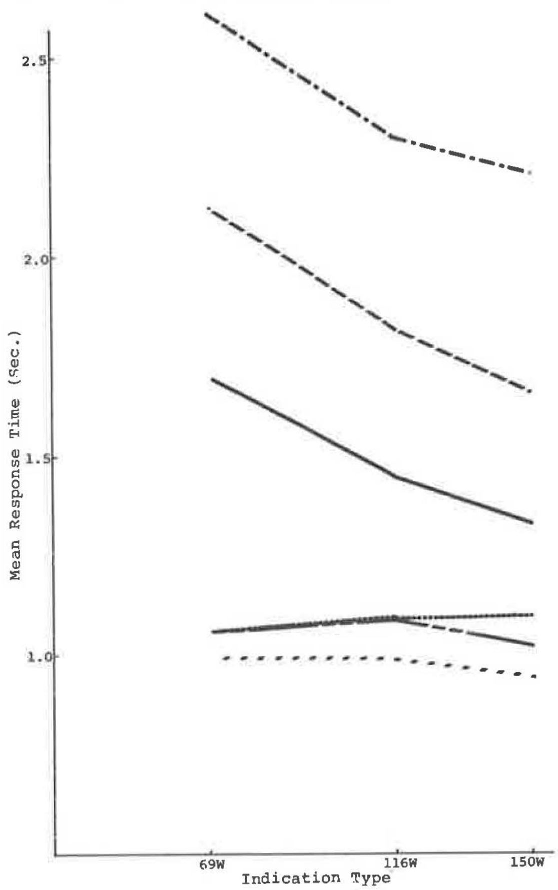
A response box and a board-mounted push-button (doorbell) switch were assigned to each subject. Each response box was equipped with three colored buttons (red, amber, and green). Subjects were instructed to press a button on their response box whenever a traffic-signal indication was illuminated. The color of the button pressed was to correspond to the color of the traffic-signal indication illuminated. They were also instructed to press the push button only when an orange lamp was illuminated on the subsidiary-task display.

Stimuli were initiated and data collected by a microprocessor-based data-collection system designed and built by the KLD Associates instrumentation laboratory. The system included the following components: microprocessor, cathode-ray tube, disc drive, and printer.

Table 3. Actual and desired age distributions of study subjects.

Subject Age (years)	Day Experiment: Actual No. Male	Female	Total	Desired No.	Night Experiment: Actual No. Male	Female	Total	Desired No.
<20	-	-	-	1	1	1	2	1
20-34	9	6	15	14	12	6	18	18
35-54	5	7	12	15	4	10	14	19
≥55	5	-	5	2	4	2	6	2
Total	19	13	32	32	21	19	40	40

Figure 2. Response latency versus type of signal indication.



Test Subjects

Test subjects were paid and were obtained through advertisements and announcements in local media. All subject candidates were required to have a valid driver's license, and the licenses were checked to determine whether corrective lenses were required. Where the licenses indicated such a requirement, subjects were obliged to wear the lenses during the experiment. Subjects with noncorrectable visual anomalies were rejected. Color vision tests were administered to each candidate to screen out color defects.

A total of 72 subjects, 40 male and 32 female, were employed. The age of subjects ranged from 17 to 72 years. An attempt was made to match the actual distribution of subject age to the estimated age distribution of U.S. drivers based on the number of miles driven. Both the actual and desired age distributions are given in Table 3. The mean age for each category is given below:

Experiment	Actual Male	Actual Female	Actual Total	Desired
Day	39.6	35.6	38.0	37.2
Night	36.0	37.1	36.5	37.5

There are no significant mean differences in age between the desired and actual subject groups nor between subject groups stratified by sex.

Data-Collection Runs

Data collection was performed only when good weather prevailed (i.e., no precipitation was perceptible on the windshield of the test vehicle). If precipitation started during a run, the subjects were instructed to turn on the windshield wipers simultaneously. Out of the nine tests (a total of 36 runs), seven tests (28 runs) were completed under good weather conditions and the remaining two tests (eight runs) were conducted under adverse weather conditions (i.e., precipitation was perceptible and required operation of windshield wipers).

