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16. Abstract

There is some concern that turn signal lamps with clear outer lenses make it difficult in bright, sunny conditions to decide whether the signal is on or not. Two studies were performed. The first study was a survey of current practice in the U.S. with regard to the use of clear-lens turn signal lamps. The main results are that clear outer lenses on rear turn signal lamps are used in about 28% of all vehicle models, while the corresponding percentage for front turn signal lamps is about 70%.

The second study photometrically evaluated, under bright, sunny conditions, both luminance contrast and color contrast between the on and off states for turn signal lamps that use either an amber lens or a clear lens. The results indicate that luminance contrast between the on and off states is greater for lamps using an amber lens. On the other hand, the results indicate that color contrast between the on and off states is greater for lamps using a clear lens. Because luminance contrast is likely to be the primary variable influencing driver performance, these results suggest that using clear-lens turn signal lamps is likely to make it more difficult to determine, in bright, sunny conditions, whether the signal is on or not. However, the magnitude of the decrement in real-world performance with clear-lens signal lamps remains to be ascertained.

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CONTENTS

INTRODUCTION

The desired color of an incandescent turn signal can be achieved by the use of a colored material either in a bulb, in a shield (a cap) surrounding the bulb, or in a lens (either an outer lens or an inner lens in combination with a clear outer lens). (See Figure 1 for a schematic diagram of a turn signal lamp.) Some of the possible approaches for obtaining a colored incandescent turn signal are shown in Table 1.

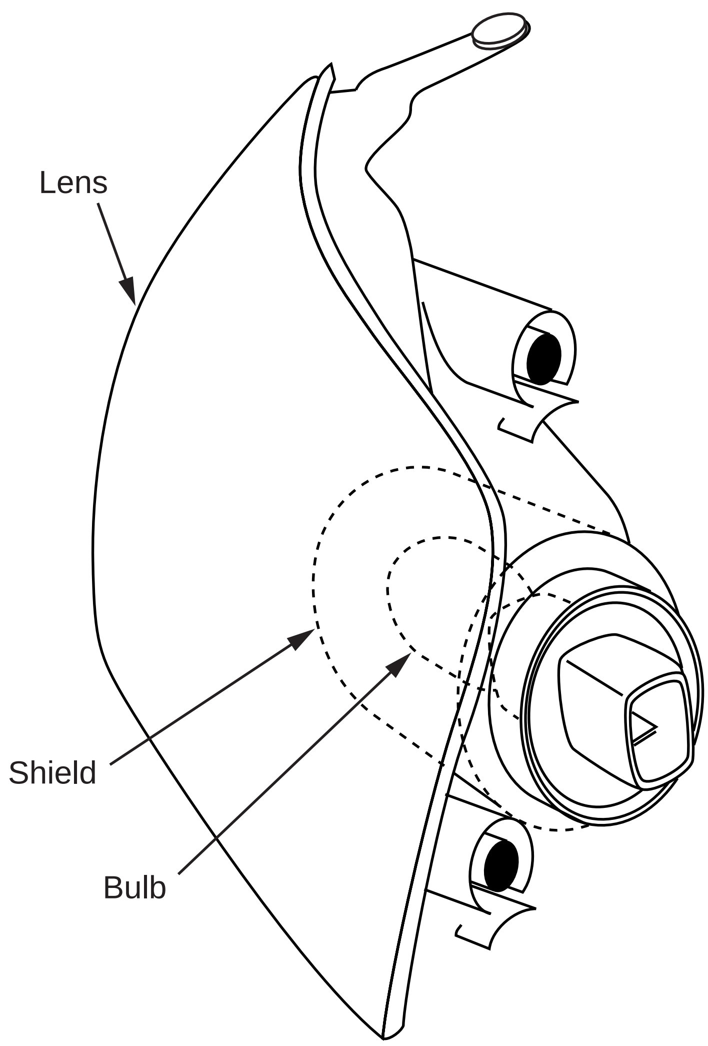

Figure 1. A schematic diagram of a turn signal. (This diagram shows a lamp without an inner lens; in a lamp with both an outer lens and an inner lens the two lenses are usually parallel and adjacent to each other.)

Table 1
Some of the possible approaches for obtaining a colored incandescent turn signal.

