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Effects of Sweeping, Color and Luminance Distribution on Response to Automotive Stop Lamps

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ABSTRACT

Immediate response to stop lamps when driving is crucial to roadway safety. Previous research has demonstrated that neon and light emitting diode (LED) stop lamps that have a dynamic sweeping luminance distribution can be just as or more effective than standard stop lamps. Sweeping neon and LED lamps with sweep-up times equal to or less than 100 ms resulted in reaction times equal to or shorter than those obtained with a conventional, non-sweeping incandescent stop lamp. At the same time, an LED stop lamp having the same far-field luminous intensity characteristics as the neon lamp, resulted in shorter reaction times than the neon lamp. The LED stop lamp differed from the neon lamp in two important ways. First, its color was different; the LED lamp had a dominant wavelength of about 630 nm, in comparison to the neon lamp with a dominant wavelength of about 615 nm. Second, the luminance distribution of the LED lamp consisted of a series of high-luminance point sources, compared with the neon lamp, which was a diffuse luminous tube having a lower overall luminance. A series of experimental investigations is described with the objective of quantifying the relative impact of color and luminance distribution on visual response of stop lamps. The implications of the color and luminance distribution results of this study will be discussed with respect to stop lamp design and regulations.

BACKGROUND

Center high-mounted stop lamps (CHMSLs) are currently mandated equipment on automobiles in the U.S. [1]. They are meant to provide additional conspicuity to following drivers when a vehicle is decelerating or stopping, which is consistent with the findings of Mortimer [2], who found that increasing the number of light sources in an array on the rear of a vehicle improved the likelihood of prompt detection when that vehicle's brakes were applied.

CHMSLs in the U.S. are designed according to several requirements [1], including:

- a minimum luminous intensity of 25 cd directly outward from the lamp
- the color of the CHMSL must be red, as defined by the Society of Automotive Engineers (SAE)
- the lensed area of the CHMSL must be at least 29 cm^2

The most common light sources used in CHMSLs are incandescent lamps, neon lamps and light emitting diodes (LEDs). There is a growing trend in the use of neon and LED sources in CHMSLs, for a number of reasons: reaction times to CHMSLs with neon and LED light sources are shorter than to incandescent CHMSLs [3,4]; neon and LEDs are generally more efficient at generating light of the appropriate saturated red color than filtered incandescent lamps, reducing the energy use [5]; and these sources also provide flexibility in styling.

Recently, a novel neon light source was described [4] that incorporated a sweeping motion. Upon onset of the lamp, the luminous area of the lamp started in the center of the tube and grew outwardly toward the ends of the tube. The speed of this sweeping motion could range from instantaneous (where the entire lamp turns on, much like a conventional neon lamp) to several seconds.

It was found in an experimental investigation that reaction times were shorter and detection probabilities higher for the sweeping neon CHMSL than for a conventional incandescent CHMSL, for sweep-up times equal to or less than about 100 ms. At the same time, a sweeping LED stop lamp having the same far-field luminous intensity characteristics as the neon lamp resulted in even shorter reaction times and fewer missed signals than the neon lamp for the same sweep-up times [4].

There were two important differences between the sweeping neon and the sweeping LED CHMSL used in that previous investigation [4]. First, the LED CHMSL used LEDs with a dominant wavelength of around 630 nm, while the neon lamp had a dominant wavelength of about 615 nm, although both met the SAE definition of red. Indeed, previous investigations have shown that reaction times to signals of equal luminous intensity are shorter for stimuli with longer dominant wavelengths in the yelloworange-red portion of the visible spectrum. Bullough *et al.* [6] demonstrated that reaction times to simulated traffic signals were shorter for red signals than for yellow signals. Ueno *et al.* [7] similarly showed that for stimuli with dominant wavelengths higher than 580 nm, reaction times were shorter as the dominant wavelength increased.

Second, the sweeping LED CHMSL had very different luminance distribution characteristics from the sweeping neon CHMSL. The neon lamp, when fully illuminated, had a uniform, fairly diffuse luminous area and easily met the spatial requirement for a lighted area of 29 cm^2. On the other hand, the LED CHMSL consisted of an array of 80 5-mm LEDs, and the total luminous area when fully illuminated was less than 16 cm^2, although the luminance of each LED was significantly higher than any portion of the neon lamp. It is altogether possible that the different luminance distribution of the LED CHMSL accounted for part of the difference in reaction times between the LED and neon lamps.

Because the relative contributions, if any, of these two differences in terms of reaction time and missed signals were not well understood, an experiment was designed to more systematically investigate these issues.