After the conclusion of trial runs, the actual data runs were started. The 45 different signal indications were illuminated in random order for 5.0 s each. The interstimulus interval was varied from 5 to 19 s; the mean was about 9 s. The subsidiary task display changed approximately every 10 s, and the orange light appeared, on the average, every ninth time. The order of presentation of the stimuli was different for each run. The test was completed after data had been collected for four runs (i.e., after each subject was tested at each of the four distances).

EXPERIMENTAL RESULTS

The raw data were reduced and obviously erroneous data points were deleted. Data analysis was restricted to data collected in good weather. The data base available for analysis consisted of day data (4101 data points) and night data (5344 data points).

Mean Response Time

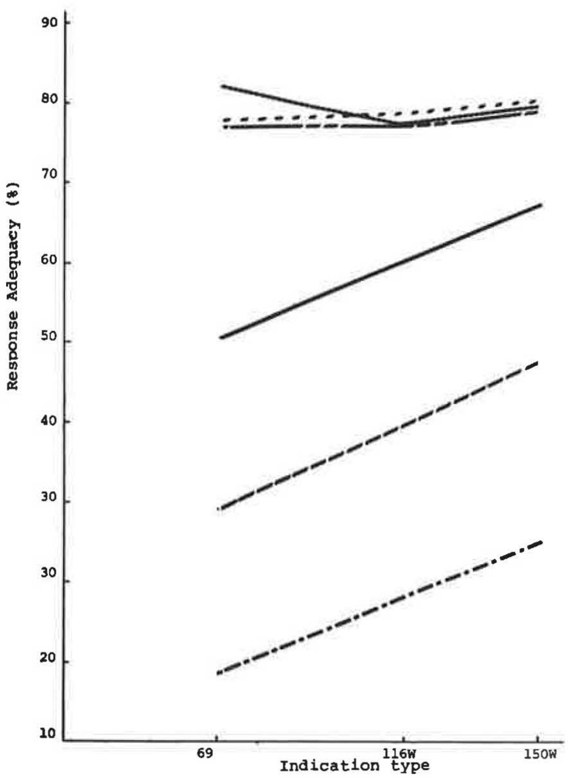
Mean response time as a function of the type and color of signal indication is shown in Figure 2. The calculation of mean response time included only those values that were less than the maximum time possible (5.0 s). Table 4 gives the proportion of the sample for which maximum time was recorded. Figure 2 shows a striking difference in response time between day and night data. The response-time distributions, aggregated over all variables, have the following parameters (180 data cells each for day and night data):

Parameter	Day (s)	Night (s)
Mean	1.830	1.033
Standard deviation	0.946	0.374
Coefficient of variation	0.517	0.362
Maximum cell mean	3.745	1.298

Table 4. Proportion of sample that yielded maximum response time.

Ambient Lighting	Indication Type: Lens (in)	Indication Type: Bulb (W)	Indication Color	Percentage of Sample by Viewing Distance: 370 ft	575 ft	995 ft	1300 ft
Day	8		Red	4.1	6.6	8.3	21.1
			Yellow	2.6	-	0.8	3.0
			Green	17.6	25.7	61.6	82.5
	12	116	Red	0.8	2.5	3.3	3.9
			Yellow	-	1.5	-	6.3
			Green	6.6	11.6	19.4	34.9
	12	150	Red	0.9	-	-	4.4
			Yellow	0.7	0.7	0.7	4.9
			Green	2.5	2.5	10.8	16.5
Night	8		Red	0.6	-	1.9	0.7
			Yellow	-	1.4	2.7	22.5
			Green	-	-	0.7	0.8
	12	116	Red	-	1.3	2.0	0.7
			Yellow	0.6	0.6	0.5	22.5
			Green	-	-	0.6	0.7
	12	150	Red	0.7	-	-	0.9
			Yellow	0.5	0.5	-	23.4
			Green	-	-	-	0.7

Figure 3. Response adequacy versus type of signal indication.