Outer lens	Inner lens	Shield	Bulb
Clear	Clear (or none)	Clear (or none)	Colored
Clear	Clear (or none)	Colored	Clear
Clear	Colored	Clear (or none)	Clear
Colored	Clear (or none)	Clear (or none)	Clear

An observer's decision concerning whether a signal is on can be made based on the brightness contrast between the on and off states (the difference in luminance), the corresponding color contrast (the difference in chromaticity), or both.

The effectiveness of clear-lens turn signals for conveying the intended message during bright, sunny conditions has recently been the subject of some debate. The concern is that under such conditions it might be difficult to discern whether or not the signal is on. During bright, sunny conditions the appearance of a clear-lens turn signal lamp in the off state can be similar to that in the on state.

The present research was designed to provide some background information concerning the potential problems with clear-lens turn signals. Two studies were performed. The first study consisted of a survey of current practice in the U.S. with regard to the use of clear-lens turn signal lamps. The second study photometrically evaluated, under bright, sunny conditions, both luminance and color contrasts between the on and off states for different types of turn signal lamps.

STUDY 1: A SURVEY OF CURRENT PRACTICE IN THE U.S.

Method

Information about the construction of rear and front turn signal lamps was obtained by examining a sample of 86 vehicles made by 16 manufacturers (Acura, Audi, BMW, Chrysler, Ford, GM, Honda, Hyundai, Mazda, Mercedes-Benz, Mitsubishi, Nissan, Porsche, Toyota, Volvo, and VW). All of the vehicles were 1997 models. The observations were made at automobile dealerships by a vehicle-lighting engineer with nine years of lighting experience.

Results

A breakdown by the type of outer lens is shown in Table 2 for rear and front lamps. These results indicate that clear outer lenses on rear turn signal lamps are used in about 28% of all vehicle models, while the corresponding percentage for front turn signal lamps is about 70%. More detailed information about lamp color and construction is shown in Tables 3 and 4. This information indicates that when a clear outer lens is used for rear turn signal lamps, the amber color is obtained about equally often by the use of either an amber bulb or an amber inner lens. On the other hand, when a clear outer lens is used for front turn signal lamps, the current choice is overwhelmingly an amber bulb.

Table 2
Percentages of rear and front turn signal lamps by the type of outer lens.

Outer lens	Rear	Front
Colored	72.1	30.2
Clear	27.9	69.8

Table 3
Percentages of rear turn signal lamps by the type of outer lens and color/construction.

Outer lens	Color/Construction	Percent
Colored	Red	30.2
	Amber	41.9
Clear	Inner amber lens	11.6
	Inner amber shield	3.5
	Amber bulb	12.8

Table 4
Percentages of front turn signal lamps by the type of outer lens and color/construction.

Outer lens	Color/Construction	Percent
Colored	Red	--
	Amber	30.2
Clear	Inner amber lens	5.8
	Inner amber shield	4.7
	Amber bulb	59.3

STUDY 2: PHOTOMETRIC EVALUATION OF LUMINANCE CONTRAST AND COLOR CONTRAST

Method

Approach. A Photo Research PR-650 spectrophotometer was used to measure luminance and chromaticity of the lens surface of three turn signal lamps. The measurements for each lamp were taken outdoors, under bright, sunny conditions, both with the lamp on and with the lamp off.

Lamps. The three lamps tested are described in Table 5. All three lamps were of the same size, shape, and optical construction. Each lamp used a parabolic reflector, cylindrical optics in the outer lens, no inner lens, and Fresnel optics in the shield surrounding the bulb. The size of the light-emitting surface was approximately 16 cm by 12 cm. The lamps were designed for the right side of a car. Two of the three lamps were production lamps; the third lamp (the one with an amber bulb) was custom-made for this study. The bulbs used (1157 NA and 1157) contain two filaments; only the main filament of each bulb was used. (Because none of the lamps contained an inner lens, in the remainder of the report we will use "a lens" to stand for "an outer lens.")

Table 5
The lamps used in the study.

