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LEGIBILITY OF URBAN HIGHWAY TRAFFIC SIGNS USING NEW RETROREFLECTIVE MATERIALS

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Abstract. Unlighted highway signs, which use newly developed retroreflective materials, were installed along the major expressway in an urban area by the local department of transportation. Photometric measurements of the signs were used to assess their legibility applying the relative visual performance model, in comparison to lighted signs, conforming to recommended illumination practices. The calculated visibility of the measured unlighted signs was similar to that of the signs equipped with exterior sign illumination. The practical significance and limitations of the relative visual performance approach are discussed.

Keywords: highway signs, visibility, visual performance, retroreflective materials.

1. Introduction

Overhead highway signs constitute an important part of the roadway visibility system (Van Derlofske *et al.* 2001). These signs provide drivers with information regarding destinations and driving maneuvers that will be required in order to reach those destinations. As such, overhead highway signs must be highly legible so that the drivers can read and interpret the contained information in an appropriate time to respond.

The 'Manual on Uniform Traffic Control Devices' (2003) requires that guide signs (green signs with destination/exit information) must be either illuminated or retroreflective. Illuminated signs could be lighted up from behind (back-illuminated). In addition, the external luminaires could be used as well to illuminate the face, a front part of the sign, or use luminous elements such as light-emitting diodes (LEDs) to make up all the features of those signs. Retroreflective signs could include individual 'button' elements that, in a similar manner to LEDs, would make up the sign characters, or materials that provide retroreflection for their entire surfaces. Retroreflective materials are commonly used on highways. An advantage of retroreflective materials is that they require no electrification because they rely on passive (and relatively efficient) reflection of light from vehicle headlamps toward drivers. Since the angle between a driver's sight line to a sign and the light rays from the driver's headlamps is usually small, especially for far viewing distances, retroreflective materials are good at directing headlamp illumination toward drivers. As this angle increases, the luminance of a retroreflective material will generally decrease.

The specific properties of retroreflective materials have been evolved. Retroreflective sheeting materials are categorized according to the American Society for Testing and Materials (ASTM D 4956-07:2007 and ASTM D4956-09e1:2009) into different types denoted by Roman numerals (e.g., types I, II, III, etc.). Generally, the retroreflective properties of these materials tend to increase as the numerical type increases, but this is not the purpose of the designations (they simply represent different types of performance), and some materials with higher numeric types could have narrower angular distributions than others so that their luminance might be brighter in a 'head on' situation but lower in 'off-axis' situation. Some materials meet the requirements for more than one ASTM type. A commonly used material for sign applications is type III, an encapsulated lens material. Newer materials (generally with higher ASTM type numbers) use microprismatic reflectors.

Many scientists have investigated the effectiveness of different materials on sign visibility either through measurement of sign luminance or through studies of visual performance or subjective evaluation. Generally, these studies have corroborated the promise of several newer reflective materials (e.g., types VII, VIII and IX) to provide superior performance to more commonly used materials (e.g., types I and III) in terms of higher luminances or longer legibility distances (Bible and Johnson 2002; Carlson and Hawkins 2003; Zwahlen *et al.* 2003;

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Carlson and Holick 2005). However, the relationship between a material type and its luminance is dependent on a variety of factors such as the light source used to illuminate the material, the geometry, the location and angular displacement of the sign, age and cleanliness of the sign, the presence of ambient illumination, complexity of the surrounding environment, weather and many other factors that are almost always beyond the control of highway engineers (Goodspeed and Rea 1999; Nuber and Bullock 2002; Hildebrand 2003; Carlson and Urbanik 2004). According to one more scientist, no reliable differences between encapsulated lens and microprismatic material types were found (Garvey *et al.* 1997).

The reason for desiring high level retroreflective signs of highways is to try to ensure sufficient luminances for adequate legibility of the characters on the signs. The relationship between luminances required for adequate legibility are dependent upon factors such as distance (which affects the apparent size of the characters) (Graham *et al.* 1997; Carlson and Hawkins 2002; Holick and Carlson 2002), the luminance contrast between the sign background and the characters (Schnell *et al.* 2004) the type of characters on the sign (i.e., letters versus symbols) (Zwahlen and Schnell 1999), and observer's age (Graham *et al.* 1997).

