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REACTION TIME TO CLEAR-LENS TURN SIGNALS UNDER SUN-LOADED CONDITIONS

John M. Sullivan
Michael J. Flannagan

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The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109-2150
U.S.A.

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16. Abstract
The use of clear-lens signal lamps on automobiles, motivated largely by styling considerations, has prompted interest in whether there are any safety consequences associated with these lamps. In a previous report (UMTRI-98-2), it was found that under bright, sunny conditions, luminance contrast between the off and on states of clear-lens turn signal lamps is smaller than for lamps using amber lenses. On the other hand, color contrast between the off and on states is greater with clear-lens turn signals. An experiment was conducted to compare the reaction time of drivers to signal lamps using clear and amber lenses. The results indicate that luminance contrast is the primary characteristic influencing driver performance and that no compensatory advantage appears to be obtained with increases in color contrast. This result is also consistent with evidence from basic research on visual search.

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vehicle signaling, turn signals, lens, clear-lens, sun loading, conspicuity, luminance, color contrast, luminance contrast

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Introduction

Although federal regulations (FMVSS 108) stipulate the color and luminance levels of an energized turn signal lamp, they do not specify how a lamp should appear in its off state. In darkness, the off states of any two lamps are identical—a red beacon looks just the same as a green flashlight. However, when ambient light is present, the appearance of the off state of a lamp is determined by how light is reflected, scattered, and absorbed by the components of the lamp—the lens, reflector, and bulb. Thus, in daylight, although turned off, a red beacon may still look reddish, and a green flashlight, greenish. This occurs because some quantity of light is being absorbed, scattered, and reflected by the beacon and flashlight components back to the observer.

How the appearance of a lamp is affected by ambient light is important for signal lamps—in particular, turn signals and brake lamps. Both types of lamp convey their information using the contrast between their off and on state—that is, they either blink to indicate a turn, or energize to signal that the brake is being applied. Both lamps provide this function regardless of the ambient light conditions. They operate the same, day or night. Since the appearance of the off state of these lamps depends on ambient light levels—under bright ambient light, they will reflect more light—and the added candlepower supplied by an energized bulb is fixed, there can be significant variation in contrast between the off and on state of the lamps between darkness and daylight. The contrast between the off and on state of a lamp is greatest in the dark, and least in strong sunlight.

Because the color of an amber or red signal lamp is usually produced by a tinted outer lens, the off state and the on state of any two signal lamps have traditionally been similar to each other. That is, despite the variation in luminance contrast between darkness and daylight conditions, most lamps displayed similar color and luminance contrast effects because they reflected ambient light in roughly similar ways. In an amber lamp, when ambient light strikes the tinted lens, some light is reflected back to the observer. Some light is also filtered and passed into the lamp, striking the lamp's reflector, and reflected back out of the lamp through the amber lens, filtering the light a second time. Thus the reflected ambient light is not only diminished in luminance, but it is also selectively filtered so that its color is similar to the color of the energized lamp. Colored lenses enhance the luminance difference between the off and on state of a lamp while reducing the color difference.

New variations in lamp styling and construction change the relationships between the appearance of the off and on states. In some cases, less ambient light is reflected from the lamp so that luminance contrast between the off and on state is increased. For example, brake lamps that are recessed behind strips of body trim restrict the amount of ambient light (particularly direct sunlight) reaching the lamp. They appear either black or the body-color of the vehicle when they are not energized. Consequently, they display both a greater luminance contrast and greater color contrast than conventional brake lamps. The effect of this contrast enhancement on reaction time appears small, albeit reliable (Sivak, Flannagan, & Gellatly, 1990) and appears to be related to both the increased luminance contrast and color contrast (Chandra, Sivak, Flannagan, & Traube, 1992). In other cases, luminance contrast is decreased while color contrast is increased. In particular, this has been observed in clear-lens turn-signal lamps (Sivak, Flannagan, Kojima, & Traube, 1998). Unlike a colored lens, a clear lens passes ambient light to the reflector with little absorption either on the way in, or on the way out from the reflector. The off state of a clear-lens signal lamp appears brighter than a lamp with a colored lens because it reflects more ambient light. When energized, the candlepower from the bulb is added to the ambient light already reflected from the lamp. Under bright viewing conditions, the ratio of on-to-off luminance becomes small. The color of a clear-lens signal lamp is produced when either a tinted bulb or clear bulb encased in an amber capsule is energized. When clear lamps are not energized, they take on the chromaticity of the ambient light they reflect, which is normally essentially white daylight. Thus, the lamp shifts from the color of the reflected ambient light when it is off, to the color of the energized bulb when it is turned on, enhancing color contrast.

