Effects of Light Sources on Highway Sign Color Recognition

SYED F. HUSSAIN, JOHN B. ARENS, AND PETER S. PARSONSON

A wide variety of light sources is used for externally illuminated highway signs. Some of these light sources change the color appearance of signs at night. This study evaluates acceptable alternative light sources for illuminating highway signs. Light sources investigated included incandescent, fluorescent, metal halide, mercury, high pressure sodium, and low pressure sodium lamps. The metal halide lamp performed best overall and is recommended to illuminate a broad range of highway sign colors. This also could include the use of metal halide lamps in future automobile headlights. Mercury lamps that are economical and provide good color rendition on green, blue, and white are recommended for overhead signs. With some compromise on the color rendition, high pressure sodium is another cost-saving alternative for overhead signs. High pressure sodium is also the best choice to illuminate construction and maintenance signs.

Highway signs are designed to provide information, guidance, and regulations for the safe and efficient flow of traffic. Traffic signs essentially contain shape, color, and legend. Shape and color are important because they convey the meanings and messages of signs before the legend can be read. Colors on signs convey certain meanings and significance to road users. Regulatory signs, usually with white or red backgrounds, are used for traffic laws and regulations. Yellow is used as the background color for warning signs; orange for construction zone signs; and green, brown, and blue are used for guidance, services, and information, respectively. Road users expect to see these color codes for their assigned meanings. Therefore, the appearance of these colors should remain the same during nighttime as during daylight. For nighttime recognition, signs can be placed generally into two categories: (a) Externally (and in some cases internally) illuminated signs and (b) non-illuminated (generally retroreflective) signs. The *Manual on Uniform Traffic Control Devices* (*1*) requires that highway signs intended to be used during the hours of darkness shall be either retroreflective or illuminated to show approximately the same shape and color day and night.

Recognition of non-illuminated signs depends on the amount of light from headlights falling on the sign. Legibility and recognition of externally illuminated signs depends on the type and amount of fixed illumination. Therefore, the selection of light sources to illuminate overhead guide signs is very important. Motorists may endanger themselves and others by slowing down or stopping because signs may not be legible and identifiable at distances necessary to take action. Proper illumination of highway signs is critical for the accurate and timely recognition of sign colors and messages. Selection of adequate illumination and the appropriate type of illuminants becomes even more important when:

- Ambient luminance/background complexities increase,
- Volume of traffic increases,
- Complexity of the highway design increases, or
- Adverse weather conditions prevail at certain locations.

The design of a highway lighting system is governed by lamp efficacy, optical controllability, color rendering properties, lamp life, and initial as well as operational costs. In recent years, energy constraints and economics have played major roles in selecting sign lighting systems. The importance of other factors has become somewhat reduced. This trend has led to selecting some light sources that distort the color appearance of signs at night.

Color appearance of an object is a function of the light source illuminating it and the spectral selectivity of the object itself. Colors of highway signs, when illuminated by different light sources, may not look the same at night as during the day. Knowledge of changes in the color appearance of signs is important because:

- A wide variety of light sources are available and used by various agencies responsible for sign lighting.
- Light sources for automobile headlamps may change, replacing the conventional incandescent or halogen lamps with high intensity discharge lamps such as metal halide lamps.
- The potential exists for changing sign materials by bringing them closer to CIE (Commission Internationale de l'Eclairage) colors.

OBJECTIVE

The objective of this study was to develop guidelines to select efficient and cost effective light sources to illuminate highway signs. The recommendations are based on the color rendering characteristics of the light sources as well as their ability to meet the minimum illumination levels recommended by AASHTO.

S. F. Hussain, Bellomo-McGee, Inc., 8330 Boone Boulevard, Suite 700, Vienna, Va. 22180. J. B. Arens, FHWA, 6300 Georgetown Pike, McLean, Va. 22101. P. S. Parsonson, Georgia Institute of Technology, Atlanta, Ga. 30332.