Outer lens	Inner lens	Shield	Bulb
Clear	None	Clear	Amber (1157 NA)
Clear	None	Amber	Clear (1157)
Amber	None	Clear	Clear (1157)

Procedure. The experimental setup is shown in Figure 2. We used a large mirror (59 cm by 48 cm) to reflect the sunlight towards the test lamp. Two angles were varied: sun angle and observation angle (both angles with respect to the optical axis of the lamp). Sun angle was varied by the position of the mirror. Two sun angles were used: 5° up, 5° right, and 10° up, 5° right. Observation angle was varied by the position of the photometer. Two observation angles were used: H, V (at the optical axis of the lamp), and H, 20° right. (As indicated above, we used right turn signal lamps. Assuming symmetrical construction of left and right lamps, the observation angles used for right lamps—H, V and H, 20° right—would also correspond to the observation angles of H, V and H, 20° left for left lamps.)

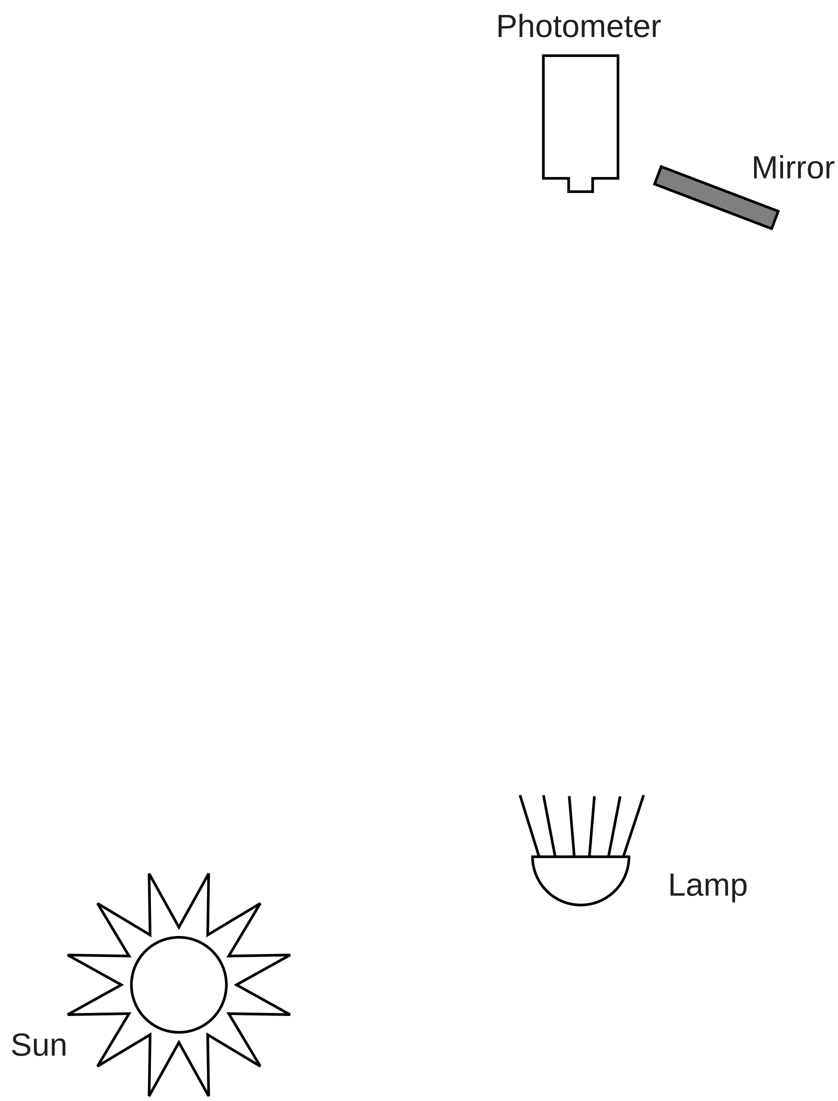

Figure 2. A schematic diagram of the experimental setup.

The distance between the photometer and the lamp (and between the mirror and the lamp) was approximately 5.7 m. The aperture of the photometer was set at 1°, covering most of the light-emitting surface of the lamp. The lamp was energized by a regulated power supply set at 12.8 V.

The measurements were made between 1:30 p.m. and 2:30 p.m. in November 1997. The lamp was facing north, with the sun in the south-southwestern skies. The total illuminance at the vertical surface of the lamp was measured at the beginning and the end of the test session. The two readings were very similar (differing by only 1.8%), and they averaged 76,120 lux.

