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Title:

Comparison of Field Measurements of the Brightness and Color of Fluorescent Yellow and Fluorescent Yellow Green Retroreflective Signs

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ABSTRACT

There is a growing body of traffic engineering research indicating fluorescent-retroreflective signing can increase safer driver behavior on the road. However, missing from these studies are quantitative evaluations of the photometric performance of fluorescent-retroreflective materials on the roadway. How do the properties of fluorescent signs differ from ordinary colors? Information on the field performance of fluorescent-retroreflective signs under daytime and nighttime viewing conditions relative to conventional signing would be of interest to both researchers and practitioners. Laboratory measurements of the photometric and colorimetric properties of traffic signing materials are typically used as a surrogate for their field performance properties in standard material specifications. Yet, there is little data in the literature illustrating the relationship between laboratory testing of sign materials using standardized test methods and the photometric performance of signs on the road. To begin to fill in these gaps, we conducted measurements of the photometric properties of a series of fluorescent and ordinary (non-fluorescent) retroreflective signs both in the laboratory and in the field. The results show that laboratory testing does correlate to some extent with field measurements of the same properties. However, the data point toward a need for improvements in the current laboratory test methods with the aim to make them correspond more directly to what is observed by the driver.

INTRODUCTION

In order to fulfill their role as safety devices, traffic signs must function effectively day and night in all driving environments and under all visibility conditions. An effective traffic sign communicates its message at a sufficient distance and within a short enough time interval, to allow the driver adequate time to adapt their behavior (speed, lane position, awareness, etc) to the upcoming road situation. Rapid and clear communication is critical for warning signs whose sole function is to alert the motorist to roadway safety hazards. They warn of existing hazards, such as changes in road alignment (e.g. Curve Ahead) and traffic flow (e.g. Stop Ahead) as well as potential hazards, such as a pedestrian crossing or school zone. The visibility of traffic signs is an increasing concern because of visual “pollution” of the driving environment – day and night. Poor visibility conditions and complex visual environments decrease the driver’s ability to locate and read signs, and therefore increase the need for signs that are highly visible and legible under these conditions. For a given sign design, the visual performance of a traffic sign is determined by the photometric properties of the materials used to fabricate the sign.

COMBINED PERFORMANCE FLUORESCENT-RETROREFLECTIVE SIGNING

Retroreflective optical elements increase nighttime sign luminance making signs visible to the driver under headlamp illumination. To insure a sufficient level of nighttime visibility, traffic signs are required to be retroreflective. The use of more efficient retroreflective materials contributes to improved nighttime roadway safety. While the number of nighttime fatal and injury crashes have continued to decline, the daytime numbers have increased 10% since 1992 [1]. What tools are available to help improve daytime roadway safety? High visibility fluorescent materials are widely used for industrial and maritime safety signing. Fluorescent signs are a great deal more efficient than ordinary signs at converting the incident daylight (solar energy) into sign luminance [2]. These high daytime luminance properties are the basis for the exceptional daytime visibility and conspicuity of fluorescent signs. By combining fluorescent and retroreflective properties into a single construction one can provide signs with enhanced 24-hour visibility performance to better serve driver needs. Fluorescent-retroreflective signs should provide an additional margin of safety for the driver under poor visibility conditions. They may also better accommodate the visual needs of disadvantaged drivers, for example older drivers.

Since 1992 there has been a steady increase in the use of fluorescent traffic control signing. A majority of states have adopted standards requiring the use of fluorescent orange signing at construction work zones. In June 1998 the US Federal Highway Administration (FHWA) officially added fluorescent yellow-green to the traffic color code [3]. This is the first new traffic signing color to be added in 30 years. Fluorescent yellow green is reserved for pedestrian, bicycle, and school warning signs. It is noteworthy that this new signing color is specifically required to be fluorescent. Collisions arising from roadway conflicts between vehicles and vulnerable road users – pedestrians and cyclists - usually result in serious injury or death. It is anticipated that high visibility fluorescent yellow-green signs will help reduce human-vehicle conflicts and increase pedestrian safety by providing earlier warning to the driver. The color yellow is assigned for general warning signs on highways in the United States. Yellow warning signs identify road safety hazards typically linked to permanent changes in road alignment, road geometry, and traffic flow. Because of their wide spread use in highway signing, any improvement that would increase the effectiveness of yellow warning signs could have a potentially large impact on road safety. Yellow fluorescent-retroreflective signing materials have recently been added to the traffic engineer's safety toolbox. All major manufacturers of retroreflective sheeting offer fluorescent-retroreflective signing materials.

There is a growing body of engineering research indicating fluorescent-retroreflective signing can influence safer driver behavior on the road. Field studies of driver behavior in open traffic where the ordinary signs were replaced with fluorescent signs provide the most direct evidence of a link between the use of fluorescent signing and improved daytime safety. Traffic field studies have been conducted in Europe by Jenssen [4] and Albach [5], and in the US by Hummer [6] and Dhar [7]. These studies have documented fewer traffic conflicts, lower speed variance, improved lane position in curves and construction work zones, increased attention to traffic control devices, and greater compliance with warning sign information when fluorescent signs were in place. In each case the fluorescent signs and ordinary signs were identical in design and size differing only in their photometric properties. How then do the properties of fluorescent signs differ from ordinary traffic colors? Information on the photometric performance of fluorescent-retroreflective signs under daytime and nighttime illumination and viewing conditions relative to conventional signing would be of interest to both researchers and practitioners. Agencies use laboratory measurements of the photometric and colorimetric properties of signing materials in standard material specifications as surrogates for the field performance of traffic signs. Yet, there is little data in the literature illustrating the correlation between laboratory characterization of sign materials and the photometric performance of signs on the road. To begin to fill in these gaps, we conducted a study comparing the photometric properties of a series of fluorescent and non-fluorescent retroreflective signs measured in the laboratory using standardized test methods and in the field from the driver's position. This paper presents the results of those measurements.