METHOD

An experiment was designed to systematically investigate the effects of both dominant wavelength (615 or 630 nm) and luminance distribution (diffuse or point source) on reaction times and missed signals to sweeping neon and LED CHMSLs. Such an experimental design would allow for comparisons among CHMSLs with the same luminance distribution but different dominant wavelengths, and with the same dominant wavelengths but different luminance distributions.

As mentioned above, the LEDs in the CHMSL used in the previous study [4] had a dominant wavelength of 630 nm, in comparison with the neon lamp's dominant wavelength of 615 nm. A second LED CHMSL was constructed with the same luminous intensity characteristics and geometry as the previous CHMSL, but the LEDs in this second CHMSL had a dominant wavelength of 615 nm, similar to that of the neon lamp. In this way, it was possible to control for each of the two factors (dominant wavelength and luminance distribution) separately, as illustrated in Table 1. All of the CHMSLs had similar luminous intensities in the forward direction: 29 cd for the neon CHMSL and 30 cd for each LED CHMSL.

Ideally, a two-by-two experimental design would have been selected, whereby a neon CHMSL with a dominant wavelength of 630 nm would be incorporated into the experiment, but no such neon lamp was available, and controlling the output of the LEDs into a uniform pattern with lenses or diffusers reduced the overall luminance well below that to provide sufficient luminous intensity for a CHMSL.

Luminance Distribution	**Dominant Wavelength**	
	615 nm	630 nm
diffuse	neon	
point source	LED	LED

Table 1. Experimental design.

The apparatus and set-up of the experiment was similar to that reported by Bullough *et al.* [4]. The CHMSLs were mounted at a height of 1 m onto a 1.3 m^2 plywood vertical wall painted light gray. A computer located behind the plywood wall controlled each CHMSL during the experiment. The software allowed the experimenter to enter the lamp display characteristics and number of presentations. A total of 24 adults between the ages of 23 and 60 years participated as subjects for each CHMSL. All had normal color vision as measured with the Ishihara test and far-field visual acuity of at least 20/25.

Subjects sat 6 m from the plywood wall. A metal halide luminaire was mounted near the bottom of the plywood wall to create a background luminance around the CHMSL of approximately 300 cd/m^2. A tracking task using LEDs was mounted 5.2 m from the plywood wall, such that the angle between them from the subject's position was 40^o (see Figure 1). The tracking task was controlled by subjects via a knob on a control box at the subject's seat. The tracking task consisted of a vertical array of red LEDs, with yellow LEDs in the center. A random program switched on several of the red LEDs either above or below the yellow LEDs in the center, and by turning the knob in the appropriate direction, the subject could cause the red LEDs to switch off. When the subject switched off all of the red LEDs, another random setting was selected and the subject repeated the exercise. Subjects were instructed to look toward this tracking task, and not directly at the CHMSLs, during all experiments.

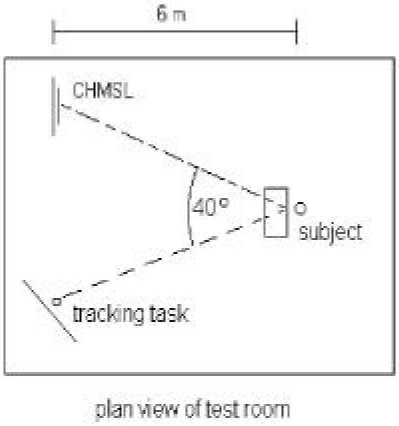

Figure 1. Experimental setup.

During the experiment, subjects continuously performed the tracking task as described above and held down a small switch on the control box. When they detected the onset of the CHMSL in their peripheral vision, they were instructed to release the switch as quickly as possible, and then to re-press the switch.

Five sweep-up times were used for each of the three CHMSLs: ~1 ms (corresponding to simply turning the entire lamp on without sweeping; this gives a total onset time of less than 1 ms), 111 ms, 230 ms, 480 ms and 1000 ms. The last four sweep-up times are spaced approximately equally on a logarithmic scale.

Each subject viewed the onset of the CHMSL 12 times, separated by a random time interval between 3 and 4 seconds. The software recorded the reaction time to onset and the number of missed signals, defined by any reaction times greater than 1 second.

RESULTS

REACTION TIME - The mean reaction times to the three CHMSLs at each sweep-up time are shown in Figure 2. According to a multi-factor analysis of variance, the reaction times for the 615-nm LED CHMSL are significantly shorter than for the neon CHMSL ($p<0.05$), which also had a dominant wavelength near 615 nm. The reaction times for the 615-nm LED CHMSL were consistently longer than for the 630-nm LED CHMSL at every sweeping time but this effect only approached statistical significance ($p>0.05$).

