EVALUATION OF AN LED HIGH-MOUNTED SIGNAL LAMP

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16. Abstract

Two studies are described evaluating high-mounted stop lamps using light-emitting diodes (LED's) compared with conventional incandescent units. The first of these studies obtained ratings from subjects who drove one car and followed another car that was equipped with the test lamps. The results indicate that the subjects generally preferred the LED's to the conventional lamp. Some subjects complained that the LED units were too bright. Most subjects commented on a color and an apparent brightness difference between the LED and incandescent lamps. Few subjects commented on the faster rise time of the LED units.

The second study was a laboratory evaluation of the attention-getting capabilities of LED and incandescent stop lamps. Under all conditions tested subjects responded faster to the LED units. The response time advantage for the LED units increased with more difficult viewing conditions, such as high levels of illumination and long viewing distance.

The results of these investigations are discussed in terms of the applicability of the LED technology to high-mounted stop lamps on motor vehicles.

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INTRODUCTION

Recent advances in technology have made it possible to produce light-emitting diodes (LED's) that have much greater output than those available previously. These devices have enough output so that it is possible, by bundling numbers of them together, to make a high-mounted stop lamp (HMSL) meeting FMVSS 108 specifications.

The technology and advantages of LED-based signal lamps have been fully described by Fujita et al. (1987), and will not be reviewed in detail here. However, certain characteristics are of particular interest to this project. These are:

1. Faster rise-time. Rise-time is defined as the interval between the point at which the unit is energized and when it reaches a given level of output. Figures 1 and 2 show the rise time of the LED and an incandescent source. The rise-time to 90% of full output is about 60 nanoseconds in the case of the LED, while it is about 140 milliseconds in the case of the incandescent source. Thus, the LED lamp should provide a faster indication of a brake application. The gain in response time probably depends to some degree on the level of output from the signal lamp at which the following driver responds. A reasonable estimate of the expected response time advantage of LED lamps may be about 0.14 second.

2. Different lamp shapes. Because an LED lamp is made up of many individual sources, it is possible to fabricate it into a variety of shapes that may be of interest for styling or other reasons, but would be difficult to achieve with conventional bulb technology.

3. Color. LED's emit light in a very narrow portion of the visible spectrum. Because of this they are noticeably redder than automotive signal lamps using incandescent bulbs.

The characteristics mentioned, particularly the first two, led to the project to be described. In particular, there was an interest (1) in determining whether the reaction-time advantage of the LED units would be manifest under a variety of operating conditions, and (2) obtaining subjective opinions of the LED lamps under representative driving conditions.