Two sets of readings were taken for each combination of lamp, sun angle, and observation angle. One reading was with the lamp on, and one was with the lamp off.

The readings consisted of the X, Y, Z tristimulus values. The ratio of the corresponding Y values was used to compute luminance contrast between the on and off states. All three tristimulus values were used to calculate the values in the CIE 1976 (u', v') uniform color space (Wyszecki and Stiles, 1982). The distance between the corresponding locations in the (u', v') uniform color space was used as an index of color contrast between the on and off states.

Results

Luminance contrast. The computed luminance contrasts between the on and off states (on-state luminance divided by off-state luminance) for the various combinations of lamp, sun angle, and observation angle are listed in Table 6. There are three consistent trends evident in Table 6. First, and of primary importance to this study, the luminance contrast is always greatest for the lamp with an amber lens, and smallest for the lamp with an amber bulb. Second, the luminance contrast is always greater for the 10° up, 5° right sun angle than for the 5° up, 5° right sun angle. Third, the luminance contrast is always greater for the H, V observation angle than for the H, 20° right observation angle.

Table 6
Luminance contrast (signal on / signal off) by lamp, sun angle, and observation angle.

Lamp			Sun angle			
			5° up, 5° right		10° up, 5° right	
			Observation angle		Observation angle	
Lens	Shield	Bulb	H, V	H, 20° right	H, V	H, 20° right
Clear	Clear	Amber	2.4	1.9	2.8	2.1
Clear	Amber	Clear	2.6	2.2	3.0	2.4
Amber	Clear	Clear	3.6	2.7	4.0	2.9

Color contrast. Figure 3 presents the (u', v') data for the sun angle of 10° up, 5° right, and the observation angle of H, 20° right; a similar pattern of data was present for the other three combinations of sun angle and observation angle. Two features of the data in Figure 3 are noteworthy. First, in both the on state and the off state, the lamp with an amber lens is closest to the spectrum locus (the perimeter of the color space), followed by the lamp with an amber shield, and the lamp with an amber bulb. Second, for each lamp, the locations for the off states are further away from the spectrum locus than those for the on states.