BACKGROUND

Many of the safety colors used for denoting hazardous situations in industrial applications are not identified accurately under common high intensity discharge (HID) light sources (*2,3*). This is equally true for highway sign colors when illuminated under these lamps.

Until the early 1950s, incandescent lamps were the most widely used light sources for street lighting and sign illumination. Good color rendering properties, simple installation, low initial costs, and easy maintenance were some of their major advantages. Short service life and low luminous efficacy were their main disadvantages. Today, the use of this lamp for roadway lighting is almost phased out.

As traffic signs grew in size, fluorescent lamps were used extensively. These lamps illuminate signs uniformly and provide very good color rendition. But they are cumbersome to maintain and susceptible to temperature variations (resulting in considerably reduced light output and starting problems during cold weather). Because of their large size (resulting in relatively large, heavy, and expensive luminaires), they were never used extensively for street lighting, but are still used for sign lighting by some states. In the mid-1960s, mercury lamps were introduced to illuminate signs. They are long-lasting and need very little maintenance. The color rendition of clear mercury lamps, however, is somewhat poor. Phosphor-coated (color-improved) mercury lamps, which provide better color rendition, have been added to the list of widely used sign lighting sources. Because of their many advantages, mercury lamps are considered a very good choice for sign lighting and are used widely.

Metal halide lamps, similar in operation, construction, and performance to mercury lamps, but with considerably better color rendition, were introduced in the late 1960s. Although metal halide lamps have very good color rendition, they have never become a favorite for sign lighting because they have a shorter life span and higher cost than mercury lamps. However, some cities and states do use this light source as a sign illuminant because of its excellent color rendition.

The energy crisis of the early 1970s gave a sudden and dramatic boost to the use of high pressure sodium lamps. There was a wholesale change to high pressure sodium lamps for street lighting and quite a few cities and states also applied this light source to sign lighting. While this lamp has very high luminous efficacy, it distorts the colors of signs considerably. Although low pressure sodium lamps for sign lighting are not suggested, they are included in this study. Low pressure sodium lamps have limited application for sign lighting, but their use for street lighting in some areas along the West Coast, especially where astronomical observatories are located, is becoming more common. Although this is the most efficient light source, all of the light produced is monochromatic yellow (i.e., all the energy emitted is contained in a very narrow band within the visible spectrum). This distorts colors completely; only yellow and orange are distinguishable.

STUDY APPROACH

A test apparatus was built to determine the percentage of people that might be confused by various light sources if such lighting were the only source of sign lighting. The test apparatus consisted of various light sources, an array of highway sign color samples, a microcomputer, and two electric motors. The computer was used for data recording and operating the electric motors to generate random movements of the color samples and the light sources. The light sources were contained in a ventilated box with openings at the bottom. Partitions between the individual lamps prevented light from one source from becoming mixed with the light emitted by adjacent lamps. The light box rotated in the horizontal plane above the viewing box until one of the openings of the light box matched up with the opening in the top of the viewing box. When these two openings were coincident, the light from the lamp being evaluated was evenly reflected to the color sample at the back of the viewing box by a 45-degree inclined diffused reflector. This reflector was made from a white material covered with a layer of non-selective white blotter paper. To provide uniform and approximately equal levels of illuminance, the openings through the lamp compartment were adjusted with perforated screens containing holes of different diameters. Table 1 gives illuminance data of the various light sources with the illuminance meter held at the sample locations before the openings of the lamp compartments were adjusted. Table 2 presents luminance data measured from white blotter paper held at the sample position with the light flux attenuators installed.

