SAE TECHNICAL
PAPER SERIES

2001-01-0301

Evaluation of Automotive Stop Lamps Using Incandescent and Sweeping Neon and LED Light Sources

John D. Bullough, John Van Derlofske and Hua Yan
Transportation Lighting Group, Lighting Research Center, Rensselaer Polytechnic Institute

Reprinted From: Lighting Technology Developments for Automobiles
(SP–1595)

The Engineering Society
For Advancing Mobility
Land Sea Air and Space®
INTERNATIONAL

SAE 2001 World Congress
Detroit, Michigan
March 5-8, 2001

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A.   Tel: (724) 776-4841 Fax: (724) 776-5760

The appearance of this ISSN code at the bottom of this page indicates SAE's consent that copies of the paper may be made for personal or internal use of specific clients. This consent is given on the condition, however, that the copier pay a $7.00 per article copy fee through the Copyright Clearance Center, Inc. Operations Center, 222 Rosewood Drive, Danvers, MA 01923 for copying beyond that permitted by Sections 107 or 108 of the U.S. Copyright Law. This consent does not extend to other kinds of copying such as copying for general distribution, for advertising or promotional purposes, for creating new collective works, or for resale.

SAE routinely stocks printed papers for a period of three years following date of publication. Direct your orders to SAE Customer Sales and Satisfaction Department.

Quantity reprint rates can be obtained from the Customer Sales and Satisfaction Department.

To request permission to reprint a technical paper or permission to use copyrighted SAE publications in other works, contact the SAE Publications Group.

GLOBAL MOBILITY DATABASE

All SAE papers, standards, and selected books are abstracted and indexed in the Global Mobility Database

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

ISSN 0148-7191
Copyright 2001 Society of Automotive Engineers, Inc.

Positions and opinions advanced in this paper are those of the author(s) and not necessarily those of SAE. The author is solely responsible for the content of the paper. A process is available by which discussions will be printed with the paper if it is published in SAE Transactions. For permission to publish this paper in full or in part, contact the SAE Publications Group.

Persons wishing to submit papers to be considered for presentation or publication through SAE should send the manuscript or a 300 word abstract of a proposed manuscript to: Secretary, Engineering Meetings Board, SAE.

Printed in USA

2001-01-0301

Evaluation of Automotive Stop Lamps Using Incandescent and Sweeping Neon and LED Light Sources

John D. Bullough, John Van Derlofske and Hua Yan
Transportation Lighting Group, Lighting Research Center, Rensselaer Polytechnic Institute

ABSTRACT

This paper describes a study of visual responses to center high mounted stop lamps (CHMSLs) using a newly developed sweeping neon lamp. This study compares sweeping neon, incandescent, and light-emitting diode (LED) technologies. The incandescent CHMSL was a conventional after-market CHMSL brake light. The sweeping neon CHMSL used a novel controller whereby the luminous signal started at the center of the neon tube and grew in a "sweeping" motion outward toward the ends of the tube at an adjustable rate. The sweeping LED CHMSL had a segmented display simulating the sweeping characteristics of the neon CHMSL. Both the neon and LED CHMSLs had faster onset times than the incandescent CHMSL. Experimental subjects performed a tracking task cognitively similar to driving, and released a flip switch upon detecting the onset of the CHMSLs, which were mounted so as to be seen peripherally. Reaction times and missed signals for incandescent and for sweeping neon and LED CHMSLs are presented for simulated daytime driving conditions. Such data permit comparisons among CHMSL technologies to examine if sweeping neon technology result in any visual benefits, and to optimize signal characteristics for minimizing reaction time and the likelihood of missed signals.

BACKGROUND

Automotive stop lamps are the only means of conveying to drivers of other vehicles that deceleration or stopping is taking place. Because of this, the ability of drivers to detect and respond quickly to stop lamps is critical. The development of center high mounted stop lamps (CHMSLs) provided an opportunity to increase conspicuity for drivers following behind vehicles equipped with them, and they have become standard equipment on all vehicles sold in the United States[1].

More recently, neon lamps and light-emitting diodes (LEDs) have been used as CHMSLs. Neon lamps are particularly suited for varied shapes and configurations, and styling is an increasingly important factor in automotive design. LEDs, too, present many opportunities for styling because of their small size. Additionally, the durability of these solid state sources is advantageous for vehicular lighting systems.