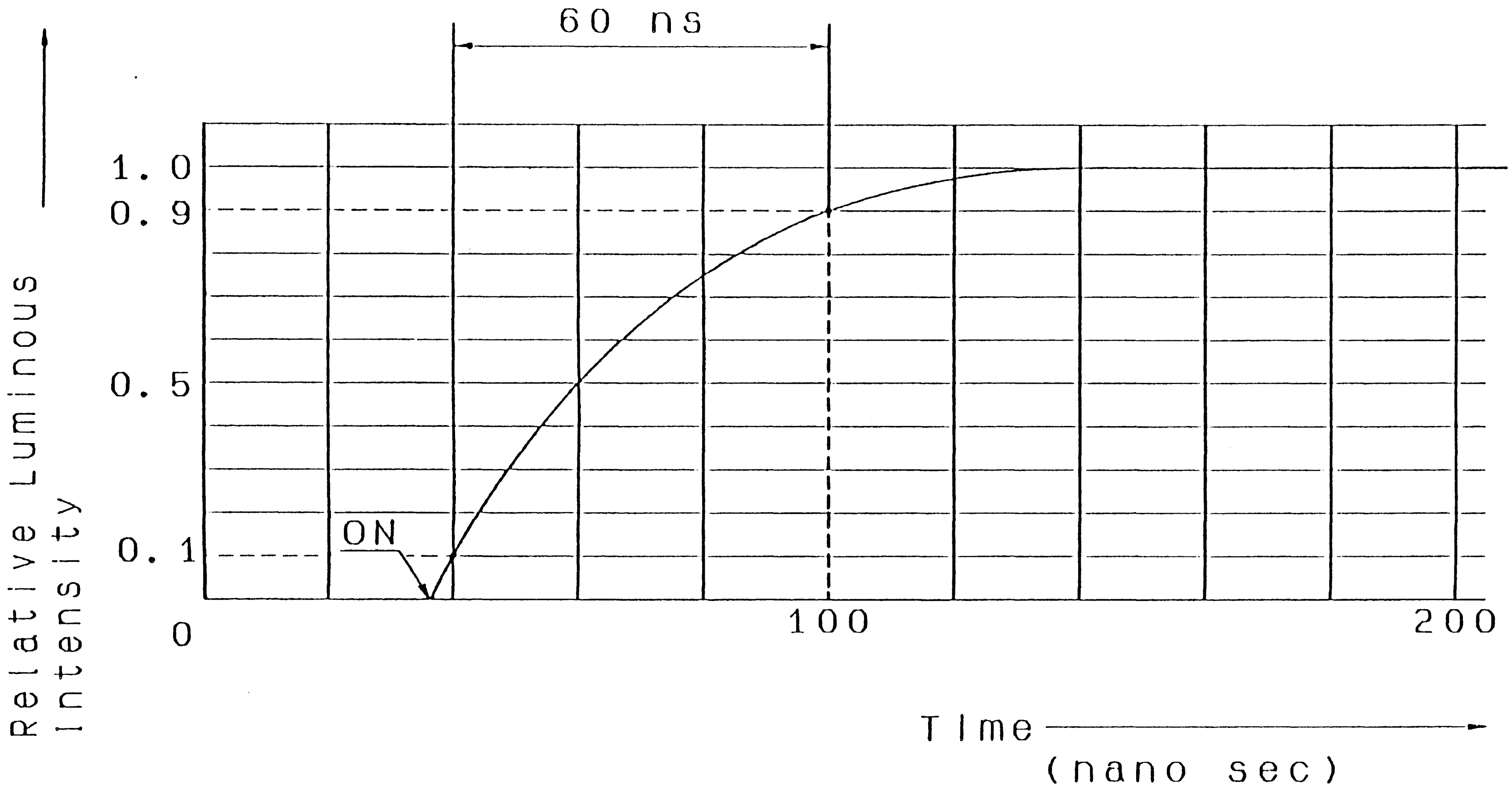

Figure 1. Rise-time characteristic of LED signal lamp.

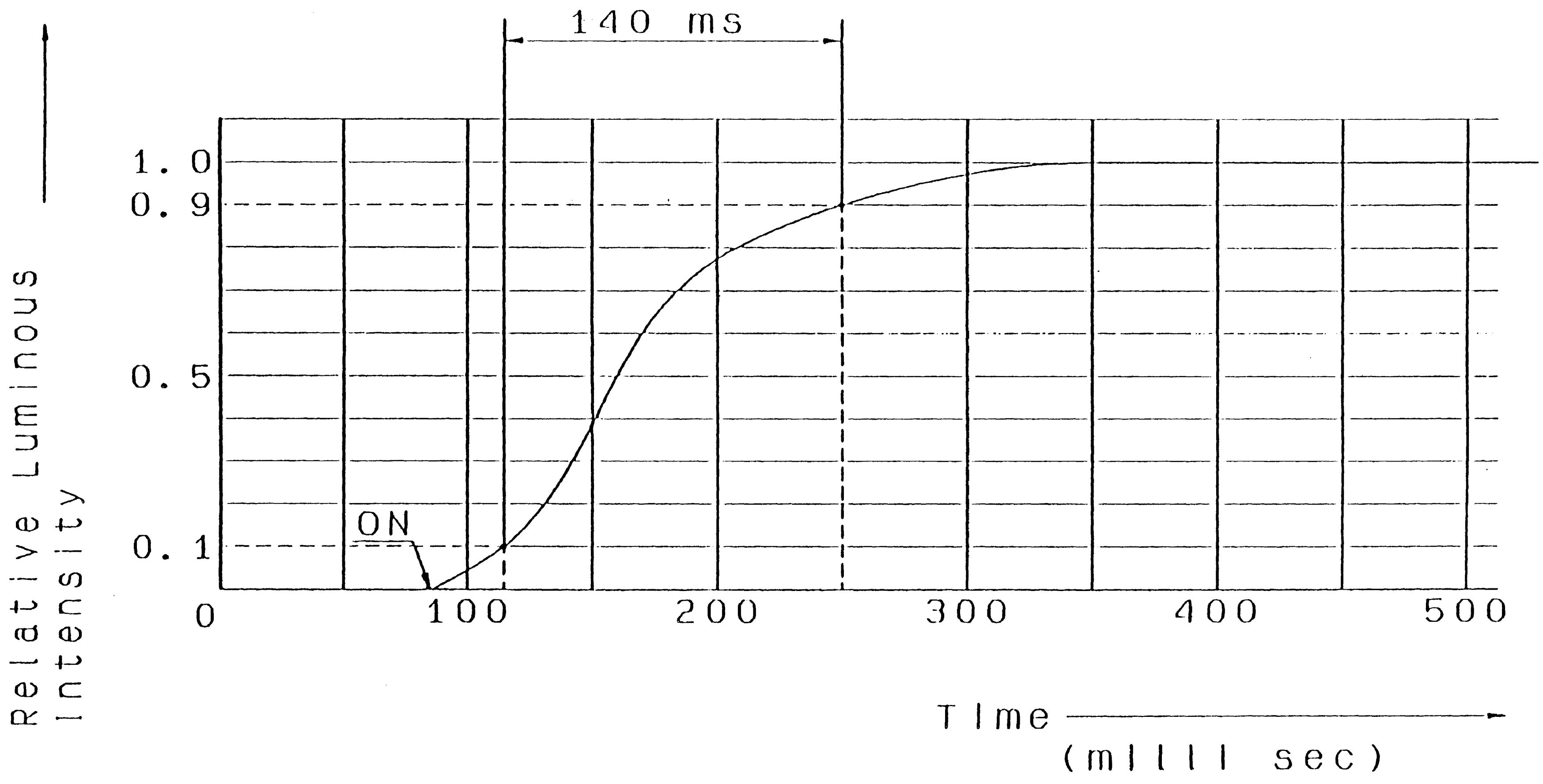

Figure 2. Rise-time characteristic of incandescent signal lamp.