EXPERIMENTAL

Test signs (60 cm x 60 cm) were fabricated from new sheeting in accordance with standard industry practices. The signs were fabricated from the following types of sheeting.

- Yellow Engineering Grade (ASTM Type I) [8]
- Yellow High Intensity Grade (ASTM Type III) [8]
- Yellow high performance prismatic (ASTM Type VIII) [9]
- Yellow wide observation angle prismatic (ASTM Type IX) [9]
- Fluorescent Yellow (FY) wide observation angle prismatic (ASTM Type IX) [9]
- Fluorescent Yellow Green (FYG) wide observation angle prismatic (ASTM Type IX) [9]
- White wide observation angle prismatic (ASTM Type IX) [9]
- Black marking film (opaque)

ASTM Type VIII sheeting has been described as a long distance sheeting. ASTM Type IX sheeting has been described as a wide angle retroreflective sheeting with optimised performance over a broad range of observation angles designed to provide high sign brightness at short sight distances. A white sign was included to allow a comparison of the effect of colors on the photometric properties of signs. White is the highest luminance ordinary color. A black sign made using an opaque marking film commonly used for legends and symbols on warning signs was included to examine the legibility contrast differences between the sign sheeting types. All of these materials are commercially available worldwide.

Laboratory Photometric Measurements

Laboratory measurements of the photometric properties of each test sign were made in accordance with the standard test methods and practices currently in sheeting specifications (Table 1). The measured properties were daytime color, daytime lightness (luminance factor, Y), nighttime (retroreflected) color, and nighttime retroreflective efficiency (coefficient of retroreflection, R_A) over a range of observation angles. The fluorescent properties of the fluorescent samples were also measured.

TABLE 1 Laboratory Photometric and Colorimetric Test Methods

Photometric Property	Test Method	Test Conditions
Daytime color (x,y)	ASTM E991 [10];	CIE D65; CIE 1931 Standard Observer; 2-monochromator method; 45/0 geometry
Daytime Lightness (Y)	ASTM E991	CIE D65; CIE 1931 Standard Observer; 2-monochromator method; 45/0 geometry
Fluorescence (Y_F)	--	CIE D65; CIE 1931 Standard Observer; 2-monochromator method; 45/0 geometry
Retroreflected Color (x,y)	ASTM E811 [11]	CIE A; CIE 1931 Standard Observer; Entrance angle = 5^o Observation angle = 0.33^o
Coefficient of retroreflection (R_A)	ASTM E810 [12]	CIE A; CIE 1931 Standard Observer; Entrance angle = 5^o Observation angle = 0.2/0.33/0.5/1.0/1.5 degrees

Fluorescent properties are a clear requirement of fluorescent-retroreflective materials, so it follows that a quantitative measure of fluorescence is necessary to adequately describe their properties. For a fluorescent sign, the daytime luminance (L) is the sum of the reflected (R) and fluorescent (F) contributions: $L = L_R + L_F$. The colorimetric value corresponding to luminance is the luminance factor (Y). A luminance factor is defined as the ratio of the luminance of a sample to the luminance of an ideal 100% efficient perfect diffuse reflector (PDR) illuminated and viewed under identical conditions: $Yx = L_{Sample}/L_{PDR}$. It follows that for a fluorescent specimen $Y = Y_R + Y_F$ (For non-fluorescent specimens $Y_F = 0$ and $Y = Y_R$.) The fluorescence luminance factor (Y_F) has been proposed as a standardized quantity for describing the fluorescent properties of signing materials [13]. While Y_F can be calculated for any illuminant, CIE standard illuminant D65 is the illuminant of choice. It is the standard illuminant required worldwide for the daytime colorimetry of traffic signs.

Accurate and reproducible measurement of the color of a fluorescent sign requires a two-monochromator spectrophotometer. Two-monochromator color instruments are general purpose instruments designed for accurate measurement of both fluorescent and ordinary (non-fluorescent) materials. The common one-monochromator colorimeters are suitable only for measurement of non-fluorescent materials. While at one time only national standards laboratories were capable of two-monochromator colorimetry, commercial systems are now available. The Labsphere^{TM} BFC-450 Bispectral Fluorescence Colorimeter was used in this study for the laboratory measurement of daytime color and fluorescence.

for nighttime distances >25 m. Nighttime color measurements were only made at 25 m due to limitations in the spectral sensitivity of the telespectroradiometer at low luminance levels. Field measurements were also made of a white Spectralon^{TM} UV-VIS-NIR Diffuse Reflectance Target SRT-99 mounted next to the test sign. SRT-99, which has a diffuse reflectance of ~99% over the entire range from 300 to 800 nm, is a physical embodiment of a PDR. This provided a method for characterizing the daylight illumination on the signs. Nighttime illuminance by the headlamps was measured at the sign using a lux meter. All sign measurements were made from the driver's eye position through the windshield of the vehicle. Daytime PDR (SRT-99) measurements were made from both inside and outside the vehicle.