The shorter onset times of neon and LED light sources is another potential benefit over conventional incandescent lamps because reaction times to neon and LED CHMSLs are shorter than reaction times to incandescent CHMSLs[2].

Recently, neon lamp technology that allows the luminous section of the neon tube to "sweep" outward from the center has been developed. Because of literature that has shown that moving objects and light sources have increased conspicuity relative to static lights[3,4], such sources might be suitable for use in automotive brake light applications, where both quick responses and robust detection of peripheral signals are of utmost importance. Because of the design flexibility of LEDs, it is also possible to develop an LED array that simulates the action of the sweeping neon lamp. This paper describes a series of experiments that investigated reaction times and detection probabilities for CHMSLs using incandescent, neon, LED and sweeping neon and LED light sources.

LIGHT SOURCE CHARACTERISTICS

INCANDESCENT - The incandescent CHMSL was a conventional retrofit unit for installation on automobiles without a CHMSL, measuring 17.5 cm in length and with a luminous intensity in the forward direction of 25 cd. The time between application of power (12.8 V dc) and reaching 95% of full light output for the incandescent CHMSL was 85 ms. The (x,y) chromaticity coordinates of the incandescent CHMSL were (0.677,0.317), with a dominant wavelength (using an equal-energy source as a reference) of approximately 615 nm.

SWEEPING NEON - The sweeping neon CHMSL was 79 cm in length. It had a controller whereby five parameters describing the profile of the sweeping motion (which always started in the center of the tube and extended outward) could be specified as a value between 0 and 255:

- starting and ending position of the luminous portion of the lamp (lower values: closer to lamp center, higher values: closer to lamp ends)
- sweep up and sweep down time: (lower values: faster, higher values: slower)
- dwell time (lower values: shorter time, higher values: longer time)

Figure 1 shows the time required for the luminous area to sweep from the center of the lamp to the end, for several different sweep up time (SUT) settings. They show the nearly linear relationship between SUT and also that the luminous area extends at a nearly linear rate across the length of the lamp. Figure 2 shows the linear relationship between the ending position value and the length of the luminous area's maximum length, and that the luminous area is symmetrical around the center of the lamp. The time between application of power to the lamp and 95% of full light output (for the center of the lamp) was less than 1 ms. The luminous intensity in the forward direction with the entire lamp illuminated was 29 cd. The (x,y) chromaticity coordinates of the neon CHMSL were (0.673,0.323), with a dominant wavelength (using an equal-energy source as a reference) of approximately 613 nm.

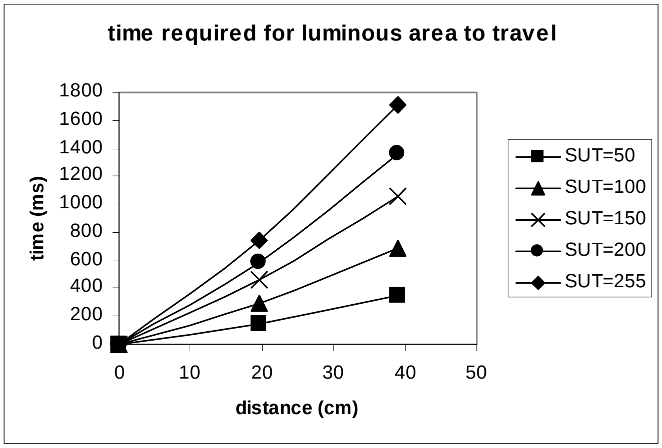

Figure 1. Time required for the luminous area to travel the length of the lamp, for different SUT settings.

SWEEPING LED - The sweeping LED CHMSL was designed to mimic the operation of the sweeping neon lamp. It had the same length and consisted of 80 individual red LEDs mounted approximately 1 cm apart. The LEDs were wired in 16 groups of five so that the sweeping motion was not perfectly continuous, but appeared so from the viewing distances used in the subsequent experiments. Just as with the sweeping neon light source, the sweeping LED could be controlled by providing five inputs corresponding to the starting and ending position of the luminous area, the sweep up and sweep down times, and the dwell time. As with the neon lamp, the time between application of power to the lamp and 95% of full light output was less than 1 ms. The luminous intensity in the forward direction with all of the LEDs energized was 30 cd. The (x,y) chromaticity coordinates of the LED CHMSL were (0.702,0.295), with a dominant wavelength (using an equal-energy source as a reference) of approximately 628 nm.