The American Association of State Highway and Transportation Officials (Roadway Lighting Design Guide 2005) provides design light levels for illuminated signs when it is believed that retroreflectivity will not provide sufficient sign visibility alone. Recommended light levels are given in illuminance (lx or fc) and in luminance (cd/m²); there are different levels for different degrees of ambient lighting in the environment ranging from low (rural areas without roadway lighting) to high (urban areas with high levels of roadway lighting, commercial signage and illuminated building surfaces). Because the luminaires used for exterior highway sign lighting are not typically located along the same axis as a driver's line of sight to the sign, the sign acts as a diffuse reflector, with the relationship between the illuminance on a sign and the luminance of that sign estimated by:

$$L = E\rho/\pi. \quad (1)$$

In Eq. 1, L is the luminance (in cd/m²), E is the illuminance (in lx [10.8 lx = 1 fc]), and ρ is the reflectance of the sign (0 = perfect black, 1 = perfect white).

For practical reasons, much of the research on retroreflective sign legibility has taken place in locations that have relatively low levels of ambient illumination, such as unused roadways or decommissioned airport runways. Recently, the New York State Department of Transportation (NYSDOT) has installed several signs containing materials of ASTM D 4956-07:2007 types VIII, IX and materials meeting specifications of a proposed type (XI, which is not presently defined by the ASTM) as well as those of an existing type (IX) in New York City, along the Gowanus Expressway, as part of an experimental investigation to evaluate visibility-related characteristics of unlighted signs constructed from these materials. The materials come from different manufacturers, and in this paper are designated as follows: VIIIa – meets ASTM type VIII specifications; VIIIb – meets ASTM type VIII specifications; IX – meets ASTM type IX specifications; proposed XI – meets proposed type XI and existing ASTM type IX specifications.

For all of these signs, both the background and characters were constructed from the same type of material, in green and white, respectively. The materials might potentially result in higher retroreflectivity, and therefore higher luminances, than signs constructed from type III materials usually used by NYSDOT for highway signs. In addition, since the ambient illumination levels around the Gowanus Expressway are expected to be higher than those found in rural areas, such illumination might also contribute to sign luminance. Exterior illumination would normally be used for highway signage in such locations, but if newer, unlighted materials could result in a similar visibility as lighted signs, savings in terms of energy and maintenance might be achieved as a result, as well as reductions in light pollution.

2. Photometric measurements

The test location was visited in order to perform photometric measurements of the sign luminances in April and June 2006. Night time measurements were made during both visits; daytime measurements were made during the second visit only. Measurements were made with a spectroradiometer (PhotoResearch, SpectraScan 705) equipped with a telephoto lens. The spectroradiometer was mounted onto a tripod in a NYSDOT vehicle (Dodge Caravan) and driven with a shadow vehicle behind it for safety, along the highway and stopped approximately at 100 m (minimum 97 m, maximum 108 m, measured using a Bushnell LIDAR range finder). The lens of the spectroradiometer was positioned as closely as possible to the vehicle driver's eye level.

Nine signs were installed along the expressway using four materials described above: two type VIIIa signs, two type VIIIb signs, four type IX signs and one proposed type XI sign. For the daytime measurement session and for the second nighttime measurement session, two additional type III signs were assessed. While these latter signs were outfitted with exterior luminaires, the luminaires were not functioning at the time of measurement, so the type III signs were (unintentionally) unlighted.

Luminance measurements were made by positioning the measurement spot of the spectroradiometer onto three backgrounds and three character locations of the signs. Table 1 lists the measured luminances for each sign during each measurement session as well as the luminance contrast calculated using the following equation:

$$C = |L_c - L_b|/\max(L_c, L_b). \quad (2)$$

In Eq. 2, C is the luminance contrast, L_c is the luminance of the characters (in cd/m²), and L_b is the luminance of the background (in cd/m²).

Observation of the values in Table 1 shows that the luminances of the signs were generally much lower during the second nighttime session than during the first nighttime session, although the luminance contrast values were moderately correlated with two nighttime sessions (Fig. 1). It was observed during the second nighttime session that the vehicle used for measurements had headlamps with very cloudy lenses; the lower luminance values from this session are consistent with the lower expected light output of these headlamps. These lower luminances would not be expected to reduce the luminance contrast, since both the sign background and characters would have lower luminances.