Daytime field measurements were made under a range of ambient daylight illumination (no daytime running lights) at a distance of 10 m. One set was made at midday under clear skies with direct sunlight on the signs. Another set was made at midday under an overcast sky with steady light rain. A third set was made in the late evening approximately 30 minutes before sunset under overcast, but dry conditions. Nighttime sign luminance measurements were made at 25, 70 and 100 m under clear conditions using low beam headlamp illumination. These distances were chosen as a representative range of minimum required legibility distances for a warning sign [14]. The correlated color temperature and illumination intensity for each condition are described below. Correlated color temperature (CCT) is the standard shorthand notation used in radiometry for describing the spectral distribution of a light source of light. Illumination intensity on the sign is reported in lux.

Daytime

- Midday/clear sky: CCT = 5380K; 70,500 lux
- Midday/overcast sky with light rain: CCT = 6000K; 10,300 lux
- Evening/overcast sky: CCT = 8800K; 470 lux

Nighttime

- Lowbeam headlamp: CCT = 2935K; 0.75 lux at 25 m, 0.3 lux at 70 m, 0.2 lux at 100 m.

RESULTS AND DISCUSSION

Daytime Color (x,y)

Figure 2 presents the results of the daytime color measurements. The ASTM daytime chromaticity limits for yellow, orange, and white retroreflective sheeting [8] and the fluorescent yellow green limits defined in the FYG FHWA rule making [3] are included for reference. Chromaticity limits, often referred to as color boxes, are useful for quality assurance purposes. Laboratory results show all the signs conform to the daytime chromaticity requirements defined by the ASTM specification and the FHWA regulation. Chromaticity alone does not provide a complete description of the color "appearance" of a sign. The perceived color of a sign is influenced by a number of factors including the absolute level of illumination, sign luminance, and the luminance and chromaticity of other objects in the field of view. However, the (x,y) chromaticity coordinates of a sample can be used to determine its general categorical color name and provide an approximation of perceived color saturation (purity).

The upper right boundary of the color boxes represents the purity limit of CIE (x,y) color space. For any set of specimens illuminated and viewed under identical conditions, a sample that plots closer to this limit will have a more colorful appearance than one plotting towards white.

The figures illustrate that the color measured under laboratory conditions is not the same as the color measured in the field under natural daytime illumination. The sign colors in the field are less saturated than the laboratory test indicates. One can attribute this to differences in both the spectral distribution of the illumination and illumination/viewing geometry. Color measurement of retroreflectors, especially prismatic materials, is strongly effected by the measurement geometry. Laboratory instruments have highly directional illumination/viewing conditions (45/0) while the outside illumination on a vertical sign is more diffuse. CIE D65 (CCT = 6500K) is simply “standardized” daylight developed for industrial instrumental color measurement. It represents an average spectral distribution for north skylight on a horizontal surface, not a vertical sign. As the results show, natural daylight varies considerably in terms of CCT and intensity over the course of a day. The field measurements show the chromaticity of the FY and FYG signs was more consistent than the ordinary yellow signs under a wide range of daylight illumination conditions. The fluorescent signs also maintained their color saturation better than the ordinary signs. This type of behavior is more consistent with the properties of a light source than a simple diffuse reflector. Their greater color saturation should make fluorescent sign colors easier to identify in the field than the ordinary sign colors. Human Factors studies on the daytime color recognition of traffic signing materials have shown fluorescent sign colors are correctly identified at greater distances and under a wider range of viewing conditions than ordinary colors [15,16].

TABLE 2 Results of Photometric Measurements under Laboratory and Field Conditions

I. Daytime Results

	Laboratory		Field					
	CIE D65		5380K; 70,500 lux		6000K; 10,300 lux		8800K; 470 lux	
Daytime Color	x	y	x	y	x	y	x	y
Yellow Type I	0.509	0.476	0.483	0.456	0.460	0.461	0.440	0.448
Yellow Type III	0.531	0.463	0.489	0.442	0.466	0.446	0.434	0.423
Yellow Type VIII	0.524	0.465	0.498	0.45	0.462	0.455	0.439	0.440
Yellow Type IX	0.534	0.459	0.490	0.455	0.472	0.466	0.448	0.454
FY Type IX	0.545	0.454	0.519	0.449	0.509	0.447	0.510	0.452
FYG Type IX	0.407	0.574	0.399	0.557	0.394	0.551	0.376	0.553
White Type IX	0.313	0.335	0.314	0.346	0.307	0.342	0.272	0.304
Black	0.297	0.319	0.294	0.316	0.305	0.341	0.272	0.301

Luminance Factor & Luminance	Y	Y_F	cd/m^2	Yfield	cd/m^2	Yfield	cd/m^2	Yfield
Yellow Type I	34	0	6314	42	979	45	46	43
Yellow Type III	18	0	3314	21	675	32	35	34
Yellow Type VIII	26	0	5401	36	913	44	45	44
Yellow Type IX	37	0	4825	30	856	39	39	39
FY Type IX	52	34	7730	52	1283	59	67	63
FYG Type IX	84	48	12600	81	2111	100	124	118
White Type IX	41	0	7301	47	1268	60	67	66
Black	0.4	0	493	3	147	7	8	8
PDR	100*	0	15,400		2130		103	
(σ)			(370)		(33)		(2.4)	