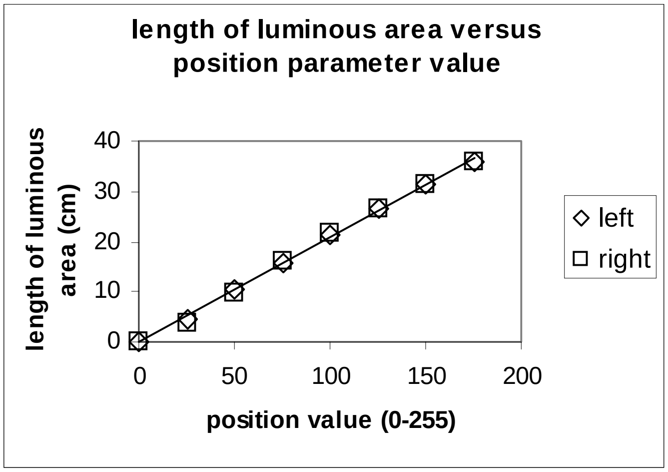

Figure 2. Relationship between ending position value and length of the luminous area on each side of the lamp.

METHOD

To measure visual response to each of the CHMSLs, they were mounted on a 1.3 m square plywood vertical wall painted light gray. The mounting height was 1 m. A computer located behind the plywood wall, running LabView software, controlled each CHMSL during the experiment. The software allowed the experimenter to enter the lamp display characteristics and number of presentations. In all experiments (described below), 24 adults between the ages of 23 and 60 years participated as subjects.

EXPERIMENT 1: INCANDESCENT CHMSL (CLOSE RANGE) - In this experiment, subjects sat 6 m from the plywood wall. A metal halide luminaire was mounted near the bottom of the plywood wall so that its illumination created 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 distance between them from the subject's position was 40^o (see Figure 3). The luminance of the wall behind the tracking task was approximately 50 cd/m^2. The tracking task could be 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.

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.

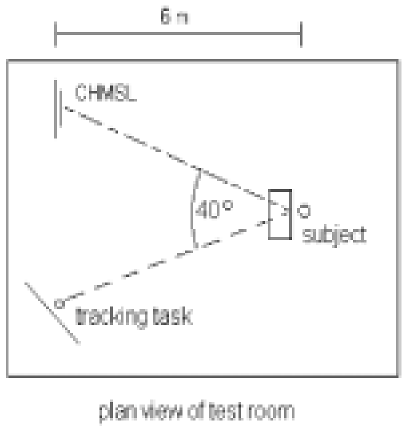

Figure 3. Experimental setup.

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 1000 ms.

EXPERIMENT 2: SWEEPING NEON CHMSL (CLOSE RANGE) - The same apparatus and geometry was used as for Experiment 1. Each of 24 subjects viewed the onset of the CHMSL 36 times, 12 for each of the following three SUT settings:

- 0-ms sweep up time, corresponding to a conventional neon CHMSL that turns on within 1 ms
- 111-ms sweep up time
- 1000-ms sweep up time

For all three settings the lamp was set to start in the center of the tube and sweep to the ends of the tube. The 111-ms time corresponds to a temporal frequency of about 9 Hz, to which the human visual system is most sensitive[1]. The 1000-ms sweep up time was selected as one that is significantly slower than 111 ms. The computer software recorded reaction times and missed signals.

EXPERIMENT 3: SWEEPING NEON CHMSL (CLOSE RANGE, ADDITIONAL SWEEP PARAMETERS) - This experiment was very similar to Experiment 2, except that different SUT settings were used, in order to understand the response to CHMSLs having sweep up times between 111 and 1000 ms. Each of 24 subjects viewed the onset of the CHMSL 36 times, 12 for each of the following SUT settings:

- 0-ms sweep up time, corresponding to a conventional neon CHMSL that turns on within 1 ms
- 230-ms sweep up time
- 480-ms sweep up time

These two sweep up times are spaced about equally on a logarithmic scale between 111 and 1000 ms.