Externally illuminated signs are illuminated either with the luminaire positioned above and light falling at an angle to the surface of the sign or the luminaire is installed at the bottom of the sign structure, illuminating it at an angle from the bottom to the face of the sign. The test apparatus was built to simulate a situation where the lighting fixture is installed above the sign. Color samples were attached to a circular wheel made of 2 mm aluminum that rotated in a vertical plane at the back of the viewing box. There was a 4-in. × 4-in. opening at the rear wall of the viewing box through which one color sample, brought in place by selective rotation of the color wheel, could be observed. Another opening of 1½ in. × 4 in. was provided for the observer, who was located at the other end of the viewing box. Two baffles were installed in the viewing box to restrict the observer's view to exactly the size of the sample to avoid possible glare on the surface of the sample. A manually operated shutter at the observer's end of the viewing box was used to prevent the observer from seeing the color samples as they and the light sources were moved between observations. This was done to avoid possible bias of the observer due to light source and color sample movements. All observations were taken in a dark room, and only one light source illuminated one randomly selected color sample at a time.

The sequence of selection of light source/color combination was changed for each subject to eliminate any possible ordering effect. Exposure of each color sample was brief, yet long enough to allow the observers time to identify each one. During the experiment, the samples were viewed only once, except for a few repetitions to assess the observer's consistency of recognition.

During the first part, each color sample, one at a time, was illuminated with one of the light sources contained in the light box and viewed by the subject. A total of 63 different color sample/light source combinations were exposed to each sub-

TABLE 1 ILLUMINANCE DATA AND COLOR COORDINATES OF LIGHT SOURCES MEASURED AT THE SAMPLE POSITION BEFORE ADJUSTMENT

Light Source	Illuminance Lux	x	y
Incandescent	93.90	.457	.403
Fluorescent	89.00	.371	.380
Clear MH	142.00	.349	.379
Color Imp. MH	97.20	.382	.385
Clear Mercury	126.00	.308	.387
Color Imp. Mercury	112.00	.366	.391
Clear HPS	118.00	.523	.424
Color Imp. HPS	64.40	.516	.416
LPS	88.90	.557	.440

ject. Observers were asked to name each of the colors they saw. In the second part, the subjects viewed a combination of miniature traffic signs, representing real-world highway signs. The signs used included a STOP sign, an overhead guide sign with green background, and a NO OUTLET warning sign. These signs cover a broad range of important colors used for roadway signs. The signs were illuminated with one light source first and then with another. Subjects were asked to indicate their preference. The paired comparison approach was used to rate the most preferred light source. The comparison was done on a "knock down" basis, i.e., after comparing four pairs in the first step, only four light sources were included in the next step. Finally, only three light sources were used in the third step to select the most preferred lamp.

SUBJECTS

The Highway Research Center at Turner-Fairbank maintains a subject pool from the driving public who have either participated in previous studies in the facility or have indicated their willingness to participate in upcoming studies. Initially, 40 subjects were selected, 20 male and 20 female, evenly divided into four groups of under 25, 26–40, 41–54, and over 55 years of age. Because of some mechanical problems with the apparatus as well as time constraints, the first part of the study is based on the response from 33 subjects; the second part contains data from 43 subjects. The overall range of subject age was from 18 to 67 with an average of 40.

All subjects were licensed drivers. Their visual acuity was tested to verify a threshold level of 20/40. Subjects were given a color vision test using pseudoisochromatic plates to identify any color defectiveness. Three subjects from the male groups indicated color defectiveness. The color defective drivers were included in the study to assess their ability to recognize sign colors.

GENERAL FINDINGS

Fluorescent, mercury, high pressure sodium, and metal halide are the most commonly used light sources for highway sign

TABLE 2 LUMINANCE DATA AND COLOR COORDINATES MEASURED FROM BLOTTER PAPER AT THE SAMPLE POSITION

Light Source	Luminance cd/m2	x	y
Incandescent	33.70	.467	.404
Fluorescent	38.10	.378	.384
Clear MH	42.60	.358	.384
Color Improved MH	33.30	.390	.388
Clear Mercury	45.00	.311	.389
Deluxe Mercury	40.90	.371	.392
Clear HPS	37.20	.537	.415
Color Imp. HPS	23.80	.525	.415
LPS	34.40	.576	.423