Although previous research suggests that a reduction in the luminous contrast should increase the time an observer requires to detect the onset of a signal, and that an increase in color contrast should reduce detection time, it is unclear what the net effect of those changes would be for typical real lamps in a daytime roadway setting. It is also unclear whether the particular magnitude of color contrast found with clear-lens signals is sufficiently large to produce an effect comparable to the color contrast found with body-color lamps.

This empirical study complements previous photometric analyses of clear-lens signal lamps under sun-loaded conditions (Sivak et al., 1998) by directly investigating the effects of these lamps on an observer's speed to detect the location of a signal lamp.

Method

Subjects

Twelve paid subjects participated in the study. Six of the subjects were younger (ranging from 20 to 30 years old, with a mean of 22.5) and six were older (ranging from 64 to 71 years old, with a mean 67). Within each age group, half of the subjects were male and half female. All subjects were licensed drivers with normal or corrected to normal vision (20/20 or better), and were color normal based on testing with an Optec 2000 Vision Tester, Stereo Optical Company, and Standard Pseudoisochromatic Plates, Igaku-Shoin.

Stimuli

Subjects viewed a pair of rear amber signal lamps mounted in a rack located 30 m directly in front of them, 0.62 m above the pavement. The lamps were separated horizontally by 1.30 m, measured between the optical axes of the lamps. These dimensions were based on the average headlamp height and separation for passenger cars in the U.S. (Sivak, Flannagan, Budnick, Flannagan, & Kojima, 1996), modified to mimic the position of turn signals flanking interior headlamps. Note that only *passenger-side* signal lamps were used, although the lamps were mounted in a configuration that suggested a normal vehicle front end. This was done to help control for potential differences in the signal lamp beam pattern between passenger- and driver-side lamps.

The lamps were pointed south to maximize the effect of sunlight. The subjects faced north; the line from the subject's location to the midpoint between the two signal lamps was oriented north-south.

Lamps were observed under clear, sunny conditions in one-hour sessions between 10:00 a.m. and 2:00 p.m., when the sun was relatively high in the sky (average horizontal illuminance was 78,000 lux; vertical illuminance 37,500 lux). During the experimental sessions, sun altitude was between 57 and 71 degrees, and solar azimuth ranged between 65 and –68 degrees with respect to a north-south axis.

The three lamps used in this experiment were the same as those described in a previous report (Sivak et al., 1998). They varied with respect to the source of the amber color: In Lamp A, color was produced by an amber bulb (1157NA); in Lamp B, by an amber shield that surrounded a clear bulb (1157); and in Lamp C, by an amber lens that covered a clear bulb and reflector. As previously described (Sivak et al., 1998), the lamps differed in the degree of color and luminous contrast between on and off states, but were the same size, shape, and construction. The bulbs in each lamp contained both high and low-intensity filaments, respectively used for turn signaling and marker functions. Both intensity levels were incorporated into the design.

Lamp Photometry

Luminance and chromaticity were measured for each of the three types of turn signal lamps. The sets of measurements were taken outdoors in bright sunlight: with the lamps off, with the low-intensity filament energized, and with the high-intensity filament energized. Illuminance on the horizontal surface of the pavement between the subject and the lamps averaged 99,300 lux; illuminance on a south-oriented vertical surface between the two signal lamps averaged 57,100 lux. The lamps were powered by a 12.8 V regulated power supply. The photometer (Photo Research PR-650) was positioned at approximately the same viewing height as an observer, with the measurement aperture covering 80% of the lamp. Luminance contrast was calculated as the on-state luminance divided by the off-state luminance (L_{on} / L_{off}), and color contrast was computed as the Euclidean distance between off and on states in the CIE 1976 (u', v') uniform color space. As can be seen in Table 1, the photometry of the high-intensity filaments follows the same basic pattern reported previously: Clear-lens signal lamps show less luminance contrast than those with amber lenses, but greater color contrast. The color contrast is illustrated in Figure 1, and clearly illustrates a smaller chromaticity shift between the off and high-intensity states for the amber-lens signal lamp, compared to the two clear-lens lamps. The clear-lens low-intensity state of the lamps, however, appears to differ little from the off state either in color or luminance. It appears that the quantity of ambient light reflected by the lamps washes out the added candlepower produced by the low-intensity filament.

Table 1.

Luminance contrast and color contrast measurements of different types of turn signal lamps.