Another observation from Table 1 is that the mean luminance contrast for the daytime session (mean 0.66) is substantially lower than both nighttime sessions (mean 0.78). Such differences would not necessarily be expected since the luminance contrast is a function of the ratio of the reflectances of the green and white materials, which should not change significantly from nighttime to daytime. An explanation for this difference is the possibility of scattered light in the telephoto lens of the spectroradiometer. Indeed, if a luminance of 300 cd/m² was subtracted from both the background and character luminances for the daytime measurements in Table 1, the resulting luminance contrasts would average 0.78 as they did during the nighttime sessions. Assuming the daytime sky luminance of 8000 cd/m² (Rea 2000), this corresponds to an average scatter of less than 4% of the overall luminance. Using 2 cd/m² as a representative value for the luminous conditions in urban nighttime environments (Li *et al.* 2006), the nighttime luminance values in Table 1 are probably higher in no more than 0.08 cd/m² owing to scattered light. This amount is quite small compared to the nighttime luminances in this table, and therefore, the values from Table 1 are used in

Table 1. Mean luminances (and standard deviations) of the backgrounds and characters for signs measured during each session

Measurement session	Sign and type	Background luminance, cd/m² (std. dev.)	Character luminance, cd/m² (std. dev.)	Luminance contrast
Nighttime 1	#1 – IX	3.4 (0.7)	19.7 (3.1)	0.83
Nighttime 1	#2 – IX	1.4 (0.1)	7.4 (0.4)	0.81
Nighttime 1	#3 – IX	1.6 (0.2)	9.6 (3.3)	0.83
Nighttime 1	#4 – IX	0.9 (0.1)	5.0 (1.4)	0.81
Nighttime 1	#5 – $VIII_a$	6.0 (0.1)	27.0 (1.1)	0.78
Nighttime 1	#6 – $VIII_a$	6.9 (2.3)	26.9 (5.1)	0.75
Nighttime 1	#7– proposed XI	6.9 (0.6)	37.4 (6.4)	0.81
Nighttime 1	#8 – $VIII_b$	2.5 (0.8)	9.6 (0.4)	0.73
Nighttime 1	#9 – $VIII_b$	4.9 (1.6)	15.9 (1.2)	0.70
Nighttime 2	#1 – IX	2.5 (0.7)	12.1 (3.6)	0.79
Nighttime 2	#2 – IX	0.8 (0.2)	4.3 (0.4)	0.83
Nighttime 2	#3 – IX	0.8 (0.1)	5.1 (1.4)	0.83
Nighttime 2	#4 – IX	0.5 (0.1)	3.4 (0.8)	0.84
Nighttime 2	#5 – $VIII_a$	2.1 (0.4)	9.4 (0.7)	0.78
Nighttime 2	#6 – $VIII_a$	1.9 (0.1)	10.1 (0.3)	0.81
Nighttime 2	#7 – proposed XI	2.3 (0.7)	10.9 (2.4)	0.79
Nighttime 2	#8 – $VIII_b$	3.6 (0.7)	14.3 (3.2)	0.74
Nighttime 2	#9 – $VIII_b$	3.4 (0.5)	15.7 (2.9)	0.79
Nighttime 2	#10 – III	1.3 (0.3)	6.7 (3.7)	0.78
Nighttime 2	#11 – III	0.5 (0.1)	2.8 (0.4)	0.83
Daytime	#1 – IX	540 (24)	1 574 (24)	0.66
Daytime	#2 – IX	501 (17)	1 225 (44)	0.59
Daytime	#3 – IX	468 (50)	1 243 (31)	0.62
Daytime	#4 – IX	393 (10)	1 013 (5)	0.61
Daytime	#5 – $VIII_a$	483 (16)	1 157 (75)	0.58
Daytime	#6 – $VIII_a$	497 (13)	1 212 (43)	0.59
Daytime	#7 – proposed XI	806 (119)	1 678 (144)	0.52
Daytime	#8 – $VIII_b$	995 (6)	3 492 (1)	0.71
Daytime	#9 – $VIII_b$	988 (32)	3 878 (226)	0.74
Daytime	#10 – III	540 (6)	1 103 (65)	0.51
Daytime	#11 – III	599 (44)	1 437 (110)	0.58