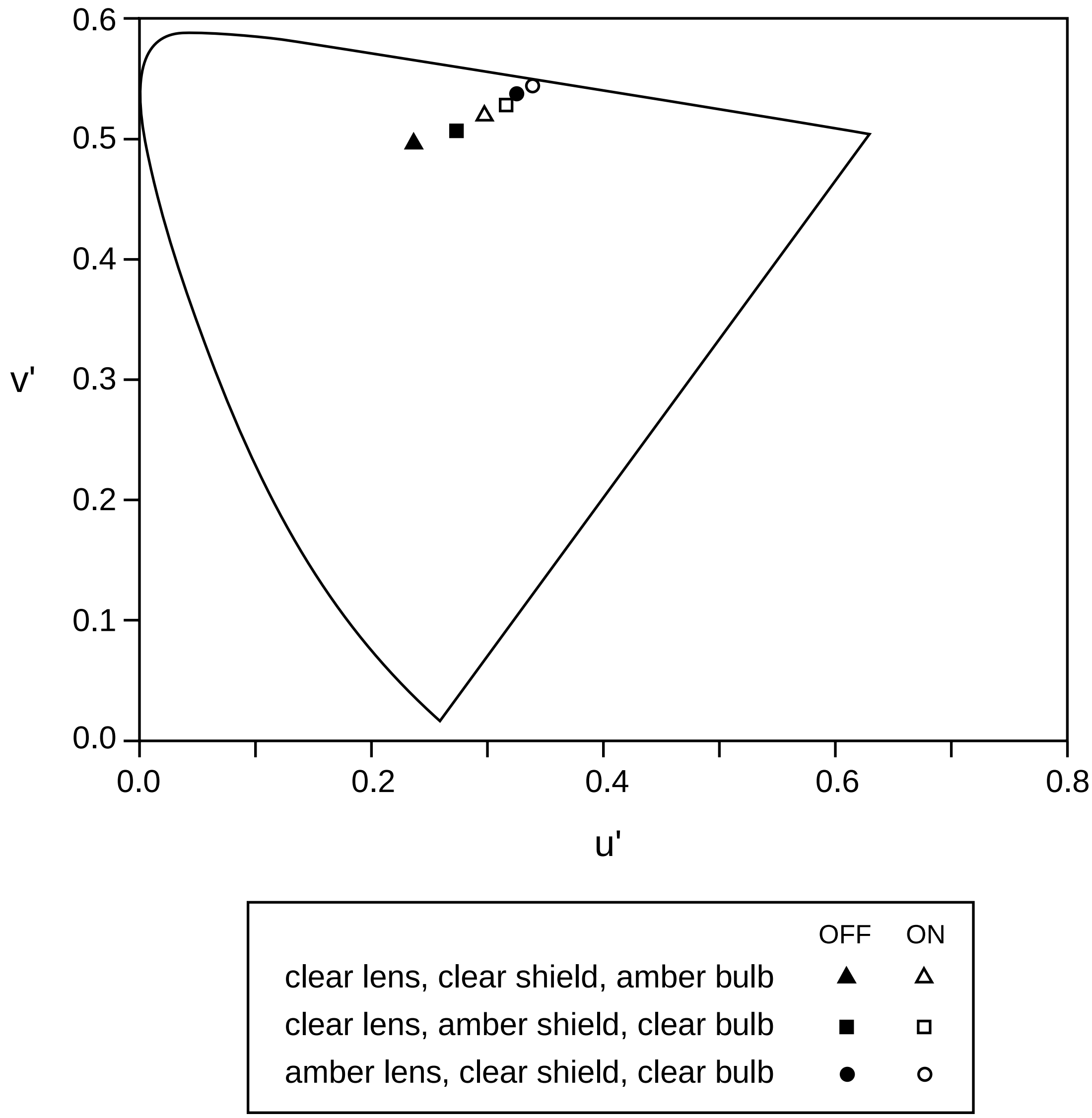

Figure 3. Locations of turn signal lamps in the (u', v') uniform color space by the type of lamp and state. (Sun angle: 10° up, 5° right; observation angle: H, 20° right.)

Table 7 presents the calculated two-dimensional perceptual distances in the (u', v') uniform color space for all four combinations of sun angle and observation angle. There are three consistent trends evident in Table 7. First, opposite to the findings for the luminance contrast, the color contrast is always greatest for the lamp with an amber bulb, and smallest for the lamp with an amber lens. Second, consistent with the luminance-contrast data, the color contrast is always greater for the 10° up, 5° right sun angle than for the 5° up, 5° right sun angle. Third, consistent with the luminance-contrast data, the color contrast is always greater for the H, V observation angle than for the H, 20° right observation angle.

Table 7
Color contrast (distance between the locations in the (u', v') color space between the signal on and off conditions) by lamp, sun angle, and observation angle.

Lamp			Sun angle			
			5° up, 5° right		10° up, 5° right	
Lens	Shield	Bulb	Observation angle		Observation angle	
			H, V	H, 20° right	H, V	H, 20° right
Clear	Clear	Amber	.082	.063	.089	.066
Clear	Amber	Clear	.054	.042	.066	.048
Amber	Clear	Clear	.015	.014	.017	.015

DISCUSSION

Appearance of a signal lamp

The appearance of a signal lamp in bright, sunny conditions is influenced by a variety of factors, including the color of the lens, optical structure of the lens, optical structure of the reflector, positioning of the bulb, sun angle, and observation angle. The color of the lens is important because the sunlight passes through the lens twice: first on its way into the cavity of the lamp, and then on its way out of the lamp (after one or more reflections inside the cavity). In contrast, not all of the sunlight will pass twice through a shield or a bulb. (The actual proportion will be influenced by the optical structure of the lens, the location of the shield and the bulb with respect to the optical focus of the lamp, and the relative sizes of the lens, shield, and bulb.) Consequently, more incident sunlight will be filtered out by a lamp with a colored lens than a lamp with a clear lens. On the other hand, most of the light that is emitted by the lamp itself passes through the lens (and shield and bulb) only once. Consequently, it is not surprising that the ratio of the on-state luminance to the off-state luminance was greater for the lamp with an amber lens than for either of the two lamps with clear lenses (see Table 6).