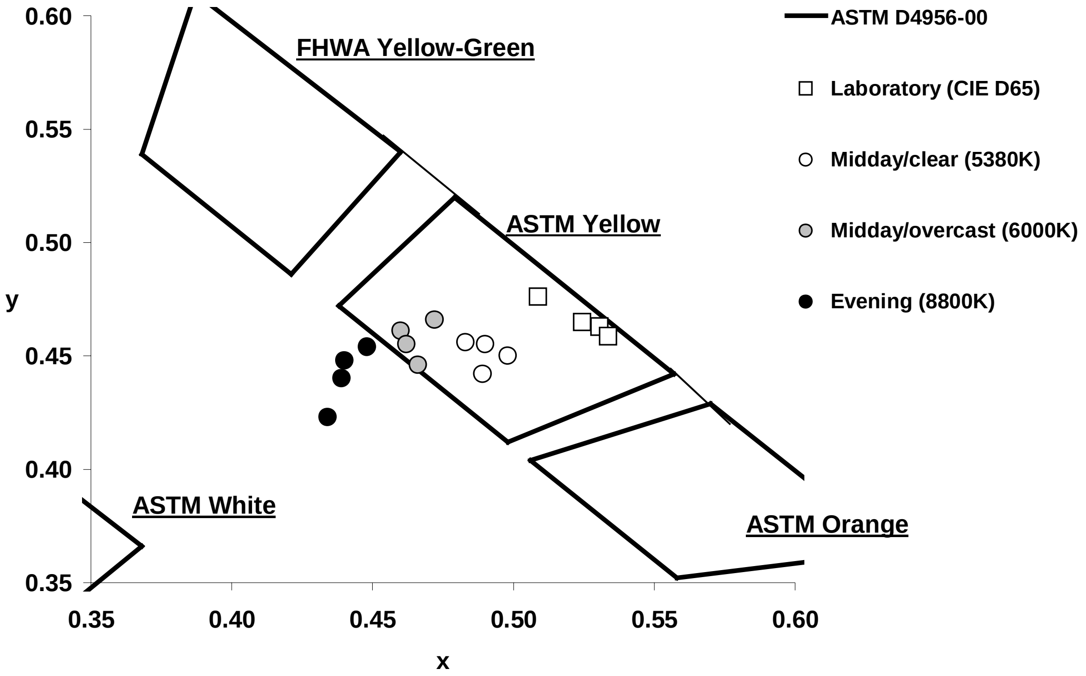
II. Nighttime Results

Laboratory	Retroreflected Color CIE A 5^{o} Entr. Angle; 0.33^{o} Obs. Angle		Coefficient of Retroreflection (CIE A @ 5^{o} Entr. Angle) (cd/lux/m^2) Obs. Angle (degrees)					
	x	y	0.2	0.33	0.5	1	1.5	2
Yellow Type I	0.535	0.442	74	55	33	16	9	6
Yellow Type III	0.549	0.447	227	161	80	27	15	5
Yellow Type VIII	0.531	0.458	556	522	252	34	10	4
Yellow Type IX	0.541	0.452	368	353	276	85	23	8
FY Type IX	0.525	0.466	260	231	196	59	16	5
FYG Type IX	0.591	0.407	397	378	289	96	27	9
White Type IX	0.439	0.405	462	412	354	98	26	9
Black	--[a]	--	--	--	--	--	--	--

Field	Retroreflected Color Low beam @ 25m		Sign luminance (cd/m^2)		
	x	y	100 m	70 m	25 m
Yellow Type I	0.541	0.443	5.5	4.1	2.8
Yellow Type III	0.566	0.430	13.1	5.9	3.5
Yellow Type VIII	0.525	0.463	50.8	28.2	2.9
Yellow Type IX	0.534	0.458	40.6	32.6	5.4
FY Type IX	0.508	0.479	26.7	24.8	2.9
FYG Type IX	0.582	0.411	43.2	35.7	5.0
White Type IX	0.432	0.418	47.2	35.6	5.5
Black	--	--	--	--	--

[a] Not measured

a) Ordinary Yellow Signs



b) Fluorescent Signs

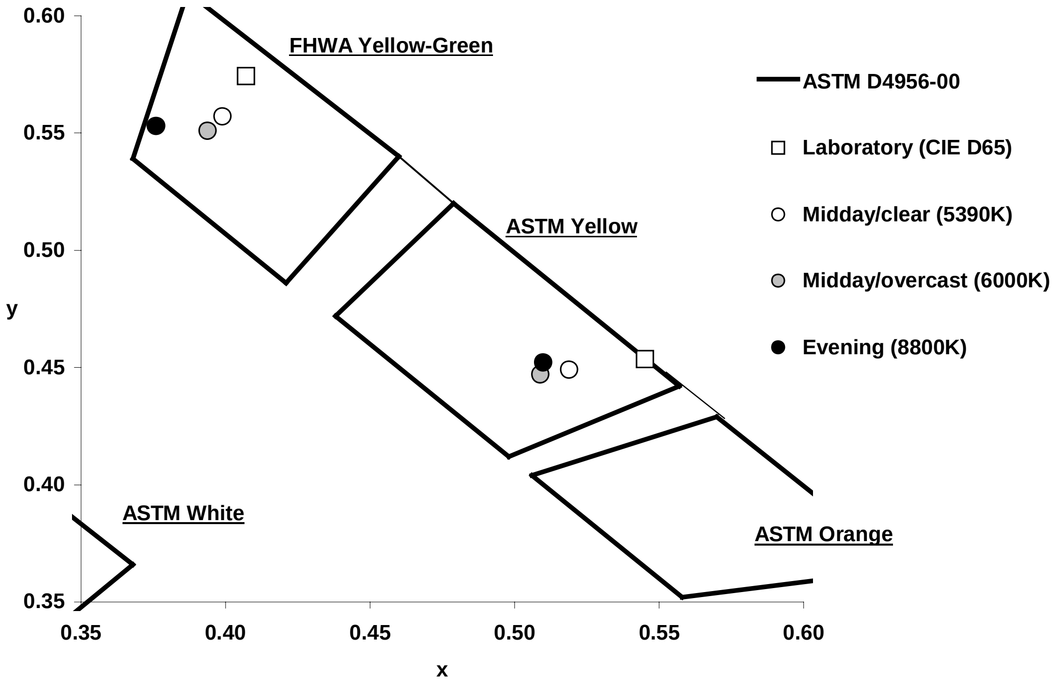


FIGURE 2 CIE 1931 Chromaticity diagram showing the daytime chromaticity of the test signs measured in the Laboratory and in the Field as a function of daylight illumination: a) Ordinary Yellow; b) Fluorescent Yellow and Fluorescent Yellow Green.