NOTE: Lamp compartment openings adjusted to provide approximately equal illumination.

lighting. Incandescent and low pressure sodium lamps have very limited applications for sign lighting. However, these lamps were included in the experiment because incandescent lamps have been used extensively for sign lighting in the past and the low pressure sodium lamp might be a future candidate for this purpose. The correct identification of various colors under different lamps is given below:

Under mercury vapor lamp:

RED SAMPLE	appeared RED to 9% of subjects. appeared PINK to 24% of subjects.
YELLOW SAMPLE	appeared YELLOW to 18% of subjects. appeared GREEN to 55% of subjects.
ORANGE SAMPLE	appeared ORANGE to 6% of subjects. appeared YELLOW to 39% of subjects.
BROWN SAMPLE	appeared BROWN to 9% of subjects. appeared GRAY to 27% of subjects.

Under metal halide lamp:

RED SAMPLE	appeared RED to 58% of subjects. appeared ORANGE to 27% of subjects.
YELLOW SAMPLE	appeared YELLOW to 73% of subjects. appeared OLIVE to 12% of subjects.
ORANGE SAMPLE	appeared ORANGE to 21% of subjects. appeared PEACH to 30% of subjects.
BROWN SAMPLE	appeared BROWN to 21% of subjects. appeared TAN to 39% of subjects.

Under high pressure sodium lamp:

RED SAMPLE	appeared RED to 33% of subjects. appeared ORANGE to 52% of subjects.
YELLOW SAMPLE	appeared YELLOW to 45% of subjects. appeared ORANGE to 52% of subjects.
WHITE SAMPLE	appeared WHITE to 3% of subjects. appeared ORANGE to 42% of subjects.
GREEN SAMPLE	appeared GREEN to 30% of subjects. appeared BLUE to 30% of subjects.
BLUE SAMPLE	appeared BLUE to 24% of subjects. appeared GRAY to 36% of subjects.
BROWN SAMPLE	appeared BROWN to 27% of subjects. appeared ORANGE to 30% of subjects.

Under fluorescent lamp:

No real confusion occurred under this lamp except for BROWN.

BROWN SAMPLE	appeared BROWN to 36% of subjects. appeared TAN to 30% of subjects.

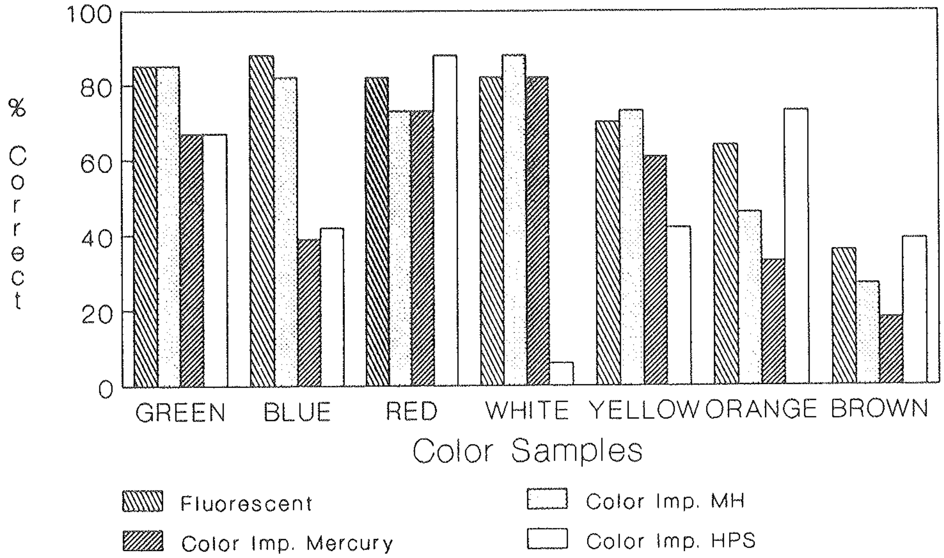

FIGURE 1 Correct identification of different colors under various lamps.