TEST LAMPS

Three test lamps were supplied by the sponsor. Two of these (an LED and incandescent unit) were square in shape, the illuminated surface of each measuring 2 5/8 inches (6.7 cm) on a side. The third lamp, also an LED, was rectangular, measuring 1/4 X 26 1/2 inches (0.7 X 67 cm). With these three units it was possible to evaluate the LED and conventional technologies by comparing performance with the square lamps. The effect of radically different shapes within the LED technology could be evaluated by comparing performance with the square and rectangular units.

Each lamp was equipped with a power supply that made it possible to attach to the brake light wire in a car and drive the test lamp at 42.3 cd (plus or minus 0.1 cd) at H-V. This value was verified for each lamp prior to starting the test program.

The cd value given above is based on stable performance after the units had been energized for at least one-half hour. It was characteristic of the LED's that they had greater output when first turned on. The difference was about 20%. Thus, under the brief and intermittent use conditions of the two studies that were carried out, the LED units were actually putting out about 51 cd at H-V. The concern that this difference created was specifically addressed in the laboratory study described later.

SUBJECTIVE EVALUATION

Introduction

The purpose of this phase of the program was to evaluate subjectively the LED and incandescent HMSL units under real-world driving conditions. The lamps were mounted on the rear deck of a mid-size sedan, which was driven by an experimenter at various speeds. The subject drove a second vehicle and followed behind, observing signals presented by the lead driver. After each run the subjects were asked questions about the unit they had observed. At the completion of the test they were asked to rank the three test units from best to worst using two criteria. The subjects were also invited to comment about the lamps.

Independent Variables

Test lamps. The three test lamps described in the introductory section of this report were used.

Car following conditions. The conditions were: (1) about 20 mph (32 km/h) in a residential area, and (2) about 35 mph (56 km/h) on through streets. The subjects were instructed to follow "as close as you comfortably can" in the former case (most stayed within three to four car lengths), and at about 150 ft (46 m) in the latter case.

Ambient lighting. The test was run both during daylight hours and after dark.

Subjects. Nine subjects participated under each of the ambient conditions. Seven participated under both conditions, four under only one (two day, two night). The subjects were all young (i.e., 25 years of age and less), with from five to seven years of driving experience.

Dependent Variables

A simple questionnaire was used to collect data. This instrument is reproduced in Appendix A. Two different forms were used. Form 1 was used after each lamp (i.e., a total of three times per subject per ambient condition). Form 2 was used at the conclusion of each test (i.e., once per ambient condition), to allow a comparison between the test lamps. Comments were offered by most subjects on most lamps.

The language "others you have seen" on Form 1 refers to other HMSL's seen by the subjects during their normal driving experience, not the test lamps. This point was made clear to the subjects prior to taking their ratings. During the test the subjects often commented on or asked about the LED units. However, they were given no technical information about the lamps until the test was completed.

Procedure

The subjects reported to the Institute, where they read and signed a consent form. They were then taken to a car and driven by the experimenter to the start of the route, where the vehicle with the test lamps was waiting. At this point the subject and experimenter changed places, the instructions were read, and any questions answered. The test then started.

The first portion of the route (about 1.5 miles [2.4 km]) was in a residential area with a speed limit of 25 mph (40 km/h). The experimenter drove the lead car about 20 mph (32 km/h), the subject was told to follow as closely as he/she comfortably could. The second portion of the route was of about the same length and was located on nearby through streets with a speed limit of 35 mph (56 km/h). The experimenter drove the lead car at or near the speed limit. The subject was asked to drop back and maintain a distance between the two cars of about 150 feet (46 m). On numerous occasions during each run the driver of the lead car applied the brakes to give the subject ample opportunity to view the signal lamps.

At the conclusion of the run the cars pulled off to the side of the road in a quiet area. While one experimenter changed the test lamp the other administered the questionnaire to the subject. The next run then started.

Results

To obtain the tables presented in this section, scores from 1 to 5 were assigned to the ratings, with 5 being the most favorable end of the scale. These values were summed across subjects and means were calculated.

Table 1 presents the mean ratings obtained from the subjects using Form 1 under both day and night conditions. On question 1 ("Compare this HMSL to others you have seen in terms of the ease with which you could see it"), the square LED unit was ranked much higher than the other two, although the rating of the rectangular LED increased considerably at night.