EXPERIMENT 4: SWEEPING NEON CHMSL (LONG RANGE) - Experiments 1 through 3, because of the distances and visual angles involved, may be more representative of viewing vehicles in adjacent lanes of multilane roadways. In addition, luminances of surfaces outdoors on clear days can easily exceed 1000 cd/m^2. To more closely simulate viewing conditions that might be experienced in a single lane roadway, and to determine the sensitivity of the experimental protocol to viewing angle, distance and background luminance, an experiment was conducted using the sweeping neon lamp with the same SUT settings as in Experiment 2, but with a viewing distance of 12 m, with the tracking task mounted 8.5^o from the CHMSL, and with the plywood wall illuminated by an electrodeless sulfur lamp that produced a background luminance around the CHMSL of 2500 cd/m^2. Each of 24 subjects aged between 23 and 60 years participated in this experiment.

EXPERIMENT 5: SWEEPING LED CHMSL (CLOSE RANGE) - The last experiment tested visual response to the sweeping LED CHMSL. The experimental conditions and characteristics of the subjects in Experiment 2 were all replicated, except for the CHMSL.

RESULTS

The results of all experiments are summarized in Table 1.

CHMSL type (viewing condition)	**Sweep time, ms**	**Mean reaction time (standard deviation), ms**	**Missed signals, percent**
incandescent (close)	-	420 (87)	3.5%
neon (close)	0	386 (101)	2.7%
neon (close)	111	421 (95)	2.8%
neon (close)	230	460 (99)	3.1%
neon (close)	480	566 (111)	3.9%
neon (close)	1000	661 (133)	25.3%
LED (close)	0	350 (62)	1.0%
LED (close)	111	357 (81)	0.3%
LED (close)	1000	394 (91)	2.4%
neon (far)	0	409 (95)	0.7%
neon (far)	111	442 (84)	0.7%
neon (far)	1000	805 (98)	12.0%

Table 1. Mean reaction times (and mean standard deviations) and missed signal percentages for all experimental conditions. Standard deviation is the mean of each subject's standard deviation.

REACTION TIME - Figure 4 shows the mean reaction times to the CHMSL onset for all experiments, plotted as a function of sweep time. The relationship between sweep time and reaction time appears to follow similar trends for both the close and the far viewing conditions, with small increases in reaction time as sweep time is increased from 0 to 111 ms, and a much larger increase for sweep times of 1000 ms. The effect of neon sweep time on reaction time was statistically significant for both viewing distances, according to one-way repeated-measures analyses of variance ($p<0.05$).

The reaction time results also show that the mean reaction times to the neon and LED CHMSLs, for a sweep time of 0 ms, were shorter than to the incandescent CHMSL, as was found by Sivak *et al.*[2], although these differences were not found to be statistically significant using t-tests ($p>0.05$).

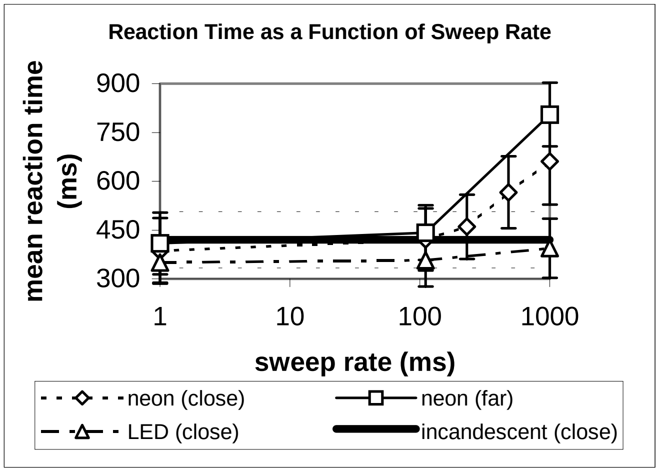

Figure 4. Reaction times to the incandescent, sweeping neon (close and far viewing distances), and sweeping LED CHMSLs, as a function of sweep time. The horizontal lines show the mean reaction time (dotted lines show standard deviations) to the incandescent CHMSL.

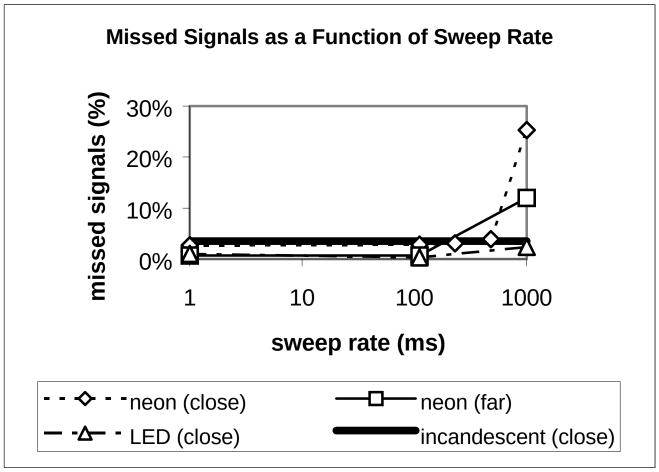

Figure 5. Missed signals for the incandescent, sweeping neon (close and far viewing distances), and sweeping LED CHMSLs, as a function of sweep time.