Parameter	Day (s)	Night (s)
Minimum cell mean	1.140	0.892
Maximum departure from grand mean	1.915	0.265

The ratio of maximum to minimum was 3.3 for day data and 1.5 for night data. The daytime data consistently show that the yellow indication yields the lowest response time and the green indication the highest.

All comparisons of response time between colors, within the same type of indication, are significant at better than α = 0.0001 for day data. All comparisons of response time between types of indication, within the same color, are significant at the same level for red and yellow indications. For green indications, the difference in response time between the 8-in indication and either of the 12-in indications is also significant at the same level; however, there is no significant difference between the two 12-in indications.

For nighttime data, the response time to yellow indications is significantly different from the response time to both the red and green indications for all types; however, there is no significant difference between red and green, except for the 12-in signal with 150-W bulbs. Three of the nine comparisons between signal indication types showed significant difference (α = 0.05): 67 versus 150 W for yellow indications, 116 versus 150 W for yellow indications, and 116 versus 150 W for red indications.

Examination of mean response time as a function of distance for each of the three indication types and colors shows that the general rank order of types and colors described above holds for all distances. Response time to red and green indications generally increases with viewing distance, especially during the day, whereas the response time to yellow indications is insensitive to viewing distance.

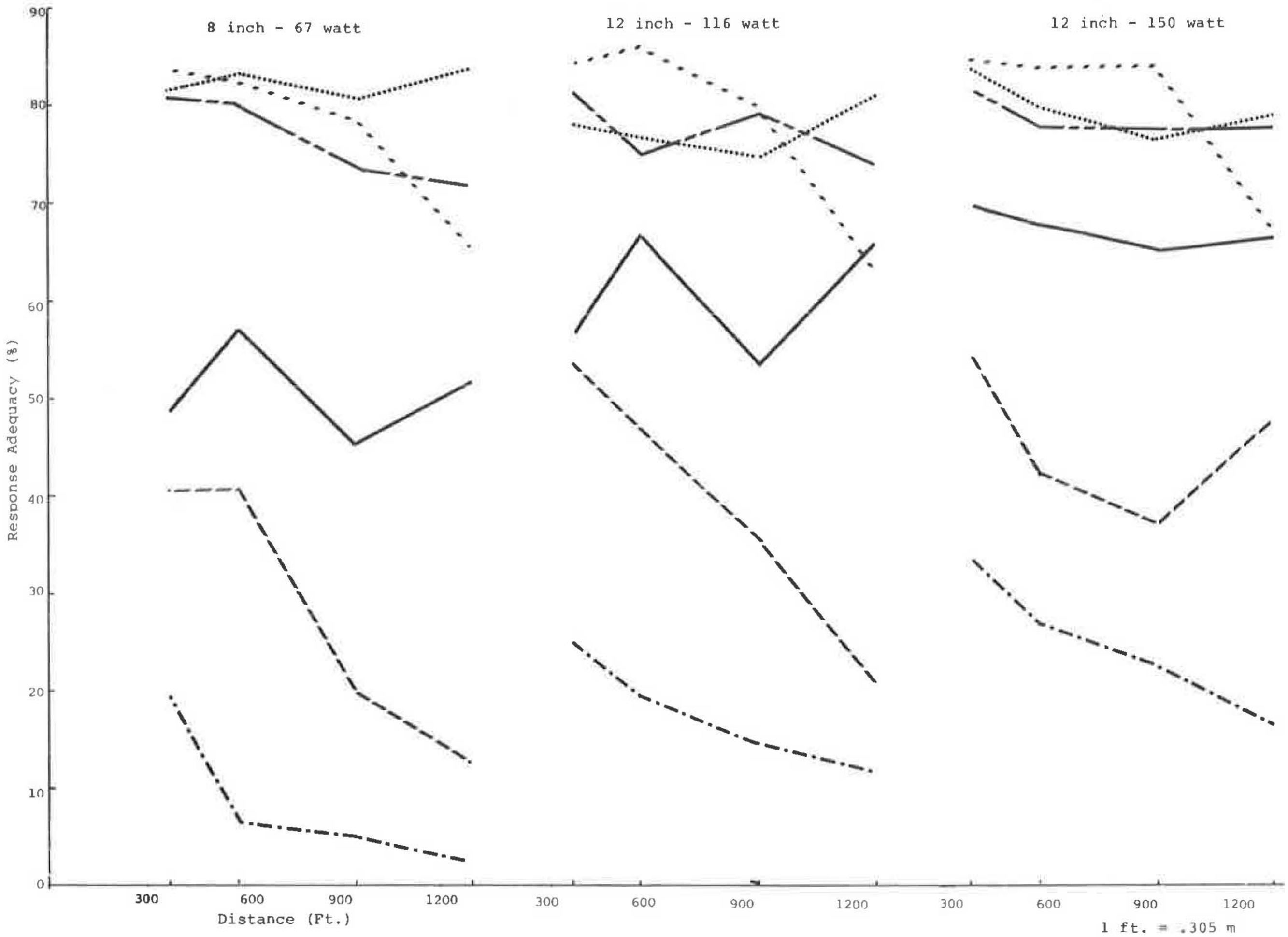
Response Adequacy

A traffic-control signal will fulfill its intended purpose if its message is received correctly, at the proper time, and while the driver is time sharing with his or her other responsibilities. The test statistic, response adequacy, is designed to combine these three aspects into one measure. A response is considered "adequate" if, and only if, all of the following criteria are satisfied: (a) the response is correct, (b) the response is made within a defined maximum response time, and (c) the response is made by a subject who gets a passing grade on the subsidiary task.