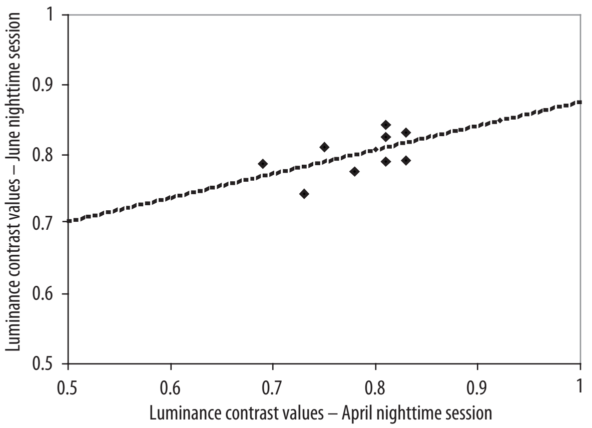

Fig. 1. Comparison of the luminance contrast values from nighttime session 1 (April) with those from session 2 (June); the values are moderately (r = 0.54) and positively correlated

subsequent analyses of visual performance for nighttime viewing conditions, assuming this amount of scatter can be considered to be negligible.

It should be noted that the nighttime luminance values in Table 1 show significant variations even among the signs constructed form the same materials. For example, signs #1 and #4, both constructed from type IX materials, had background luminances ranging from 0.9 to 3.4 cd/m^2, and from 0.5 to 2.5 cd/m^2, during nighttime sessions 1 and 2, respectively. As stated above, the luminances of retroreflective materials can vary a lot and can be based on factors including the roadway geometry, the location of the signs, the amount of ambient light on the signs at each location, and the traffic density during the measurement period. Therefore, it is not possible to quantify the relative impact of these factors and of the likely decreased headlamp illumination during the nighttime session 2, when interpreting the values in Table 1. It can only be stated that the range of values for each type of sign material demonstrates the range of luminances that can be experienced along this expressway. Certainly, the degree of variation limits the ability to generalize about the legibility of signs constructed from specific materials.

By comparison, we measured the luminance of the same green and white materials used in the signs installed along the expressway under more controlled conditions. NYSDOT provided 30-cm square material samples, which were mounted 100 m ahead of a properly-aimed low-beam halogen headlamp set (General Motors) and 5 m above the ground. The same instrument used during the expressway field measurements was used. The luminance contrast values were calculated from the measured luminances using Eq. 2. These measurements confirm the range of luminance contrasts measured during the nighttime sessions along the expressway. The luminance values of the sign materials were generally between those of the two nighttime sessions in Table 1, consistent with the poor headlamp lens condition during nighttime session 2.

The photometric data in Table 1 were used along with photometric values calculated from the AASHTO (Roadway Lighting Design Guide 2005) guidelines for highway sign lighting, to estimate the legibility of these signs, relative to lighted signs meeting AASHTO recommendations.

3. Legibility analyses

The basis for the legibility analyses is the relative visual performance (RVP) model (Rea and Ouellette 1991). This model provides a basis for calculating the speed and accuracy with which visual information can be processed in order to give a number of input parameters: the size of the visual target, the luminance of the background around the visual target, the luminance contrast between the visual target and its background, and the age of the observer.

The RVP model (Rea and Ouellette 2001) was based on the results of two experiments. In the first one, the response times to flashed targets of varying size and luminance contrast against backgrounds varying in luminance were measured. In the other, the speed and accuracy with which people could perform a numerical verification task consisting of pages which contain two matching columns of twenty five-digit numbers was measured. On each page, anywhere from zero to six of the five-digit numbers contained a single mismatched digit and subjects were instructed to identify these mismatches. This latter task was performed under a range of lighting and luminance contrast conditions. The results of both types of experiments, despite the obvious methodological differences, provided nearly identical data when converted to speed and accuracy of visual processing. RVP is compared to speed and accuracy of a reference condition corresponding to high light levels, high luminance contrast and large size (e.g., reading black 10-point type on white paper under office light levels), which is defined to have an RVP value of 1.0. RVP values close to 1.0 are expected to result in similar speed and accuracy as the reference to the visual task. RVP values of zero correspond to the threshold for legibility or recognition, and negative RVP values correspond to the visual targets that can be detected but not recognized.

When both luminance and luminance contrast are low, visual performance drops precipitously. Once both luminance and luminance contrast are even moderately high, further increases in either luminance or luminance contrast will not result in substantial increases in visual performance. This plateau and escarpment nature of visual performance has been illustrated in many other experiments as well. Rea (1989) suggested that an RVP value of 0.80 might be used as a criterion for adequate visual performance along urban highways.