On question 2 ("Taking all factors into consideration [visibility, effectiveness, appearance, etc.], how do you think this HMSL compares with others you have seen?"), the square LED unit still received the highest ratings, although it was lower relative to the

TABLE 1

MEAN RATINGS PROVIDED IN RESPONSE TO
VARIOUS QUESTIONS – ALL SUBJECTS

Question	Day Night	Ratings		
		Incandescent Lamp	Square LED	Rectangular LED
1 Visibility	Day	3.4	4.0	2.8
	Night	3.3	4.2	3.8
2 Overall	Day	3.1	3.6	2.8
	Night	3.1	3.4	2.8
4 Own Car	Day	3.1	3.4	2.9
	Night	3.6	3.7	3.1

visibility rating. The ratings of the incandescent lamp went down slightly as well. The night rating of the rectangular LED fell a full point.

On question 4 ("How would you feel about having this unit on your car?"), the square LED still had the best ratings, although the margin over the incandescent lamp was still less than in the case of question 2.

Table 2 is identical to Table 1, except that it includes only those seven individuals who participated under both day and night conditions. The differences between comparable cells in the two tables are no greater than 0.4 rating point, and in most cases within 0.1 point.

In using Form 2, the subjects were asked to rank the three lamps from best to worst. These categories were assigned numerical values from 1 to 3, with 3 being equal to best. Mean rankings were then calculated.

Table 3 summarizes the mean rankings obtained using Form 2 under both day and night conditions. For question 1 ("Please rank the three HMSL units from best to worst in terms of visibility"), the square LED received much the highest ranking. The mean rankings for the rectangular LED and incandescent units averaged much lower and relatively close to each other, although the rectangular LED was ranked a little higher at night.

For question 2 on Form 2 ("Rank in overall preference, taking all factors into

TABLE 2

MEAN RATINGS PROVIDED IN RESPONSE TO VARIOUS QUESTIONS – SEVEN SUBJECTS WHO RAN BOTH DAY AND NIGHT

Question	Day Night	Ratings		
		Incandescent Lamp	Square LED	Rectangular LED
1 Visibility	Day	3.4	3.9	2.9
	Night	3.4	4.3	3.4
2 Overall	Day	3.3	3.6	2.9
	Night	3.0	3.4	2.7
4 Own Car	Day	3.0	3.4	2.7
	Night	3.6	3.7	2.7

TABLE 3

MEAN RANKINGS – ALL SUBJECTS

Question	Day Night	Mean Rank		
		Incandescent Lamp	Square LED	Rectangular LED
1 Visibility	Day	1.7	2.7	1.7
	Night	1.4	2.7	1.9
2 Overall	Day	1.8	2.4	1.8
	Night	1.9	2.2	2.0

account"), the square LED was still ranked best on average, although the margin was less than in the case of question 1, particularly at night.

Table 4 is the same as Table 3, except that it includes only those seven subjects who participated under both day and night conditions. The differences here are no greater than 0.2 rank level and in most cases within 0.1.

Comments were received from most subjects concerning most of the test lamps. These are summarized in Appendix B. Most subjects noted that the LED lamps had a

TABLE 4

MEAN RANKINGS – SEVEN SUBJECTS WHO RAN BOTH DAY AND NIGHT

Question	Day Night	Mean Rank Incandescent Lamp	Square LED	Rectangular LED
1 Visibility	Day	1.9	2.6	1.6
	Night	1.4	2.7	1.9
2 Overall	Day	1.9	2.6	1.6
	Night	1.9	2.3	1.9

different color than the incandescent HMSL, as well as the lamps with which the lead car was equipped. Many subjects also commented that the LED lamps appeared brighter than either the incandescent HMSL or the brake lamps on the lead car. Only two subjects noted that the rise-time was shorter for the LED's.

Most of the comments received pertaining to the square LED unit were favorable. The only consistent complaint about it was that it was too bright. On the other hand, some subjects thought the additional brightness was an advantage.

The rectangular LED unit provoked more extreme responses than the other two. Some subjects liked it very much, because of its distinctive shape. Other subjects downrated it severely for the same reason.

The comments about the LED's being brighter than the incandescent lamp, and especially the complaints about their being too bright, were not expected. The LED's probably were brighter per unit area than the stock brake lamps on the lead car. Although the candela output of the latter were greater than the HMSL's, they were also much larger in area. Hence, at least under the close car-following conditions, the HMSL's would be expected to appear brighter. However, the fact that the LED HMSL's had approximately 20% greater output than the incandescent HMSL was not expected to be noticeable under the conditions of this test.

Follow-up photometric tests showed that the lamps were operating at the proper output level. To determine whether there were subjective differences between the LED and incandescent lamps a brightness matching study was conducted. The two square HMSL's were mounted side by side. The incandescent unit was operated at design level (i.e., 42.3 cd), and the subjects varied the voltage to the LED unit until it appeared to be equally bright. The matching was done six times by each of 13 subjects at two viewing distances (10 and 138 feet [3 and 42 m]), and in the dark and with all room lights on.

The viewing distances in this study were selected with the intention that the HMSL would be seen as an extended source at one extreme, and as a point source at the other. The illuminated surfaces of the LED and incandescent lamps differed in terms of homogeneity. The LED units were very uniform, while the incandescent unit had a hot spot in the middle, and was of lower luminance elsewhere. If the impression that the LED's were brighter came from this lack of homogeneity on the part of the incandescent lamp, then it should only be apparent at the shorter viewing distance.