The preceding table indicates a striking difference in performance of the different light sources for illuminating various sign colors. The low pressure sodium lamp performed very poorly; red, green, and blue were not correctly identified with this lamp. The fluorescent lamp appeared to perform substantially better when compared with the other light sources. The difference is not significant, however, when compared with the incandescent or the color-improved metal halide lamps. Figure 1 shows the correct identification of various colors under four light sources commonly used for sign lighting. A quick look at the data above shows that highway brown was rarely identified as brown under any light source. Brown was mingled mostly with tan and cream; it was confused with orange or yellow under low pressure sodium. Under mercury lamps, yellow was confused with green and red with orange. Recognition of all colors except red was improved significantly for metal halide lamps. Red was confused with orange and orange with yellow. It is noteworthy that highway yellow was confused with construction zone orange under almost all light sources. Yellow, used for warning signs, appears close to construction zone orange. A current FHWA research study is investigating this problem.

It should be noted that different light sources affect the appearance of colors to varying degrees. The major factor affecting color appearance is the spectral composition of the light emitted by the source. Visual radiations (light) are contained in a region of the electromagnetic spectrum between 400 and 700 nm. Just below 400 nm are invisible ultraviolet radiations and above 700 nm are infrared radiations. Each light source emits a different composition of spectral energy. A basic knowledge of how this affects color rendering of objects and a knowledge of the spectral energy distribution of various light sources are necessary to understand the problem investigated in this study.

Figures 2 through 7 show the spectral energy distributions of the lamps used in this study. Absence or overabundance of a particular wavelength in a light source may cause serious distortion of a particular color when illuminated by such a light source. The low pressure sodium lamp, for example, emits monochromatic yellow energy (single wavelength only). As a result, the only colors that can be recognized correctly under this light are yellow and orange. All other colors are distorted. Fluorescent and metal halide lamps contain spectral energy from all ranges of the spectrum and so provide very good color rendition for most colors.

STATISTICAL ANALYSIS

An appropriate statistical test is determined by the nature and level of the measurement for a particular set of data under consideration. Another important factor is knowledge of the distribution of the sampling population. In the case of no previous knowledge of the population distribution, nonparametric tests are the best choice. Data collected in this experiment were both nominal and dichotomized as "yes" or "no." Therefore, without any assumption of the sampling population, a Cochran *Q*-test was executed to determine whether the performance of each light source based on subject responses was statistically different for illumination of various sign colors. Table 3 demonstrates that each light source exhibited significantly different performance for the various sign colors except brown. That is, no matter what light source is used for the brown color sample, the appearance of this color may still be confused.

Chi-square comparisons of various light sources were made to rate them on their overall performance. The data given in Table 4 demonstrate that the performance of the fluorescent lamp is significantly better when compared to clear mercury and to both clear and color-improved high pressure sodium (HPS) lamps. The fluorescent lamp did not perform significantly better than incandescent, metal halide (both clear and color-improved), and color-improved mercury lamps. The incandescent lamp performed significantly better than the clear

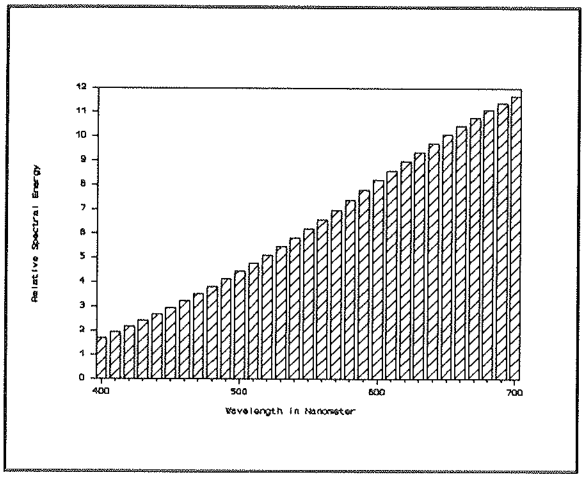

FIGURE 2 Spectral energy distribution of incandescent lamp.