Daytime Lightness (Y) and Luminance

The luminance factor (Y) values measured in the laboratory are reported in Table 2 along with each sign's luminance measured in the field through the windshield. The data shows the highest luminance ordinary signs were White followed by Yellow Type I. The daytime luminance of the fluorescent signs is significantly higher than any of the ordinary yellow signs. FY Type IX is about 50% higher than either ordinary yellow prismatic sign and equal to White Type IX. FYG is 2 to 3 times brighter then the ordinary yellows. Table 2 also reports the average and standard deviation (σ) of the PDR values measured through the windshield immediately after each individual sign. The PDR value represents the maximum luminance to the driver obtainable from an ordinary reflecting surface. Using the sign and PDR luminance values we calculated field luminance factors (Yfield = L_{Sign}/L_{PDR}) for each set of daytime conditions. Y and Yfield are relative measures of how efficient a sign is at converting the available daylight illuminance into luminance useable by the driver. They enable a direct comparison between the laboratory and field results. One would expect the laboratory Y (CIE D65 = 6500K) to fall between the Yfield values at 6000K and 8800K, but they do not. This can again be attributed to differences in laboratory and field measurement conditions. It suggests that a better laboratory test method may be necessary if one wants to accurately characterize the daytime luminance efficiency of signs.

Sign luminance plays a determining role in the visibility, conspicuity, and legibility of every traffic sign, both during the day and at night. Figure 3 compares the relative luminance of the five yellow signs scaled so that FY = 1.0 under each daytime condition. The figure shows the fluorescent sign's daytime luminance is significantly greater than the other yellow signs under a wide range of daylight conditions. The difference actually increases under what can be characterized as “poor visibility” conditions (6000K -overcast with rain and 8800K –evening). FYG behaved similarly except the differences between FYG and ordinary yellows were even greater. The ease with which a driver can locate a traffic sign is controlled by the sign's luminance contrast, which is the luminance of the sign relative to its visual background. Studies indicate that search time decreases and detection probability increases with increasing luminance contrast [17,18,19]. Traffic warning signs are typically viewed against relatively low luminance backgrounds such as trees and fields, buildings, etc. [20]. In situations where the sign luminance > background luminance, higher sign luminance should translate directly into higher sign visibility and conspicuity.

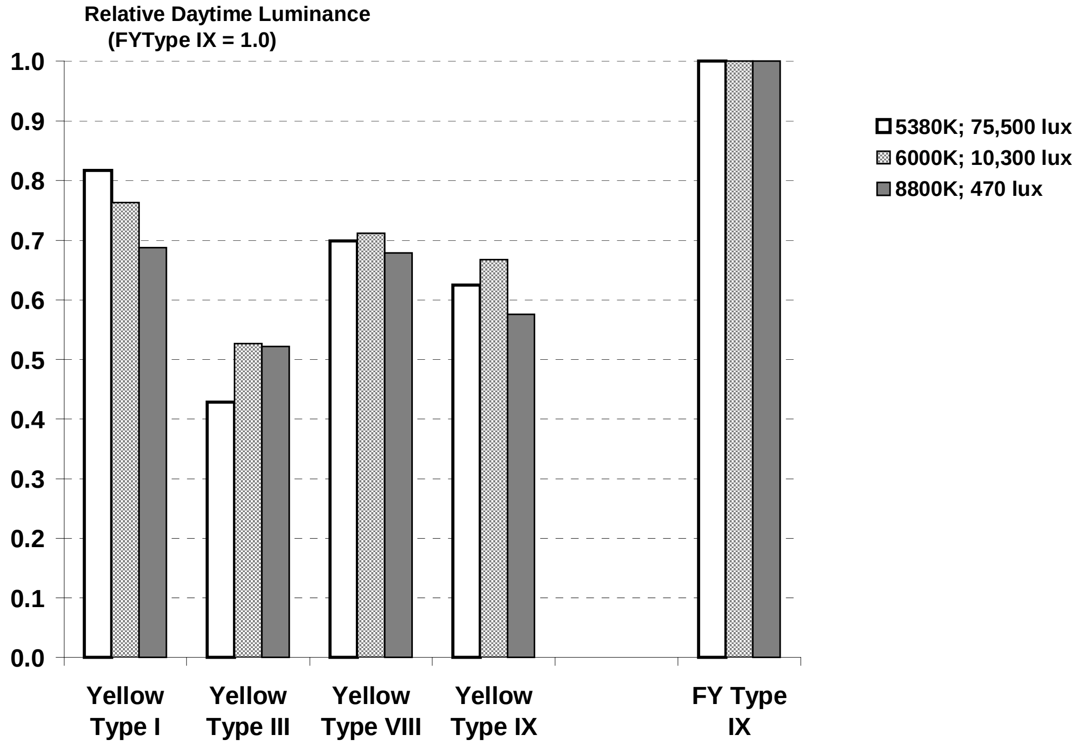


FIGURE 3 Daytime luminance of Ordinary Yellow Signs relative to Fluorescent Yellow

Adequate sign legibility is also required for effective communication. The single most important factor in legibility is the luminance contrast between the legend, either symbol or text, and the background plate of the sign [21]. Table 3 shows the legibility contrast for each sign assuming the black marking film had been used for the legend. The legibility contrast for the fluorescent signs is equivalent to the white under the range of daylight conditions examined and much higher than the ordinary yellow signs. The higher legibility contrast of fluorescent signs should result in their being easier to read than the ordinary yellow signs, especially under low ambient daylight.