The results of the matching study are given in Table 5. Each of the values shown is the mean of 78 matches. At the greater viewing distance the subjects set the LED lamp to within 0.5 cd of the incandescent lamp, on average, for both light and dark ambient conditions. However, at the shorter viewing distance the subjects set the LED unit an average of from about 2 to 5 cd lower than the incandescent unit. This indicates that the subjects indeed saw the LED unit as brighter than the incandescent unit when both had identical output, at least under close viewing conditions. Hence, the non-homogeneous surface of the incandescent lamp may be a factor in this judgment.

TABLE 5

RESULTS OF BRIGHTNESS MATCHING STUDY

Viewing Distance Feet (Meters)	Ambient Illumination	Mean Output of Square LED HMSL in Candelas*
10(3)	Light	40.5
10(3)	Dark	37.2
138(42)	Light	42.6
138(42)	Dark	42.8

*Reference incandescent HMSL set at 42.3 cd.

However, the results of the matching study described indicate that the subjective difference in brightness of the units is only 5 to 10%. It would not be expected that subjects would be able to reliably distinguish such a small difference on an absolute basis (i.e., without being able to make a side-by-side comparison). Hence, the frequency with which the subjects commented on a brightness difference under the field test conditions is still surprising. It may be that other factors are involved that were not explored here.

Discussion

The results of this study suggest that the LED concept would meet with approval from the driving public if used as a HMSL. Most of the responses received were positive toward the LED units. Differences that were known to exist between the LED and incandescent HMSL's at the start of the study were not seen as problems by the subjects. For example, many subjects noted the difference in color between the LED and incandescent lamps, but only two regarded that as a negative characteristic. Very few subjects noted the difference in rise-time between the LED and incandescent lamps.

The most frequent complaint about the LED lamps, as already noted, concerned their apparent brightness. It is not clear that this would be a problem under actual use conditions. However, there may be merit in evaluating the issue of subjective brightness prior to the actual adoption of LED-based HMSL's, to determine whether a different photometric specification would be appropriate.

LABORATORY EVALUATION

Introduction

This was a laboratory study, comparing the LED HMSL's to an incandescent unit. The purpose was to evaluate the peripheral attention-getting qualities of the lamps under a variety of simulated driving conditions.

It was noted in the introductory section of this report that the incandescent rise-time characteristics of the LED lamp were such as to give it an apparent response time advantage of about 0.14 second over an incandescent lamp. The question of primary interest in this phase of the investigation was the degree to which this difference might be affected by various conditions that would be encountered in the real world.

Independent Variables

Test lamps. The three HMSL's described in the introductory section were used. A comparison of subject performance across the two square units provided an indication of the effect of the LED vs incandescent technology. A comparison of subject performance across the square and rectangular LED units provided an indication of the effect of lamp shape.

Peripheral location. The subjects' point of fixation while signals were being presented was determined by having them continuously operate a tracking task. The task was presented on a small television located about 20 feet (6.1m) in front of them. The television could be in two locations. One (referred to as "near") was just under the lamp array, the other (referred to as "far") was off to the side, approximating a situation in which the subject was fixating a point in the adjacent lane about 100 feet (30m) distant.

Ambient illumination. Two lighting levels were employed. In the "dark" condition the laboratory lights were off, except for a fluorescent desk lamp at each end, which provided enough illumination to keep the subjects adapted to mesopic levels appropriate for night driving. For the "light" condition all the laboratory lights were turned on. In addition, two photographer's flood lamps were used to provide an illumination of about 6,000 ft/c (64,600 lux) at the face of the lamps. Care was taken in placing these flood lamps to ensure that they did not produce specular reflections on the surfaces of the test units.

Viewing distance. The distance from the subjects' eyes to the lamp array was set at two levels, 50 and 140 feet (15.2 and 42.6m). Since the laboratory was only 75 feet

(22.9m) long, the subjects viewed the lamps in a mirror at the greater distance.

Subjects. Twenty subjects participated in the test. Half of these were younger (i.e., 20 to 45 years of age), and half were older (i.e., 65 to 80 years of age).

Unit intensity. It was noted earlier that the LED lamps were operating at about 20% higher intensity than the incandescent lamp under the conditions of this test. Since reaction time is affected by stimulus intensity, the battery of conditions to be tested was expanded to include one in which the square LED lamp was covered by an 80% transmission filter. This reduced its output to the same level as the incandescent lamp, and allowed an estimate of the effect of the additional intensity.

Dependent Variable

The criterion was the time required for the subjects to respond to the signals presented by the HMSL's. This interval was measured from the time the lamps were energized until the subject responded by pressing a button.

Procedure

The three test lamps were attached to a frame in a cluster as shown in the photograph in Figure 3. The center of the cluster was 45 inches (114cm) above the floor, which was about the average eye height of the seated subjects.

Subjects were seated at the small table shown in Figure 4. With their preferred hand they responded to the signal lamps by pressing the white button (here shown set up for right-hand operation). With their other hand they operated a knob that controlled the tracking task.