Lens	Shield	Bulb	Filament	Luminance Contrast	Color Contrast
Clear	Clear	Amber	Low	1.01	0.003
			High	2.31	0.077
Clear	Amber	Clear	Low	1.03	0.006
			High	2.44	0.064
Amber	Clear	Clear	Low	1.17	0.007
			High	3.27	0.018

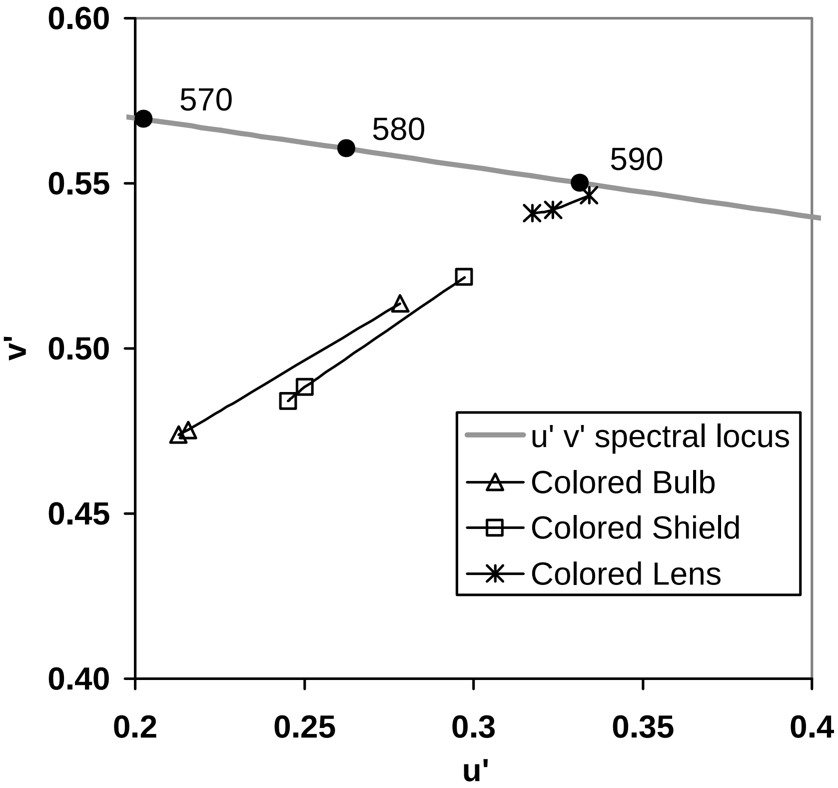

Figure 1. Chromaticity changes in CIE 1976 (*u'*, *v'*) uniform color space for two forms of clear-lens lamps (with colored bulb or colored shield) and the colored-lens lamp. The line for each bulb shows chromaticity with the bulb turned off (lower left point), with the low-intensity filament energized (middle point), and with the high-intensity filament energized (upper right point).

Procedure

Subjects viewed pairs of signal lamps mounted in the lamp rack while seated in a stationary vehicle parked 30 m from the rack. In this position, the observer's eye height was approximately 1.1 m above the pavement. Two of the lamps were used at a time, one mounted in the left position, and one mounted in the right position. An experimenter signaled the start of each trial. At a randomly selected delay (4, 6, or 8 seconds) after the start of an experimental trial, one of the two lamps was switched on using either the low-intensity or high-intensity filament. The lamp remained on for a maximum of 3 seconds, or until the observer identified the lamp by a key press. A left button press indicated the left lamp; a right button press indicated the right lamp. If an observer failed to respond within three seconds of presentation or pushed the wrong button, the trial was tagged as a 'missed' trial or an 'error' trial, respectively, and randomly run later in the block.

The six combinations of lamp pairings (three lamps, used two at a time) were blocked; within each block, the two lamp intensities (high and low), the selected position of the activated lamp (left or right), and three delay intervals (4, 6, and 8 seconds) were randomized. Thus, there were six blocks of lamp pairings (A-B, A-C, B-C, B-A, C-A, C-B). Within each block there were twelve trials (2 intensities x 3 delays x 2 positions). Block orders were counterbalanced across the twelve participants. A randomly selected practice block was run at the beginning of each session.

Results

Reaction time data from practice trials, missed trials (91 trials; 9.5%), and error trials (five trials; 0.5%) were excluded from the analysis. Of the 91 missed trials, 85 occurred during the low-intensity trials, where observers reported some difficulty seeing the energized lamps. An analysis of variance was then performed on the reaction times. The analysis included three within-subject variables: lamp, intensity, and location; and two between-subject variables: sex and age. Not surprisingly, the effect of lamp intensity was significant ($F_{1,8} = 60.6$, $p < .01$), with observers responding faster to the high-intensity filaments (557 msec versus 816 msec). An effect of position was also observed ($F_{1,8} = 10.8$, $p < 0.05$), with faster reaction times for the right than the left position (659 msec versus 723 msec). Of particular interest, an effect of lamp type was observed ($F_{2,16} = 4.55$, $p < 0.05$), such that the lowest reaction times occurred with the colored lens lamps, followed by the clear-lens lamp with a colored shield and the clear-lens lamp with a colored bulb (Figure 2). An interaction between intensity and position was also found ($F_{1,8} = 7.093$, $p < .05$) such that average reaction time to the high-intensity lamps were similar across position (557 msec, left; 558 msec, right), but differed with position at low intensity (890 msec, left; 741 msec, right). No other interaction effects were significant, nor were the between subjects factors, age and sex.