The price that is paid for keeping the luminance down in the off state with an amber lens is the change in color contrast: The color of the lamp in the off state is more amber with an amber lens than is the color of the lamps with clear lenses. In other words, the colors of the lamps with clear lenses are more desaturated than the color of the lamp with an amber lens. This is evident in Figure 3, which shows that the location of the lamp with an amber lens in the off state is closer to the spectrum locus (the perimeter) of the (u', v') color space than are the off-state locations of either of the two lamps with clear lenses.

As is evident in Figure 3, the same general trend is also present for the on states of the lamps. However, the color differences among the lamps with amber and clear lenses are smaller in the on states than in the off states. Consequently, the resultant distance in the (u', v') uniform color space is smaller for the lamp with an amber lens than for either of the two lamps with clear lenses.

The patterns of the results for luminance contrast and color contrast are summarized in Table 8. The amber-lens lamp is best for luminance contrast, but it is worst for color contrast. Conversely, the amber-bulb lamp is best for color contrast, but it is worst for luminance contrast.

Table 8
Rank ordering of the lamps on luminance contrast and color contrast.

Lamp	Luminance contrast	Color contrast
Clear lens, clear shield, amber bulb	Smallest	Largest
Clear lens, amber shield, clear bulb	Medium	Medium
Amber lens, clear shield, clear bulb	Largest	Smallest

Luminance contrast vs. color contrast

The fact that none of the lamps is superior to the others on both luminance contrast and color contrast leads to the following question: What is more important, luminance contrast or color contrast? Presumably a big difference in either one would be more important than a small difference in the other. But we do not know whether the gain in color contrast with clear lenses is small or large relative to the loss in luminance contrast. Thus, this is an empirical question, deserving a formal study. At the same time, however, there is an a priori consideration that strongly favors the importance of luminance contrast. Cones, the color-sensitive retinal cells, are found primarily in the fovea, and their density decreases with an increase in eccentricity (e.g., Dawson, 1976). Consequently, color sensitivity decreases as the eccentricity of the stimulus increases. This fact probably diminishes the practical importance of color contrast in the driving context, because color contrast will only be important for stimuli that a driver is looking directly at, and those stimuli are most likely to be recognized even if they are weak.

Desirable level of luminance contrast

To the extent that luminance contrast is likely to be the primary parameter of the effectiveness of a turn signal, what is a reasonable minimum luminance contrast? In the following paragraphs we will attempt to address this issue by using three different sources of information: basic laboratory studies on luminance threshold, a field study on just noticeable differences for automobile signal lamps, and the current SAE Standard for intensity ratio of signal lamps that provide two different functions.

The data from basic laboratory studies indicate that to detect a luminance increment over a uniform background, the increment needs to be approximately equal to a constant proportion of the background luminance. This relation is know as Weber's Law (e.g., Coren, Porac, and Ward, 1979). Formally, Weber's Law states that $\Delta L = KL$, where ΔL is the magnitude of the increment at threshold, L is the background luminance, and K is a constant. Although the precise value of K depends on a variety of factors, including the duration of the exposure and the age of the observer, a reasonable value for K in the fovea is 0.08 (or 8%) (Teghtsoonian, 1971). In other words, in well-controlled laboratory studies, subjects' threshold for a detectable increment in luminance is about 8% over the background luminance (regardless of the absolute level of the background luminance). The threshold increment can, in turn, be used to estimate the necessary luminance increment for sufficient suprathreshold visibility (or conspicuity). Although there is no general agreement on this issue, there is evidence that an increase in ΔL by at least a factor of 10 over the threshold value is needed for sufficient visibility under demanding conditions (e.g., Adrian, 1993). Using the factor of 10 would result in an increment of about 80%, or a contrast of 1.8 between the stimulus and its background.

Huey, Dekker, and Lyons (1994) investigated the just noticeable differences in the brightness of two simultaneously presented stimuli representing automobile signal lamps. (Two viewing distances were used. Judging from a schematic diagram in the report, the resulting gaps between the two light-emitting surfaces were about 0.2° and 1.0°, respectively.) The results indicate that, on average, subjects required the intensities to differ by about 25% for the stimuli to be noticeably different. If we, again, apply a factor of 10 to move from threshold difference to a reasonable visibility level (Adrian, 1993), we obtain a difference of 250%, or a contrast of 3.5 between the two stimuli.