As it was already mentioned that the size, background luminance, and luminance contrast of the visual target determines its visibility, the age of the observer should be pointed out as well. During adulthood, the human visual system undergoes gradual changes, primarily reductions in the transmittance of light through the lens, and reductions in the pupil eye's size. There is an approximately linear decrease in the amount of light reaching the retina as age increases from 20 to 60 years. Until the age of about 60 or 70 years, these optical changes almost exclusively explain reductions in visibility exhibited by older adults. After this age, neural and other physiological effects begin to contribute to visual deficits as well.

An important consideration in the use of any predictive model of visibility is the degree to which the model has been independently validated. Eklund *et al.* (2001) performed an experiment in which subjects had to correctly identify alphanumeric codes of varying sizes (6 through 16 point text viewed from about 40 cm) printed in varying luminance contrasts (from 0.10 to 0.93) and background luminances (from 8 to 2400 cd/m²). The performance measured in this experiment was very highly correlated with the calculated RVP values.

In a context related to highway signs directly, Goodspeed and Rea (1999) studied the effects of luminance contrast on the ability to identify correctly the orientation of Landolt ring symbols similar in appearance to the letter 'C'. For simulated highway sign displays, subjects had to identify the direction of the gap in the symbol (for a properly oriented 'C' the gap is to the right). Subjects were presented conditions under varying levels of surrounding complexity and luminance contrast. Goodspeed and Rea compared their data to predictions of response time generated by the RVP model, and the RVP model closely predicted the suprathreshold response times measured by Goodspeed and Rea (1999), again reinforcing the ability to make and use predictions from the model.

In addition to the RVP values, the model also provides estimates of the visual processing time required for the visual target under consideration. Lower values of RVP are associated with longer visual response times.

In order to assess the visual performance of the signs measured along the expressway, they were compared to visual performance estimates for lighted signs meeting recommendations for highway sign illumination. The minimum recommended illuminances for highway signs (Roadway Lighting Design Guide 2005) are: 100 lx in areas of a low ambient luminance (rural areas with little or no roadway or commercial lighting); 200 lx in areas of medium ambient luminance (urban areas with roadway and commercial lighting); and 400 lx in areas of a very high ambient luminance (urban areas with the high roadway light levels, commercial signage and illuminated building surfaces).

Information provided by NYSDOT revealed that the measurement location along the expressway was classified as having a medium ambient luminance, so a value of 200 lx was assumed as the illuminance on the sign for the RVP calculations involving lighted signs. The diffuse reflectance of green type III sign material was assumed to be 0.09 based on ASTM D 4956-07:2007 specifications, resulting in a background luminance of 5.73 cd/m², according to Eq. 1. Since the luminance contrast values of all sign materials measured along the expressway were similar, the mean value of 0.78 was used in the RVP calculations for this sign. Finally, the analyses assumed a driver age of 60 years, and a letter height of 40 cm based on information provided by NYSDOT. RVP values for a 40-cm uppercase letter *E* was calculated for all signs.

What is more, the nighttime reference sign condition, which assumed a lighted sign with a background reflectance of 0.09, a luminance contrast of the uppercase *E* of 0.78, and an illuminance of 200 lx on the sign surface, the data in Table 1 were used to calculate visual response times and RVP values for these conditions, which are illustrated in Figs 2–4 (for the daytime measurements, the nighttime reference condition is not illustrated because exterior illumination would not be used during the daytime).

Inspection of the data in Figs 2 and 3 disclose that the calculated RVP values and visual response times for the unlighted signs are quite close to those of the reference conditions assuming illumination to AASHTO (Roadway Lighting Design Guide 2005) recommended levels. In fact, some conditions during nighttime session 1 would result in improved visibility relative to the reference lighted sign condition at 100 m, but none of the conditions in nighttime session 2 were as visible as the reference lighted sign condition. All of the RVP values exceed 0.80, the value suggested by Rea (1989) as a visibility criterion for urban highways.

The visual response times shown in Figs 2–4 provide some utility in understanding the relative differences among the RVP values in these figures. From Fig. 4, for daytime viewing conditions, the average visual response time is 322 ms. The visual response time for the illuminated sign is 366 ms, a difference of 44 ms. In other words, one might expect a 60-year-old observer to take 44 ms longer to process the uppercase visually *E* character on a lighted sign at night than during the daytime. At a driving speed of 80 km/h (22 m/s), 44 ms corresponds to a driving distance of 1.0 m.