The study was run by a microcomputer. On a random basis the computer selected the next lamp to be energized and the intertrial interval (6 to 14 seconds), then presented the stimulus, extinguished the lamp after the subject had responded, and recorded the response time in milliseconds. If the subject failed to respond in three seconds the lamp was turned off, a "miss" was recorded, and the trial was readministered either at the halfway point or at the end of the test sequence. The data were printed out and also recorded on floppy disks. The latter were read into the University's main-frame computer for data analysis.

Subjects were run individually. They reported to the Institute at an appointed time, and read and signed a consent form. They were then taken to the laboratory and seated at the subject's table. The instructions were read to them and any questions answered. In

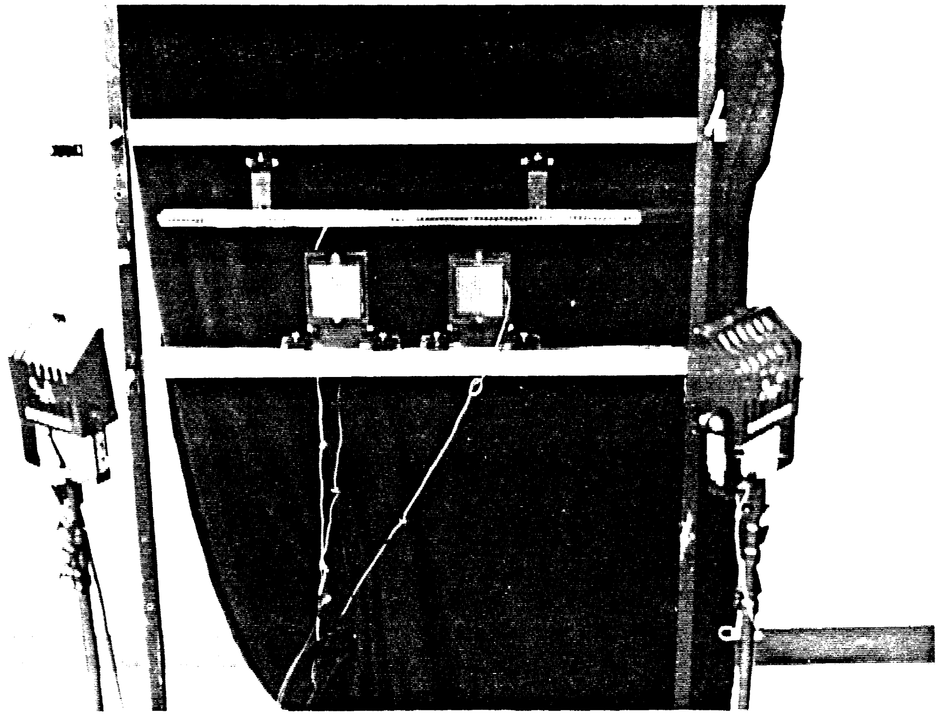

Figure 3. Arrangement of test lamps.

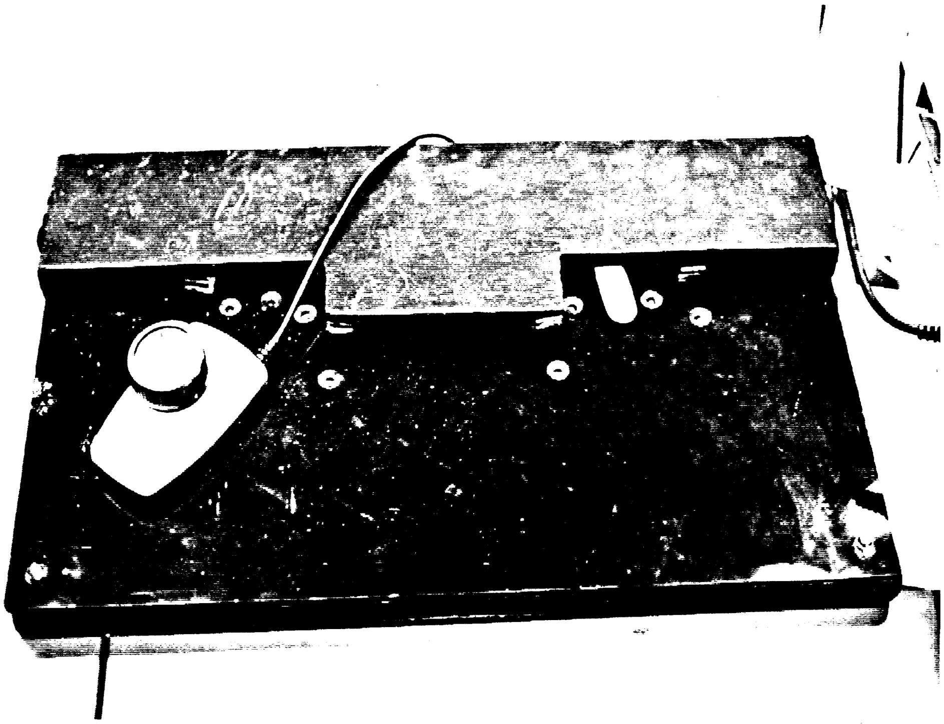

Figure 4. Photograph of subject's table.

brief, the subjects were told to operate the tracking task with their off hand (generally the left), and respond to signal lights by pressing the button with the index finger of their favored hand. It was emphasized that they must attend to the tracking task at all times. They were not to look directly at the lamps.