The SAE standard for turn signal lamps (Society of Automotive Engineers, 1994), and, by reference to the SAE standard, also the current U.S. regulations (Office of the Federal Register, 1996) provide additional guidance for a reasonable luminance contrast. The SAE standard states the following:

> When a tail lamp or parking lamp is combined with the turn signal lamp, the signal lamp shall not be less than three times the luminous intensity (a) of the tail lamp at any test point, or (b) of the parking lamp at any test point on or above horizontal except that at H-V, H-5L, H-5R, and 5U-V, the signal lamp shall be not less than five times the luminous intensity of the tail lamp or parking lamp. (Society of Automotive Engineers, 1994, p. 2)

Although the SAE standard refers to the situation where two signals are being conveyed by the same light-emitting surface, the sun-loading effect under consideration in the present study is somewhat analogous. Consequently, the SAE Standard has potential relevance to the present situation.

In summary, the results of basic laboratory studies, coupled with the use of a factor of 10 between a threshold increment and a reasonable level of suprathreshold visibility, indicate that to achieve a reasonable level of visibility, the luminance contrast between the on and off states for foveal stimuli needs to be at least 1.8. Analogously, field research on just noticeable difference in lamp brightness (coupled, again, with the use of a factor of 10 between threshold and suprathreshold visibility) yield, for stimuli in near periphery, a minimum contrast of 3.5. Finally, the current SAE Standard for signal lamps that use different signals from the same light-emitting surface calls for a contrast of 3 or 5 (depending on the observation angle) between the two signals. Which of these contrasts should we use as a guideline for evaluating the luminance contrast obtained in the present study between the on and off states of turn signals? The minimum contrast derived from laboratory studies is likely to be too small for real-world situations requiring simultaneous performance of another task, such as driving. Therefore, the other two recommendations are more realistic, and they are not that different from each other (3.5 vs. 3 or 5).

The obtained luminance contrasts for the two lamps with clear lenses were all less than the minimum contrast of 3.5 based on field research on just noticeable differences for signal lamp intensities. (The actual contrasts for the four combinations of the sun and the observation angle ranged between 1.9 and 2.8 for the lamp with an amber bulb, and between 2.2 and 3.0 for the lamp with an amber shield; see Table 6.) On the other hand, the obtained contrasts for the lamp with an amber lens (from 2.7 to 4.0) were all relatively near 3.5.

For all lamps and both sun angles, the obtained luminance contrasts (see Table 6) fall short of the values in the SAE standard. This is the case for the H, V observation angle (where the SAE standard calls for a minimum luminance contrast of 5), as well as for the H, 20° right observation angle (where the SAE standard calls for a minimum luminance contrast of 3).

Although the obtained luminance contrasts are all less than the potentially relevant values in the current SAE standard, the luminance contrasts for the lamp with an amber lens are not too far off, especially for the observation angle of H, 20° right. (The contrast ratios are 3.6 and 4.0 vs. 5 for the observation angle of H, V; and 2.7 and 2.9 vs. 3 for the observation angle of H, 20° right.) Using an amber shield reduced the luminance contrasts to values that are between 72 and 83% of those obtained with an amber lens (computed from the data in Table 6). Finally, using an amber bulb reduced the luminance contrasts to values that are between 67 and 72% of those obtained with an amber lens (again computed from the data in Table 6).

The preceding analysis suggest that, regardless of the type of lamps used, bright, sunny conditions can lead to difficulties in determining whether or not a turn signal is on. Furthermore, these difficulties are likely to be more substantial for lamps using a clear outer lens (with an amber shield or an amber bulb).

Conclusions

The obtained reduction in luminance contrast for lamps with clear outer lenses are large enough to make it more difficult to determine, in bright, sunny conditions, whether the signal is on. However, it is uncertain whether the effects of the reduced luminance contrast for lamps with clear lenses are somewhat mitigated by the increased color contrast for these lamps. Furthermore, it is likely that the effects of the color of the outer lens interacts with the lens optics and the reflector optics. These considerations deserve additional study in order to ascertain real-world consequences of the use of clear-lens signal lamps.

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