Data on subsidiary-task performance had been recorded manually. For each individual subject, these data consisted of the following counts: number of orange-light actuations per run, total number of push-button actuations per run, and correct (i.e., coincident) number of push-button actuations per run. Performance of the subsidiary task was scored manually through a subjective evaluation of these three counts. The criterion used was substantial agreement of the three numbers. Each subject was assigned a pass or fail grade for each run.

Data on the proportion of the sample with adequate responses are shown in Figures 3 and 4. For these graphs, 1.5 s was taken as the maximum permis-

Figure 4. Response adequacy versus viewing distance.



sible response time in accordance with current criteria of the American Association of State Highway and Transportation Officials (11).

Examination of the data in Figure 4 shows that a criterion of 75 percent response adequacy could be satisfied by all indications tested at night. None of the indications could satisfy this criterion during the day. A criterion of 50 percent response adequacy could be met, for daytime conditions, only for yellow indications with 12-in lenses and for red indications with 12-in lenses at the 370-ft distance (20-mile/h speed).

Significance tests for equality of proportions were made and showed that for daytime data all proportions were significantly different, except for the red indication in the two 12-in lenses.

For data taken at night, the only significant differences found were for (a) red versus green for the 8-in lens, (b) red versus yellow for the 12-in lens with 150-W bulb, (c) 12-in lens with 150-W bulb versus 12-in lens with 116-W bulb for all colors, and (d) 12-in lens with 150-W bulb versus 8-in lens with 116-W bulb for all colors.

To interpret these results, it is necessary to select a minimum acceptable threshold value for response adequacy. In picking such a value, it must be remembered that a maximum response time of 1.5 s represents an extremely conservative approach. The viewing distances used in the test were selected in accordance with an analysis of required viewing distance as a function of approach speed (12). This analysis used a total reaction-decision time component of 4.0 s. The extra 2.5 s were added to represent the additional reaction time of nonalerted drivers and the additional signal detection time required for low signal-noise ratios.

Relaxation of the stringent 1.5-s criterion would obviously serve to increase the properties of response adequacy. This increase is illustrated in Table 5, which gives data showing the effect of increasing the criterion value from 1.5 to 3.0 s. The average increase in response adequacy is 30.3 percentage points for day data and 5.4 percentage points for night data.