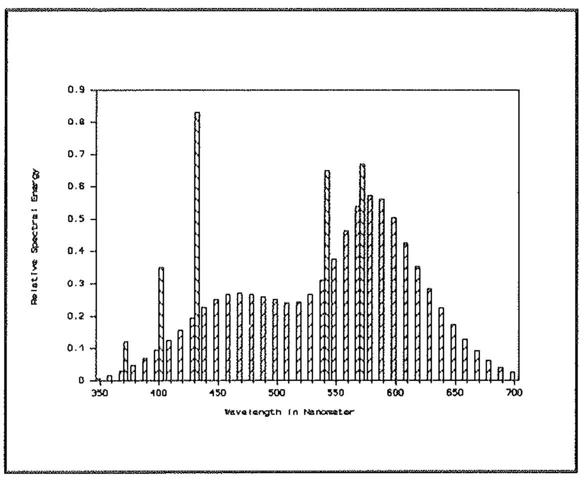

FIGURE 3 Spectral energy distribution of fluorescent lamp.

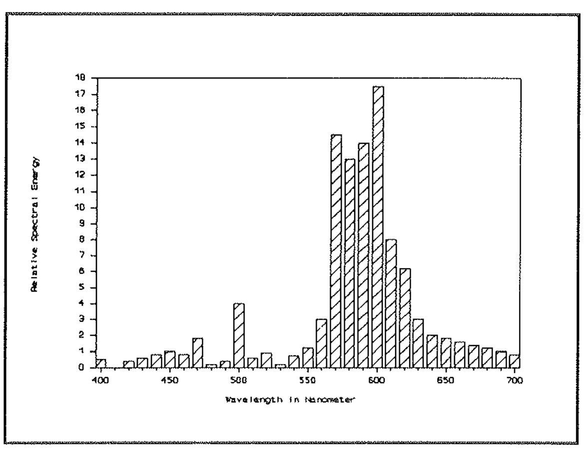

FIGURE 4 Spectral energy distribution of HPS lamp.

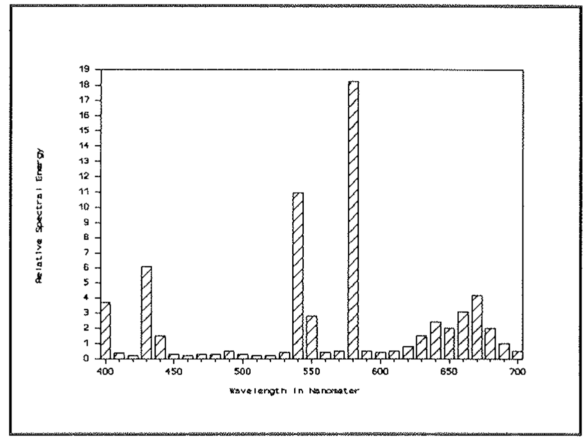

FIGURE 5 Spectral energy distribution of mercury lamp.

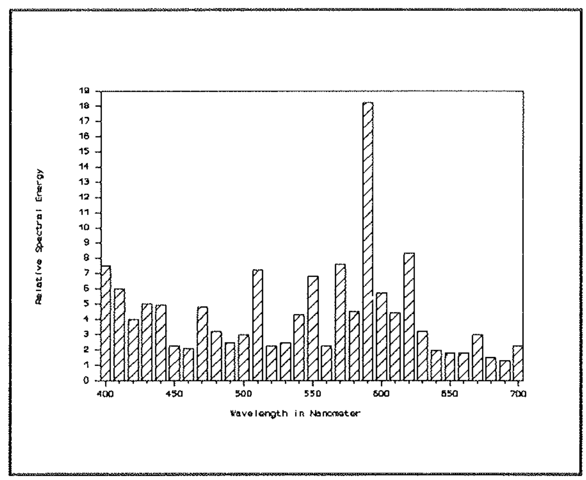

FIGURE 6 Spectral energy distribution of metal halide lamp.