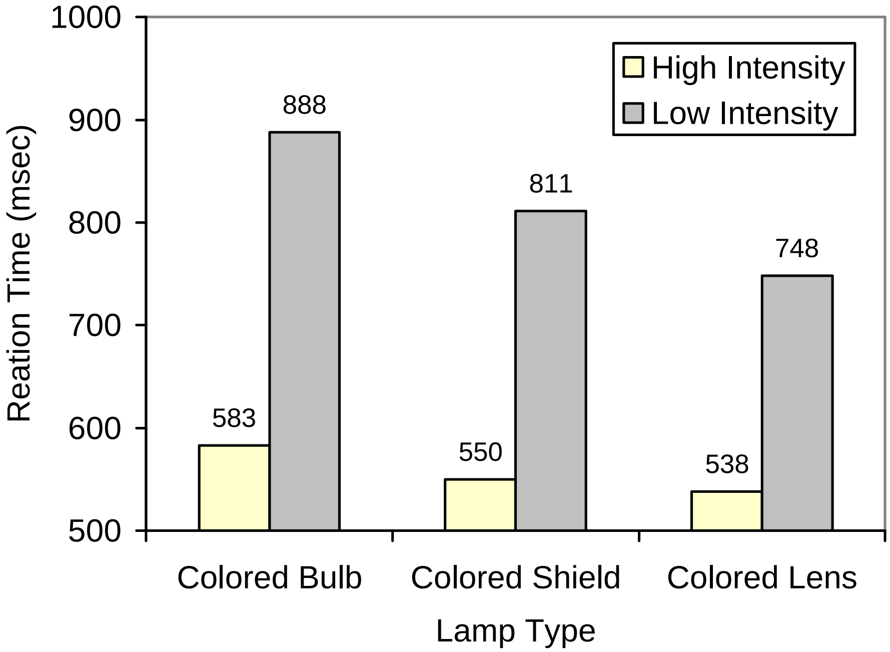

Figure 2. Reaction time as a function of lamp type and intensity level.

Discussion

The analysis of variance data indicate that, despite the surface similarities of each lamp, reaction time to the onset of the turn signal with the amber lens was reliably faster than reaction time to the clear-lens lamps. Apparently the small on/off color contrast of the amber-lens signal lamp compared to similar clear-lens lamps does not substantially influence an observer's reaction time. Instead, the data suggest that luminance contrast plays the most significant role.

The magnitude of the luminance contrast effect also appears to be rather small if one discounts the data from the low-intensity condition. The low-intensity condition is arguably unrealistic—this intensity is only used for nighttime running lights and not at all expected to be easily visible during the daytime. It was introduced primarily to explore effects in another intensity range. Thus, the practical extent of the luminance contrast effect observed with these lamps is about 45 msec with a luminance contrast change of 2.3 to 3.3.

The primacy of luminance contrast over color contrast has been reported before in the literature on visual psychophysics. For example, Nissen and Pokorny (1977) investigated reaction time response to spectral lights matched in luminance. If the luminance level of an achromatic background was dimmer than the target light, reaction time to the light did not vary with wavelength. An effect of wavelength was only observed when the background luminance was equal to the target light. Psychophysical models of color vision have postulated that the human visual system has *chromatic* and *achromatic* visual channels (Nissen, Pokorny, & Smith, 1979). The achromatic channel responds to luminance changes with short response latency and higher temporal resolution; the chromatic channel responds to changes in both luminance and wavelength. Unless the operation of the achromatic channel is neutralized (by requiring responses to equiluminous stimuli), the chromatic visual channel's influence on detection reaction time is almost never observed. Likewise, in studies of attentional capture using visual search paradigms, chromatic change appears to be far less effective in attracting attention than a luminance change. For example, Irwin, Colcombe, Kramer, and Hahn (2000) found that luminance increments elicited reflexive saccadic eye movements, whereas transient color changes did not.

The picture that emerges is that the conspicuity of signal lamps that use luminance contrast (i.e., lamp onset and offset) to mark a braking or turning maneuver is little influenced by color change. In the present study, there appeared to be no measurable advantage in the color change properties of the clear-lens signal lamps. In general, lamps with the lowest on/off luminance contrast—clear-lens signal-lamps—had the longest reaction times. While it is unclear whether the size of this effect is large enough to have a practical safety importance, these results suggest that color changes are unlikely to compensate for reductions in luminance contrast.

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