Each subject was administered nine blocks of thirty trials each (i.e., ten trials per lamp). Eight blocks covered the two levels each of the primary independent variables (ambient illumination, viewing distance, and peripheral location). The ninth block was identical to one of the original eight (dark ambient, and near viewing distance and peripheral location), except that the square LED was covered with an 80% transmission filter.

The various test combinations were administered in different orders, using a balanced design. There were some restrictions to the design. Since it was relatively difficult to change the viewing distance, this was done only once per subject. Similarly, the location of the fixation point was changed only once per viewing distance.

Results

The data were subjected to an Analysis of Variance (ANOVA). Since response time data typically do not conform to a normal distribution, two ANOVA's were carried out, one using raw data, the second using the data after they had been transformed to $\log_{10}$. The two analyses were then compared. Any discrepancies found were generally small. In the following discussion, differences reported as "statistically significant" were so in both ANOVA's. If there was a difference in the level of significance in the two analyses (e.g., 0.01 in one and 0.05 in the other) the lower level will be reported.

Main effects. The mean response times for the square and rectangular LED units were identical at 0.43 second. Response times to the incandescent unit averaged about a quarter-second slower, at 0.69 second. This difference was significant at the 0.01 level.

The effect of viewing distance was also significant at the 0.01 level. The mean response time at the closer distance was 0.46 second; that for the further distance was 0.57 second.

The effect of ambient illumination was also significant at the 0.01 level. The mean response times were 0.59 and 0.44 second for the light and dark conditions respectively.

The effect of subject age was significant at the 0.01 level as well. The mean response times were 0.46 and 0.57 second for the young and old subjects respectively.

The mean response times for the peripheral locations were 0.51 and 0.53 second for the near and far location respectively. This difference was not significant ($p > 0.05$). However, this factor was involved in some significant interactions, to be described shortly.

The effect of reducing the intensity of the square LED to that of the incandescent lamp is shown in Table 6. The mean response time increased by 0.01 second for each of the lamps in the "filtered" condition (although only the intensity of the square LED was actually reduced with a filter). The difference is not significant ($p > 0.05$).

TABLE 6

MEAN RESPONSE TIME IN SECONDS – EFFECT OF FILTER

Lamp Type	Filter Condition	
	Non Filter	Filter*
LED Square	0.37	0.38
LED Rectangular	0.36	0.37
Incandescent	0.56	0.57

*Only the square LED lamp was filtered.

A count was made of misses (i.e., a failure to respond to a signal presentation within 3 seconds). The results of this analysis are shown in Table 7, as a function of the primary independent variables of interest. Most misses occurred in the far viewing, high ambient illumination, and far peripheral location condition. Misses were more frequent with the incandescent unit. Not evident from the table is the fact that most misses were recorded by a small number of subjects in each age category. Most subjects made no or very few misses, even in the most difficult condition.

Interactions. Table 8 summarizes the relationship between lamp type and ambient illumination. This interaction is significant at the 0.01 level. Under dark conditions the mean response time difference between the incandescent and LED units was 0.2 second. This is close to the predicted difference of 0.14 second. Under the light ambient conditions, the response time was greater for all the lamps, as expected. However, the difference between the LED and incandescent units increased to about 0.3 second.

A similar pattern is seen in the relationship between lamp type and viewing distance, summarized in Table 9. This interaction is significant at the 0.01 level. Mean response times are shortest in the near condition, and the difference between the LED and

TABLE 7

ANALYSIS OF MISSES

Viewing Distance	Ambient Illumination	Peripheral Location	Lamp Type	Number of Misses	
				Young Subjects	Older Subjects
Far	Dark	Near	LED Square LED Rectangular Incandescent	0 0 0	0 0 0
Far	Light	Near	LED Square LED Rectangular Incandescent	3 3 3	3 0 9
Far	Dark	Far	LED Square LED Rectangular Incandescent	0 0 0	0 0 0
Far	Light	Far	LED Square LED Rectangular Incandescent	8 12 44	2 4 16
Near	Dark	Near	LED Square LED Rectangular Incandescent	0 0 0	0 0 0
Near	Light	Near	LED Square LED Rectangular Incandescent	0 1 1	0 4 2
Near	Dark	Far	LED Square LED Rectangular Incandescent	0 0 0	2 0 1
Near	Light	Far	LED Square LED Rectangular Incandescent	0 0 1	3 1 3

TABLE 8

MEAN RESPONSE TIME IN SECONDS AS A FUNCTION OF LAMP TYPE AND AMBIENT ILLUMINATION

Lamp	Ambient Illumination	
	Light	Dark
LED Square	0.49	0.38
LED Rectangular	0.48	0.37
Incandescent	0.80	0.57

incandescent units is about 0.2 second. In the far condition all response times increased, but the difference between the LED and incandescent units increased to about 0.3 second.