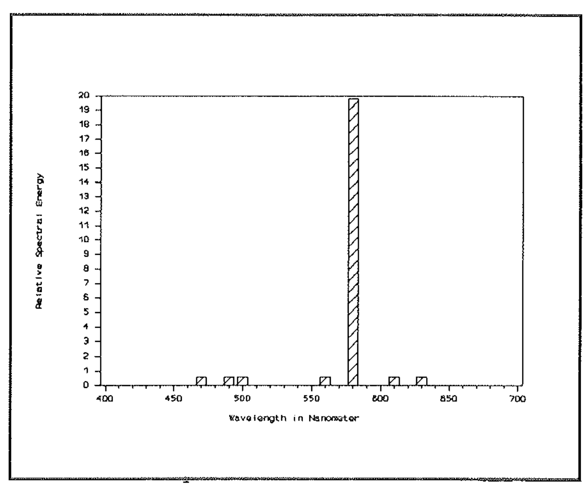

FIGURE 7 Spectral energy distribution of LPS lamp.

TABLE 3 COCHRAN Q-TEST RESULTS FOR VARIOUS COLORS

Color	Q-Value	DF	Probability
White	146.7	6	<.001
Red	145.9	6	<.001
Blue	126.5	6	<.001
Green	105.2	6	<.001
Orange	78.5	6	<.001
Yellow	38.5	6	<.001
Brown	15.5	6	<.05

metal halide and both versions of the mercury and HPS lamps, but did not perform significantly different from the color-improved metal halide lamp. Both the clear and the color-improved versions of the metal halide lamps performed significantly better than the clear mercury and both versions of the HPS lamps. Mercury lamps (clear and color-improved) exhibited better performance than either clear or color-improved HPS lamps. Performance between clear and color-improved HPS lamps was not statistically different.

In the second part of the study, subjects viewed several scaled-down signs against a dark background. Each subject saw these signs illuminated alternatively by a pair of relatively similar light sources, i.e., color-improved high pressure sodium and clear high pressure sodium; color-improved mercury and clear mercury; and color-improved metal halide and clear metal halide. Subjects expressed a preference for one light source for each pair viewed. The preferred light sources were used to again illuminate the signs and again the subjects expressed preferences based on overall appearance and not necessarily on true color recognition.

In comparing the two types of high pressure sodium in the first group, 77 percent of the subjects preferred the color-improved lamp. Eighty-four percent of the subjects preferred the color-improved mercury lamp over the clear mercury lamp, and 58 percent preferred the color-improved metal halide lamp over the clear metal halide lamp.

Once the choice was narrowed down to the color-improved versions of the high pressure sodium, mercury, and metal halide lamps, the HPS lamp was compared to the mercury lamp and the metal halide lamp was compared to the fluorescent lamp. This "pre-selection" of pairs to compare may have led to a slightly biased result; however, it was felt that by grouping the clear and color-improved versions first and then the best two sets (metal halide versus fluorescent and HPS versus mercury), a true preference scaling could be developed. These short-cuts in the paired comparisons were necessitated by time constraints.

Results from the second step indicated that 91 percent of the observers preferred the mercury lamp over the HPS lamp and only 51 percent of the observers preferred the metal halide lamp over the fluorescent lamp. Because there was