For a 3.0-s maximum response time criterion, 75 percent response adequacy is achieved by all indications tested at night and by all yellow indications tested during the day. Red indications, for daytime conditions, met the 75 percent criterion for all conditions except the longer distances with the smaller indication sizes. None of the green indications could satisfy this requirement at any distance in daytime conditions.

CONCLUSIONS

The results of the experiment presented in this paper provide the basis for postulating a number of conclusions:

1. Currently used circular traffic-signal indications are generally adequate for nighttime service,

Table 5. Effect on response adequacy of increasing the response-time criterion from 1.5 to 3.0 s.

Indication Type		Indication	370 ft		580 ft		945 ft		1300 ft	
Lens (in)	Bulb (W)	Color	1.5 s	3.0 s	1.5 s	3.0 s	1.5 s	3.0 s	1.5 s	3.0 s
Day										
8	67	Red	0.408	0.775	0.408	0.750	0.200	0.583	0.125	0.413
		Yellow	0.486	0.787	0.570	0.833	0.451	0.778	0.515	0.835
		Green	0.196	0.558	0.069	0.326	0.050	0.171	0.023	0.081
12	116	Red	0.537	0.815	0.466	0.771	0.355	0.754	0.205	0.686
		Yellow	0.569	0.884	0.664	0.882	0.534	0.813	0.657	0.873
		Green	0.250	0.625	0.191	0.600	0.144	0.389	0.116	0.271
12	150	Red	0.544	0.861	0.420	0.850	0.370	0.780	0.477	0.800
		Yellow	0.697	0.901	0.678	0.921	0.650	0.857	0.661	0.892
		Green	0.333	0.733	0.268	0.680	0.225	0.591	0.165	0.485
Night										
8	67	Red	0.809	0.850	0.801	0.847	0.738	0.823	0.717	0.786
		Yellow	0.839	0.867	0.823	0.852	0.786	0.841	0.653	0.709
		Green	0.818	0.855	0.832	0.868	0.807	0.864	0.837	0.914
12	116	Red	0.813	0.853	0.750	0.822	0.790	0.871	0.738	0.800
		Yellow	0.843	0.879	0.859	0.890	0.797	0.869	0.626	0.704
		Green	0.780	0.825	0.766	0.844	0.748	0.825	0.806	0.891
12	150	Red	0.816	0.839	0.776	0.823	0.772	0.840	0.777	0.851
		Yellow	0.847	0.864	0.838	0.861	0.838	0.890	0.671	0.677
		Green	0.838	0.896	0.798	0.857	0.761	0.819	0.789	0.909

but their adequacy for daytime conditions is suspect.

2. The single most important factor affecting the ability of traffic signals to transmit required information during the day is signal color.

3. Green signal indications generally lead to the poorest performance by subjects in terms of both response accuracy and response time during daytime conditions.

4. In daytime conditions, driver response to red and green traffic-signal indications generally deteriorates with increased viewing distance. Responses to yellow indications during the day, and to all colors of indication at night, are generally insensitive to viewing distance.

5. Signal type, a variable that combines both lens size and illumination intensity, has a significant effect on signal visibility for daytime operations. However, signal visibility is somewhat insensitive to signal type for nighttime operations, which implies that even the dimmest signal (8-in lens with 67-W bulb) is above threshold visibility.

6. The data presented provide strong support for the prospect of dimming all colors of 12-in signal indications at night. The actual feasibility of dimming signals without causing adverse effects on traffic safety and operations can only be definitely determined by full-scale field testing in real-world traffic environments. Similarly, the extent to which dimming can be undertaken cannot be determined on the basis of the data collected. This extent depends on the degree to which motorist responses are affected by actual field conditions: the driving task, driver attention, competing visual noise, and type of roadway facility.