For the data from nighttime session 1, the unlighted signs constructed from the newer materials would be expected to result in visual response times between 40 and 87 ms longer than for the average daytime sign (for the most and least visible signs in this set of data, respectively). These times correspond to driving distances from 0.9 to 1.9 m at 80 km/h. The difference in visual response times between daytime and nighttime are greater for nighttime session 2 (when the headlamp illumination was relatively poor): between 53 and 108 ms longer for nighttime than for daytime conditions, corresponding to driving distances from 1.2 to 2.4 m at 80 km/h.

The visual target assumed for the analyses was a single uppercase letter *E*, as described above. The visual task of reading a highway sign involves reading strings of characters to form meaningful words. However, it is unlikely that one simply detects and recognizes single characters in sequence. Shapes of words are also meaningful visual elements for reading (the word 'Street', containing letters with ascenders, has a different shape profile than the word 'Alley', which contains both ascenders and de-

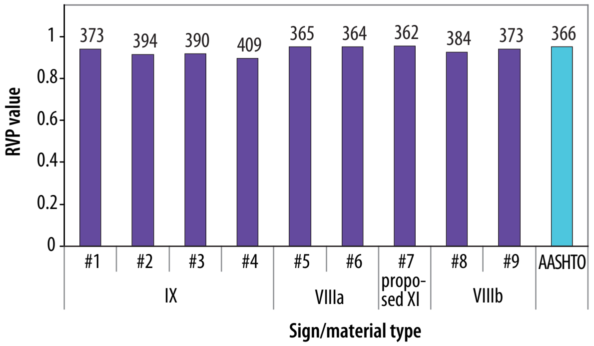

Fig. 2. RVP values for signs measured during nighttime session 1; shown above each vertical bar is the calculated response time (in ms) for each sign

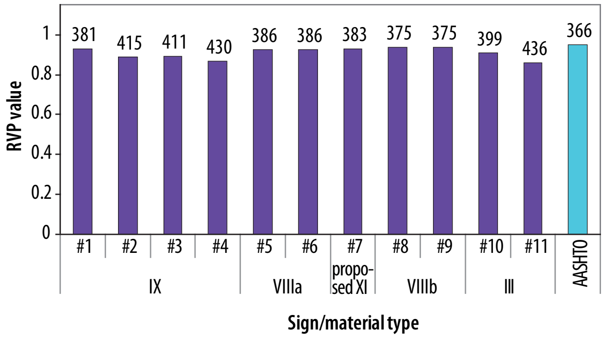

Fig. 3. RVP values for signs measured during nighttime session 2; shown above each vertical bar is the calculated response time (in ms) for each sign

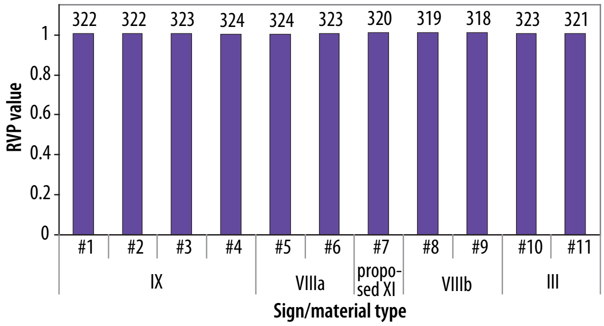

Fig. 4. RVP values for signs measured during the daytime session; shown above each vertical bar is the calculated response time (in ms) for each sign

scenders) and arguably, these shapes, having larger sizes than individual letters, could be relevant visual targets (Gibson and Levin 1978). Individual parts of characters (e.g., the lower horizontal element of the letter *E* that is not present in the letter *F*) are also meaningful visual targets in some cases. Reading speed data from Bailey *et al.* (1993) indicate that the size of a typical character is a reasonable visual target for reading. For the visual response times in Figs 2–4, an equation published by Bailey *et al.* (1993) relating RVP to reading speed (in words/s, for words averaging seven letters in length) estimates that the speed would be 3.1 words/s for daytime conditions, 2.9 words/s for the exterior-lighted sign illuminated to AASHTO (Roadway Lighting Design Guide 2005) recommendations, 2.6 to 2.9 words/s for signs #1 through #9 based on the nighttime session 1 measurements, and 2.5 to 2.8 words/s for signs #1 through #9 based on the nighttime session 2 measurements.