MISSED SIGNALS - The percentages of missed signals (shown in Figure 5) follow similar trends as the reaction time results. Misses were rare except for sweep times of 1000 ms.

DISCUSSION

Reaction times to the LED CHMSL were shorter than those to the neon CHMSL for the close viewing conditions, even though these lamps had similar output characteristics. Two factors might potentially explain these differences: the spatial characteristics of the LED CHMSL's sweeping motion, and the different spectral characteristics of the CHMSLs.

As noted above, the LEDs in the sweeping LED CHMSL were wired together in 16 groups of five, and upon application of power, the first group of LEDs would be illuminated and might have provided a strong enough stimulus to observers to be detected immediately. In comparison, the sweeping neon CHMSL began to be illuminated gradually from the center of the lamp tube, and might not be detected immediately. Furthermore, the LED CHMSL consisted of high-luminance point sources that might have provided stronger stimuli than the more diffuse neon lamp.

As for the spectral characteristics of the lamps, the longer dominant wavelength of the LED CHMSL (~628 nm) in comparison to the incandescent (~615 nm) and neon (~613 nm) CHMSLs could have resulted in shorter reaction times. Such results are consistent with Bullough *et al.*[5] and Ueno *et al.*[6], who all found that reaction times to nearly monochromatic light sources against high-luminance backgrounds were shorter for long-wavelength ("red") stimuli than for middle-wavelength ("yellow") stimuli. The differences between the LED and other CHMSLs used in this study might partially explain the shorter reaction times obtained with the LED CHMSL.

CONCLUSION

The results of the series of experiments described in this paper show the impact of a novel parameter, sweep time, on reaction time and percentage of missed detections to the onset of the signal. Because of their shorter onset times, both neon and LED sources appear to result in shorter reaction times than incandescent sources, although reaction time and the likelihood of missing a signal seems to increase with an increase in sweep time. It appears, based on the results found in this study, that neon and LED CHMSLs with sweep times of around 111 ms result in reaction times that are no higher and missed signal percentages that are no larger than those found with incandescent CHMSLs. Such stimuli might also result in increased conspicuity for continually sweeping stimuli, although this study did not investigate that possibility. The shorter reaction times and lower missed signal percentages found with the LED CHMSL might be explained by the manner in which individual LEDs were grouped together, and by the longer dominant wavelength of the LEDs relative to the incandescent and neon sources, although this study did not separate out these potential effects. Opportunities for styling, and the potential to easily create dynamic effects such as sweeping with neon and LED technologies will spur continued development of CHMSLs and other signage and signalling applications using these light sources.

ACKNOWLEDGMENTS

This work was supported by OSRAM SYLVANIA under the supervision of Harold Rothwell and Jeanne Evans. Richard Pysar and Veeravach Jamjureeruk of the Lighting Research Center (LRC) developed the test apparatus; Nishantha Maliyagoda and Andrew Bierman of the LRC assisted with electrical and photometric measurements.

REFERENCES

1. Rea, M. S. (ed.). 2000. *IESNA Lighting Handbook: Reference and Application*, 9th ed. New York, NY: Illuminating Engineering Society of North America.
2. 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.
3. Bartley, S. H. 1938. Subjective brightness in relation to flash rate and the light-dark ratio. *J. Exp. Psychol.* 23(3): 313.
4. Bartley, S. H. 1951. Intermittent photic stimulation at marginal intensity levels. *J. Psychol.* 32: 217.
5. Bullough, J. D., P. R. Boyce, A. Bierman, K. M. Conway, K. Huang, C. P. O'Rourke, C. M. Hunter and A. Nakata. 2000. Response to simulated traffic signals using light-emitting diode and incandescent sources. *Transport. Res. Rec.* (1724): 39-46.
6. Ueno, T., J. Pokorny and V.C. Smith. 1985. Reaction times to chromatic stimuli. *Vision Res.* 25: 1623-1627.