TABLE 4 CHI-SQUARE COMPARISONS OF VARIOUS LIGHT SOURCES

Light Sources Comparisons			Probability
Fluorescent	vs.	Incandescent	N.S.
Fluorescent	vs.	Imp MH	N.S.
Fluorescent	vs.	Clear MH	N.S.
Fluorescent	vs.	Imp Mercury	N.S.
Fluorescent	vs.	Clear Mercury	<.0003
Fluorescent	vs.	Imp-HPS	<.0011
Fluorescent	vs.	Clear HPS	<.0002
Incandescent	vs.	Imp MH	N.S.
Incandescent	vs.	Clear MH	<.0143
Incandescent	vs.	Imp Mercury	<.0415
Incandescent	vs.	Clear Mercury	<.0000
Incandescent	vs.	Imp HPS	<.0132
Incandescent	vs.	Clear HPS	<.0003
Imp MH	vs.	Clear MH	N.S.
Imp MH	vs.	Imp Mercury	N.S.
Imp MH	vs.	Clear Mercury	<.0028
Imp MH	vs.	Imp HPS	<.0000
Imp MH	vs.	Clear HPS	<.0000
Clear MH	vs.	Imp Mercury	N.S.
Clear MH	vs.	Clear Mercury	<.0265
Clear MH	vs.	Imp HPS	<.0000
Clear MH	vs.	Clear HPS	<.0000
Imp Mercury	vs.	Clear Mercury	<.0004
Imp Mercury	vs.	Imp HPS	<.0000
Imp Mercury	vs.	Clear HPS	<.0000
Clear Mercury	vs.	Imp HPS	<.0000
Clear Mercury	vs.	Clear HPS	<.0000
Imp HPS	vs.	Clear HPS	N.S.

little difference between the metal halide and the fluorescent lamps, the third step compared the mercury, metal halide, and the fluorescent lamps. The mercury lamp was preferred by 44 percent of the subjects, and 28 percent of the subjects preferred either the metal halide or fluorescent lamp.

CONCLUSIONS AND RECOMMENDATIONS

Fluorescent, metal halide, mercury, and high pressure sodium lamps are widely used light sources for sign lighting. The results of this study indicate that fluorescent lamps provide slightly better color rendition/color recognition than the next best light source, the metal halide lamp. However, because of the higher purchase and operating costs of a fluorescent lamp system, along with starting problems and reduced light output during cold weather, metal halide lamps are a better choice. Therefore, where color identification is the most important criterion, metal halide lamps are recommended. This also could include the use of metal halide lamps in future automobile headlights.

For overhead lighting of signs with green backgrounds and white legends or blue backgrounds and white legends, savings can be achieved by using mercury lamps. Mercury lamps, especially the color-improved version, do not seriously distort these sign colors. The least desirable light source, from a color rendering standpoint, is the high pressure sodium lamp. However, even this lamp provides an acceptable color rendition where system and operational costs are more important than true color recognition. It is the opinion of the authors that a directional sign that can be seen and read, even if the colors are distorted to some degree, is considerably better than a sign which is dark, invisible, or illegible.

For construction and maintenance areas where orange signs are used and illuminated, high pressure sodium lamps are a very good choice. This lamp is economical and provides very good color rendition of orange signs.

Because of the extreme absence of any color recognition other than yellow or orange, the low pressure sodium lamp is not recommended for sign lighting. For economic reasons, the incandescent lamp (including any quartz-halogen lamps) also should not be considered for sign lighting except where the lighting is temporary and equipment costs are to be held to a minimum.

In the present experiment, nonretroreflective signing materials were used. It must be recognized that the real-world nighttime color appearance of signs is a function of both the fixed lighting and the vehicle's headlamps. Fixed lighting provides the visual component of the diffusing quality of the sign surface. Headlamps deliver the retroreflective component. We used diffuse color samples and diffuse lighting geometry in our experiment, which represents only the visual component. Our rationale was that unless you are relatively close to a lighted sign, or use high beams, most headlamps will have little impact on the color appearance of a sign. We understand the FHWA is considering another study using retroreflective color samples to investigate the impact of low beam headlamps, when added to fixed lighting, on the color appearance of a sign. It may also be interesting to include some very small incandescent light sources in the visual field to simulate color reference points such as automobile headlamps, taillights, or surrounding ambient lighting.

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