In general, the calculated legibility of the unlighted signs constructed from the newer retroreflective materials as measured in the nighttime sessions along the expressway was close to and sometimes exceeded the legibility that could be expected from exterior illuminated signs. Differences in visual processing time were small, corresponding to 1–2 m of driving distance at a speed of 80 km/h, and probably have little practical significance in terms of one's ability to read and process the information on a sign. Estimated reading speeds for the nighttime sign measurements range from slightly longer to slightly shorter than those for the exterior-lighted signs.

4. Caveats

There are several caveats associated with the visual performance analyses. The measured luminances resulting RVP, and visual response times are associated with a specific viewing distance of 100 m, corresponding to the distance at which photometric measurements were made. (At a distance of 100 m and a speed of 80 km/h there is 4.5 s of driving time to reach the sign.) Because the retroreflective characteristics of different material types differ, the luminances of the signs would certainly differ at different viewing distances, and longer viewing distances might be more appropriate for other locations than the urban expressway in the present study. The headlamps used on the test vehicle contained halogen lamps and were not in especially good condition, especially during the second nighttime session.

Therefore, the luminance data are unlikely to represent conditions that might be experienced as headlamp technologies evolve in the future toward greater use of high-intensity discharge and light-emitting diode light sources. Additionally, as noted earlier, there were luminance variations among signs constructed of the same materials, at least in part, because of variations in roadway slope, sign location, overall traffic patterns and ambient light levels in specific locations.

Finally, all of the visual performance analyses assumed a driver age of 60 years old with corresponding reductions in retinal illuminance relative to younger drivers, but without any special visual health issues. Drivers with early stages of cataract, for example, might be expected to have even lower retinal illuminances and greater scattered light within the eye that would reduce luminance contrast of signs (Rea 2000); the present analyses do not take such drivers into account.

5. Discussion

The measured luminances and luminance contrasts, and the resulting RVP and visual response time values, generally indicate that the unlighted highway signs constructed from new retroreflective materials installed along the expressway were similar, in terms of visual performance, to exterior-lighted signs meeting AASHTO (Roadway Lighting Design Guide 2005) recommendations for sign illumination, when viewed from 100 m away. Specific factors, including location of the signs relative to the vehicles, headlamp condition, ambient illumination and others would affect the actual luminance of a sign's background and characters. All of the RVP values for the unlighted signs exceeded the value of 0.8 suggested as a possible criterion for the urban highways by Rea (1989).

The RVP model (Rea and Ouellette 1991) has been validated in a number of contexts (Bailey *et al.* 1993; Goodspeed and Rea 1999; Eklund *et al.* 2001) including a study of simulated highway sign performance. The model provides a tool for *a priori* predictions of visibility of signs to help to ensure that they are adequately visible, provided the size of the relevant detail, the luminances of the background and characters, and the observer's age can be defined. Several software packages exist that could assist the user in calculating luminance values for retroreflective materials based on geometric inputs and information about vehicle headlamps provided by the user (ERGO2001 User's Guide 2002; User Manual for the Target Visibility… 2004). If such software packages are reasonably accurate (Carlson and Urbanik 2004) and if manufacturers can provide independent retroreflectivity data for their materials, they can be used in conjunction with the RVP model (Rea and Ouellette 1991) to confirm that sign legibility is at or above a specified RVP level (e.g., 0.8) for a range of viewing distances appropriate for a specific roadway location.

For example, if an agency wants to ensure that a sign has sufficient legibility between 50 and 200 m away from the sign, the predicted luminances of the sign background and characters could be calculated for distances between 50 and 200 m in 10-m steps. By calculating the solid angular size of the letters at each distance, and assuming a particular 'design driver' age, RVP values for each distance could be calculated. Such calculations could be performed for specific headlamp types or for a market-weighted average headlamp (Schoettle *et al.* 2002).

In conclusion, even though the visual performance characteristics for these unlighted signs are all quite similar to lighted signs meeting AASHTO (Roadway Lighting Design Guide 2005) recommendations for exterior illumination, it should be noted that people might notice differences in sign appearance before those differences would substantially affect visual performance (Rea 1989; Goodspeed and Rea 1999; Freyssinier *et al.* 2006). Use of RVP in the specification of adequate sign legibility should also be considered alongside subjective sign appearance as well.

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