TABLE 3 Daytime Legibility Contrast: $C = (L_{Sign} - L_{Black})/L_{Sign}$

	Midday/clear 5380K	Midday/rain 6000K	Evening/overcast 8800K
Yellow Type I	11.8	5.7	4.6
Yellow Type III	5.7	3.6	3.3
Yellow Type VIII	10.0	5.2	4.6
Yellow Type IX	8.8	4.8	3.7
FY Type IX	14.7	7.7	7.2
FYG Type IX	24.6	13.4	14.2
White Type IX	13.8	7.6	7.2

Coefficient of Retroreflection and Nighttime Luminance

Measurements of coefficient of retroreflection and nighttime sign luminance on the road are summarized in Figure 4. The laboratory and field results show similar rankings and trends for each sign. The nighttime brightness profiles of the FYG, FY and ordinary yellow Type IX signs, which have the identical optical design, differ only in absolute intensity. FY Type IX is less bright than ordinary yellow Type IX. This is typical of fluorescent colorant systems, which tend to be slightly less transparent than ordinary colorants. One trades a little retroreflective efficiency for significantly higher daytime luminance. Even so, the FY sign provided higher nighttime luminance than conventional Yellow Type I or Type III signs.

R_A is the surrogate measure for sign luminance used in sheeting specifications, so it would be of interest to see the correlation between the laboratory and field measurements. The observation angles for a right shoulder mounted sign correspond to approximately 0.33^o at 100m, 0.5^o at 70 m, and 1.5^o at 25 m. A simple linear regression analysis of R_A versus sign luminance for these sets of observation angle-distance data yields an R^2 of 0.9791, ($p<0.001$). The correlation is highly significant even though the measurement conditions differ considerably (Laboratory - 1 light source with precisely controlled geometry; Field - 2 headlamps and imprecise estimates of illumination and viewing geometry on the road). The results support the use of R_A as a useful tool to assess the relative luminance of different sign materials on the road, at least for a simple driving scenario.