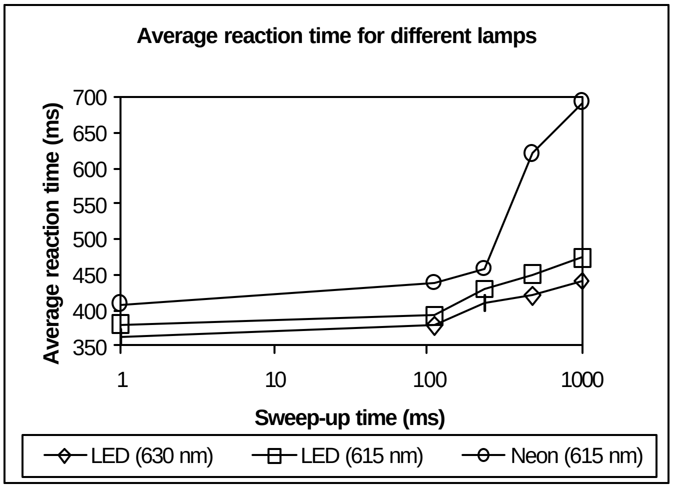

Figure 2. Average reaction times to neon and LED CHMSLs as a function of sweep-up time. Typical standard deviations are about 50 ms.

MISSED SIGNALS - The average percentages of missed signals to the neon and LED CHMSLs at each sweep-up time are shown in Figure 3. Here the differences among each of the three CHMSLs appear to be less evident, although they are largely consistent with the reaction time results shown in Figure 2. There are small differences in the percentage of missed signals between the two LED CHMSLs; the LED CHMSL with a dominant wavelength of 630 nm has slightly fewer misses than the 615-nm LED CHMSL. However, the responses found to the neon CHMSL were unexpected. In particular, at a sweep-up time of 480 ms, there were very few missed signals for the neon lamp, yet at a sweep-up time of 1000 ms, the neon lamp was missed nearly 10% of the time.

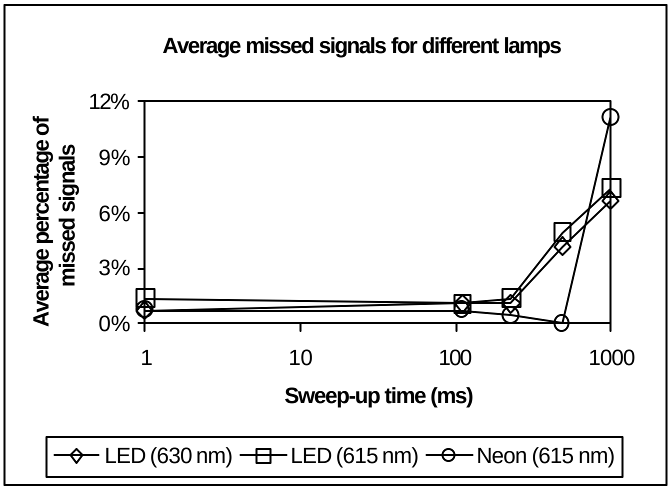

Figure 3. Average percentage of missed signals for the neon and LED CHMSLs as a function of sweep-up time.

DISCUSSION

In a previous experimental investigation of visual response to the sweeping neon CHMSL, reaction times were longer and missed signals were more frequent for the neon CHMSL than for the LED CHMSL, and this effect grew as the sweep-up time increased [4]. With the exception of the percentage of missed signals to the neon CHMSL at a sweep-up time of 480 ms, the results of the present study are largely consistent with the results of that previous study.

As for the relative impacts of dominant wavelength and luminance distribution on visual response, it appears that the effect of dominant wavelength, while consistent at each sweep up time and consistent with previously published results [6,7] using various colored stimuli, is at most quite small. The curves for the LED CHMSLs in Figures 2 and 3 showing reaction times and missed signals track one another quite closely.

In comparison, the 615-nm LED CHMSL and the neon CHMSL demonstrated quantitatively larger differences from one another. Assuming that the missed signals reported here for the neon CHMSL at a sweep-up time of 480 ms is an anomaly (an assumption made more likely when considering the context of previous results [4]), the differences between the neon and 615-nm LED CHMSLs are particular large at the longest sweep-up times. Here, the two lamps being compared have similar dominant wavelengths (near 615 nm) but very different luminance distributions: diffuse for the neon and point-source for the LED CHMSL. Based on this result, it appears likely that the main cause of differences between the neon and LED CHMSLs found previously is primarily a function of luminance distribution, with the effect of dominant wavelength a secondary one. This finding is significant especially in consideration of the fact that the two LED CHMSLs used in the present study do not in fact meet SAE requirements [1] for total luminous area.