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Abridgment

Standardization of Light Signals for Road Traffic Control

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A recent technical report on road-traffic-control signals prepared by the International Commission on Illumination is briefly discussed. The report represents a first step toward international standardization of traffic signal lights in order to benefit trade and transportation. The principal subject areas of the technical report—color, luminous intensity, and luminous intensity distribution—are outlined. It is concluded that the report can be highly beneficial to road traffic and that official recommendations should be prepared.

Light signals for road traffic control are applied in an increasing number of cases to promote the flow of traffic at highly trafficked intersections. Although individual waiting times may increase, it is generally accepted that the capacity of intersections and road safety are increased.

International harmonization of industry and traffic requires standardization; lacking better grounds, these standards are usually based on the plausible assumption that road-traffic-control signals must be clearly visible for all road users. "Clearly visible" cannot be defined precisely, but it is usually understood as being well above the threshold of visibility found in a laboratory setup.

In recent years, a number of countries have set up national recommendations, regulations, or standards for traffic signals. Although they show a certain similarity, important discrepancies still exist that are unfavorable to trade and transportation. The International Commission on Illumination (CIE) took the initiative for further international harmonization. A technical report has been prepared and will be published in the near future (1). This paper briefly discusses that report.

The CIE report is restricted to those aspects of road-traffic-control signals that are directly seen by the users and are directly related to the signaling function. It does not cover other important matters concerning traffic signals, such as traffic engineering matters, the regulatory status, the legal obligations of local authorities and the road user, and electrical and mechanical engineering. The report deals with the color, the luminous intensity, and the luminous intensity distribution of signal lights. The "phantom effect" is also discussed. Since recognition of "cut-out" figures, or symbols, used with lights has become important, the report examines some details of their shape and size. Only lanterns of 20- and 30-cm diameter are considered.

COLORS

Road-traffic-control signal lights consist normally of three separate units that emit red, yellow (or amber), and green light. The colors given in the CIE technical report are in agreement with the 1975 CIE recommendation (2). In road traffic, people whose color perception is defective can take part as pedestrians and drivers. Therefore, even the "restricted" green was considered too wide, and further restrictions are given as follows (all boundary colors for the red signal and the yellow boundary for the green and white signals are restricted):

Color of Signal	Boundary	Equation
Red	Purple	y = 0.990 - x
	Yellow	y = 0.320
	Red	y = 0.290
Yellow	Red	y = 0.382
	White	y = 0.790 - 0.667x
	Green	y = x - 0.120
Green	Yellow	y = 0.726 - 0.726x
	White	x = 0.650y
	Blue	y = 0.390 - 0.171x
White	Yellow	x = 0.440
	Purple	y = 0.047 + 0.762x
	Blue	x = 0.285
	Green	y = 0.150 + 0.640x

The result is a rather bluish green, an amber yellow, and a light (nearly orange) red (3).

PEAK INTENSITY AND LIGHT DISTRIBUTION

For normal roads and for built-up areas, the rule-of-thumb value of 100 m has been adopted as the minimum distance from which signals must be (clearly) visible. When perceived from 100 m, lenses of 30- and 20-cm diameter have discernible dimensions. However, experiments did show that for viewing conditions that pertain to practical conditions of road traffic--notably taking into account the peripheral vision--the "power" of the beam can be described adequately in terms of the luminous intensity alone. Considerable research has indicated that under full daylight conditions a peak value (maintained value) of 200 cd ensures adequate visibility [see, for example, Adrian (4), Cole and Brown (5), Jainski and Schmidt-Clausen (6), and Fisher (7)]. It is desirable that at night the peak intensity should be between 50 and 100 cd; intensities of less than 25 cd or more than 200 cd should be avoided. At least 100 cd should be provided in directions making an angle of ±11° laterally or 8° down with the beam axis. Further research is required to find out whether a more detailed description of the beam and the light distribution is necessary.

SHAPE OF SYMBOLS

It is recommended that the signal be a light-emitting cut-out figure on a dark (black) background rather than a dark symbol on a bright background. Because the latter suffers from irradiation, the signal with a symbol can easily be confused with the