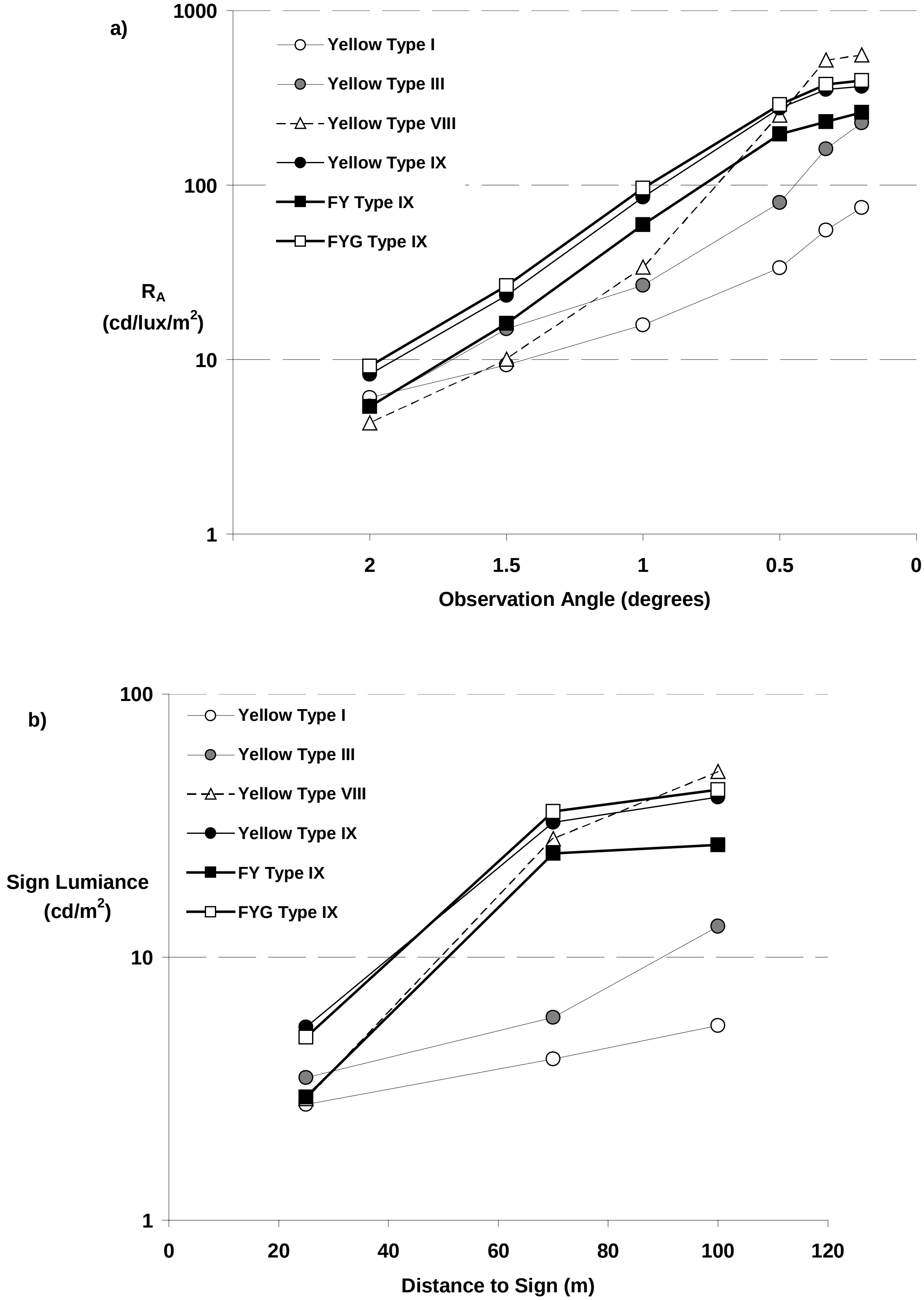
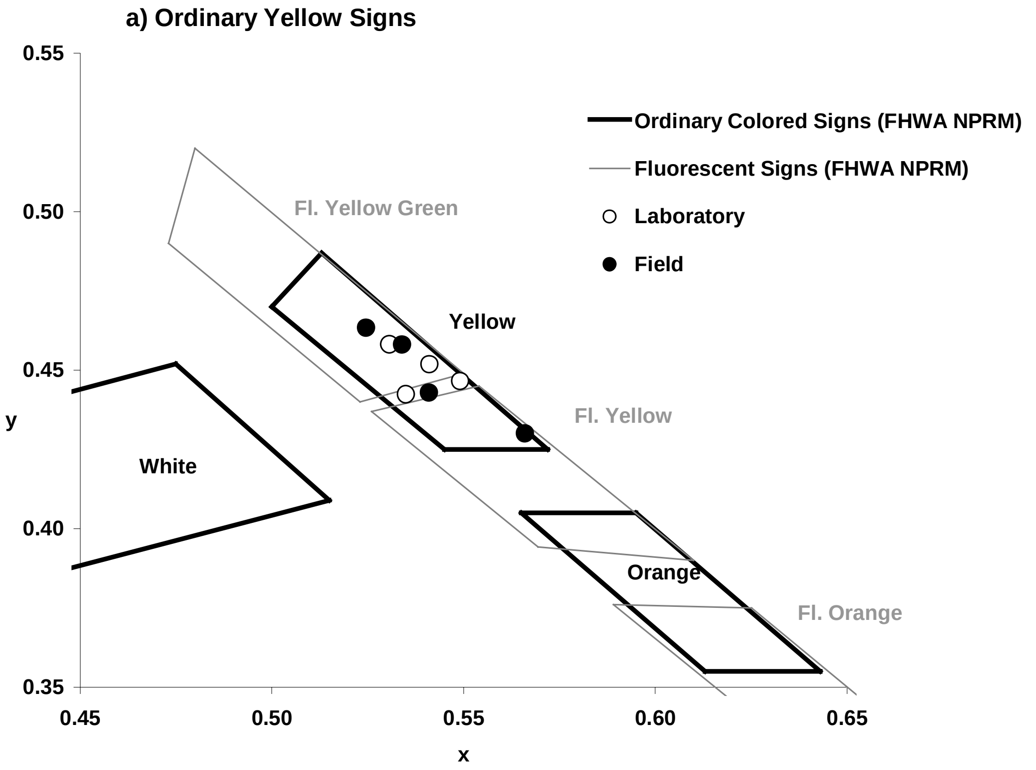


FIGURE 4 Retroreflective properties of Ordinary Yellow and Fluorescent Signs: a) Coefficient of retroreflection (R_A) as a function of Observation angle at 5^o Entrance angle; b) Sign luminance measured in the field through the windshield under low beam headlamp illumination as a function of distance.

Nighttime (Retroreflected) Color

There are no widely adopted photometric requirements for the nighttime color of traffic signs. Section 2A-16 of the Manual on Uniform Traffic Control Devices states all regulatory and warning signs shall be reflectorized “to show the same shape and color both by day and night” [22]. Unfortunately there is little guidance as to what is meant by “same color by day and night.” Several standardizing organizations are in the process of developing nighttime color specifications for road singing to help resolve this issue. These bodies include the FHWA, ASTM, and CIE. The FHWA has progressed to the point where a Notice of Proposed Rule Making was issued in December 1999 [23]. The nighttime color results are presented in Figure 5. The proposed FHWA nighttime color limits are included for reference. Different color limits have been proposed for fluorescent and ordinary color signs. Just as in the daytime results, there is a shift in the measured chromaticity between the field and the laboratory. Yellow Type III showed the greatest shift in nighttime chromaticity out of the four ordinary yellow signs. A relatively large shift was also found with FYG. Overall, the differences in nighttime color between the laboratory and field are generally smaller than those observed for daytime color. This may be attributed to greater similarity in the spectral distribution of illumination (vehicle headlamp = 2935 K; laboratory Source A = 2856 K). Both conditions also have a highly directional illumination and viewing geometry. The vehicle headlamps used for this study are common in the current US national vehicle fleet. The future trend in headlamps is towards more efficient forward lighting systems, such as high-intensity metal halide headlamps [24]. The next generation of headlamps may have spectral power distributions, and beam patterns, significantly different from conventional incandescent headlamps. This could result in greater differences in the future between the current standard laboratory tests and what the driver would encounter on the roadway.