Of course, the results also indicate the detrimental impact of increasing sweep-up time on both immediate reaction time and the percentage of missed signals. They are consistent with previous findings [4], which also compared the visual response to an incandescent CHMSL and found that at sweep-up times longer than approximately 100 ms, visual response became worse to the sweeping CHMSLs (LED and neon) than to a conventional, non-sweeping, incandescent signal. Based on this result one might argue that sweeping an LED or neon CHMSL offers no benefits over the simple onset of the same lamp. This argument could be correct for a situation in which a driver is directly behind a vehicle about to stop or slow down, but in situations where a vehicle is parked or stopped on the side of the road, the dynamic aspects of the sweeping motion could provide a more conspicuous signal to other drivers [8,9].

Regardless, the use of longer sweep-up times has an important and potentially valuable consequence for research of this type. Longer sweep-up times tended to increase the magnitude of the differences among the various CHMSLs studied, for both reaction time (Figure 2) and missed signals (Figure 3). This can be especially important for the effects of dominant wavelength, which are relatively small. By incorporating viewing conditions that magnify these differences, it might be easier to determine more precisely how effects like dominant wavelength and luminance distribution impact the visual system.

CONCLUSIONS

The results of this study demonstrate the relative impact of both dominant wavelength and luminance distribution on visual responses to sweeping and non-sweeping CHMSLs under the conditions that were used. In particular, both of these factors appear to influence visual response, but the impact of dominant wavelength, while consistent for a wide range of sweep-up times and compatible with other published literature on wavelength and spectrum [6,7], seems to be a relatively small effect.

The data presented here add to the possibility that the luminance distribution of a CHMSL is an important factor in the resulting visual response. Even though the neon CHMSL and the 615-nm LED CHMSL had similar dominant wavelengths and provided nearly the same luminous intensity, reaction times to the neon CHMSL were consistently and significantly longer than to the LED CHMSL. It does appear that an array of small point sources can be more effective than an equivalent (here, equivalence is defined in terms of luminous intensity in the forward direction) diffuse source at eliciting rapid visual responses.

Certainly, the preliminary results presented here need to be extended to additional viewing conditions and geometries, but if true, they call into question the necessity of a 29 cm^2 luminous area requirement [1] for CHMSLs. The LED CHMSLs in the present study have a total luminous area of 16 cm^2, yet the same lamps appear to result in superior visual performance. This type of point-source distribution is a common feature of many signal products using LEDs and other miniature lamps in arrays. Certainly, there are limits to how small an array could be before it might itself become a glare source, for example. Future research should explore the tradeoffs between luminance, luminous area and luminous intensity in terms of visual response to signals.

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REFERENCES

1. Society of Automotive Engineers. 1999. *Ground Vehicle Lighting Standards Manual*, HS-34. Warrendale, PA: Society of Automotive Engineers.
2. Mortimer, R. G. 1969. Requirements for automobile exterior lighting. In *Visual Factors in Transportation Systems*. Washington, DC: National Research Council.
3. Sivak, M., M. J. Flannagan, T. Sato, E. C. Traube and M. Aoki. 1994. Reaction times to neon, LED, and fast incandescent brake lamps. *Ergonomics* 37(6): 989.
4. Bullough, J. D., J. Van Derlofske and H. Yan. 2001. Evaluation of automotive stop lamps using incandescent and sweeping neon and LED light sources (SAE paper number 2001-01-0301). In *Lighting Technology Developments for Automobiles*, SP-1595. Warrendale, PA: Society of Automotive Engineers.
5. Conway, K. M. and J. D. Bullough. 1999. Will LEDs transform traffic signals as they have exit signs? *Proceedings of the Illuminating Engineering Society of North America Annual Conference*, New Orleans, LA, August 9-11. New York, NY: Illuminating Engineering Society of North America.

6. Bullough, J. D., P. R. Boyce, A. Bierman, K. M. Conway, K. Huang, C. P. O'Rourke, C. M. Hunter and A. Nakata. 2001. Response to simulated traffic signals using light-emitting diodes and incandescent sources. *Transportation Research Record* (1724): 39.
7. Ueno, T., J. Pokorny and V. C. Smith. 1985. Reaction times to chromatic stimuli. *Vision Research* 25: 1623-1627.
8. Bartley, S. H. 1938. Subjective brightness in relation to flash rate and the light-dark ratio. *Journal of Experimental Psychology* 23(3): 313.
9. Bartley, S. H. 1951. Intermittent photic stimulation at marginal intensity levels. *Journal of Psychology* 32: 217.

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