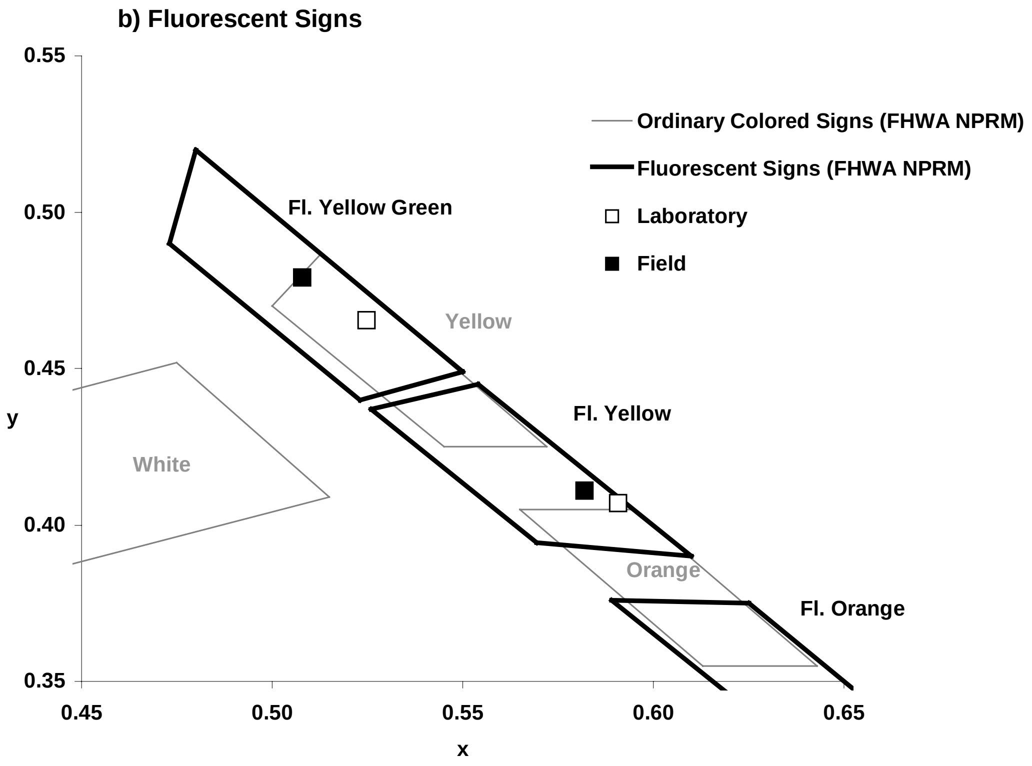


FIGURE 5 Chromaticity diagram showing the nighttime chromaticity of the test signs measured in the laboratory with CIE A and in the field through the windshield under low beam headlamp illumination: a) Ordinary Yellow; b) Fluorescent Yellow and Fluorescent Yellow Green.

CONCLUSIONS AND RECOMMENDATIONS

Laboratory testing of traffic signing materials is useful when it can provide information that allows one to estimate the performance of a sign on the road under conditions of actual use. In order for a user to be confident a material can provide adequate visibility performance on the road they must first properly establish the level of photometric field performance required. These levels can only be determined through well designed Human Factors research that takes into account vehicle, driver and roadway characteristics. The next required step is to correlate the field requirements to laboratory test methods that can then be used for routine conformance and quality assurance testing. Accurate and reproducible test methods are necessary tools for both the manufacturer and the user. By monitoring the photometric and colorimetric properties for specific daytime and nighttime illumination conditions and viewing geometry, the manufacturer can insure production is uniform and consistency is maintained. By using the same test methods the user can be assured of getting materials having the required properties. Meaningful correlations based on sound psychophysical relationships are the key requirement for relating the photometric properties of materials to the visibility and legibility performance of signs on the road.

This study compared the photometric properties of a series of fluorescent and ordinary retroreflective signs measured in the laboratory using standardized test methods to those measured in the field under typical driving conditions. The experimental results support the following conclusions:

1. Daytime color measured under laboratory conditions is not the same as the color measured in the field under natural daylight illumination due to differences in both the spectral distributions of the illumination and illumination/viewing geometry.
2. Combined performance fluorescent-retroreflective signs maintain greater color saturation (purity) over a wider range of daylight conditions than ordinary signs.
3. The current laboratory test method for the Luminance Factor (Y) of signs does not accurately characterize their daytime luminance efficiency.
4. The daytime luminance of FY and FYG signs are significantly higher than ordinary yellow signs under a wide range of daylight conditions and the differences increase under characteristically “poor visibility” conditions.
5. There is a correlation between coefficient of retroreflection and sign luminance for corresponding sets of observation angle-distance data.
6. Nighttime color measured in the laboratory provides a reasonable approximation of the nighttime chromaticity measured under low beam headlamp illumination when the CCT of the headlamp and laboratory source are similar.

The experiment shows the standard laboratory tests of the colorimetric and photometric properties of retroreflective signs correlate to varying degree with field measurements of the same properties. A limited number of sign sheeting types and colors were tested with only a single vehicle and headlamp type being used for the nighttime field study. Additional photometric research is needed using a larger number of signing materials and a greater range of illumination conditions – daytime and nighttime (i.e. different headlamp types). Human Factor research is also required to better define the relationship between the photometric properties of traffic signing materials and the daytime and nighttime visibility performance of signs. Of special practical interest is the relationship between sheeting photometric properties and traffic sign conspicuity in complex visual environments. Human Factors and traffic engineering studies indicate a connection between the daytime and nighttime photometric properties of combined performance (fluorescent-retroreflective) signs and a potential for improving road safety. Additional traffic engineering research is needed to confirm this connection.

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