TABLE 9

MEAN RESPONSE TIME IN SECONDS AS A FUNCTION OF LAMP TYPE AND VIEWING DISTANCE

Lamp	Viewing Distance	
	Near	Far
LED Square	0.39	0.47
LED Rectangular	0.39	0.47
Incandescent	0.60	0.77

These relationships are further explored in Table 10, which shows the mean response times obtained as a function of lamp type, viewing distance, and ambient illumination. This interaction is significant at the 0.05 level. Three things are of interest in this table. First, the LED units are associated with the shortest mean response times under all conditions. The longest response times for the LED units are about equal to the shortest response times for the incandescent unit. Second, response times are shortest under the dark ambient condition, and there is little difference as a function of viewing distance. Third, response times are longer under the light ambient condition, and there are larger differences as a function of viewing distance for all units. However, the response time difference as a function of viewing distance for the incandescent lamp is about double that for the two LED units (i.e., 0.31 as compared with 0.14 second).

TABLE 10

MEAN RESPONSE TIME IN SECONDS AS A FUNCTION OF LAMP TYPE, VIEWING DISTANCE, AND AMBIENT ILLUMINATION

Lamp	Viewing Distance	Ambient Illumination	
		Light	Dark
LED Square	Near	0.42	0.37
	Far	0.56	0.39
LED Rectangular	Near	0.41	0.37
	Far	0.55	0.38
Incandescent	Near	0.65	0.56
	Far	0.96	0.59

Table 11 illustrates the relationship between lamp type, ambient illumination and subject age. This interaction is significant at the 0.05 level. The relationships involving the two LED lamps are very consistent. That is, response times average longer in the light ambient condition and for the older subjects, and the differences are about the same for each lamp. However, while the difference between the young and old subjects is about the same for the dark ambient condition with the incandescent lamp as it was for the LED's, it is much less for the light ambient condition. The change is apparently due to poorer performance on the part of the young subjects in that condition. The reason for the change is not known.

A similar pattern can be seen in Table 12, which shows the relationship between lamp type, peripheral location, and subject age. This interaction is significant at the 0.05 level. The table shows that the difference in mean response time between the young and old subjects is consistently between 0.10 and 0.14 second for all conditions except for the incandescent lamp at the far peripheral location, where the difference is 0.04 second. As in the case of the relationship shown in Table 11, the change is apparently attributable to poorer performance on the part of the young subjects in that condition. The reason for the change is not known.

TABLE 11

MEAN RESPONSE TIME IN SECONDS AS A FUNCTION OF LAMP TYPE, AMBIENT ILLUMINATION, AND SUBJECT AGE

Lamp Type	Ambient Illumination	Subject Age	
		Young	Old
LED Square	Light Dark	0.43 0.31	0.55 0.44
LED Rectangular	Light Dark	0.41 0.32	0.56 0.43
Incandescent	Light Dark	0.79 0.51	0.82 0.64

TABLE 12

MEAN RESPONSE TIME IN SECONDS AS A FUNCTION OF LAMP TYPE, PERIPHERAL LOCATION AND SUBJECT AGE

Lamp Type	Peripheral Location	Subject Age	
		Young	Old
LED Square	Near Far	0.36 0.39	0.50 0.49
LED Rectangular	Near Far	0.35 0.37	0.49 0.49
Incandescent	Near Far	0.61 0.68	0.74 0.72

Table 13 describes the relationship between ambient illumination and viewing distance. In this and all following tables the data have been summed across lamps. This interaction is significant at the 0.01 level. In the dark ambient condition the mean response times associated with the two viewing distances were essentially the same. Viewing distance had a much greater effect under the light ambient condition.

These relationships are explored further in Table 14, which adds in the effect of

TABLE 13

MEAN RESPONSE TIME IN SECONDS AS A FUNCTION OF VIEWING DISTANCE AND AMBIENT ILLUMINATION

Ambient Illumination	Viewing Distance	
	Near	Far
Light	0.49	0.69
Dark	0.43	0.45

peripheral location. This interaction is significant at the 0.05 level. The table shows that there were no differences associated with peripheral location at the near viewing distance for either ambient illumination condition. The same is true at the far viewing distance, dark ambient condition. However, there is a difference of 0.1 second for the light ambient condition, far viewing distance. It was expected that the light ambient condition would maximize differences associated with peripheral location. It is not clear why it only shows up at the far viewing distance.

TABLE 14

MEAN RESPONSE TIME IN SECONDS AS A FUNCTION OF VIEWING DISTANCE, AMBIENT ILLUMINATION, AND PERIPHERAL LOCATION

Viewing Distance	Ambient Illumination	Peripheral Location	
		Near	Far
Near	Light	0.50	0.49
	Dark	0.43	0.43
Far	Light	0.64	0.74
	Dark	0.47	0.44

Differences were also found in peripheral location as a function of subject age. These are shown in Table 15. This interaction is significant at the 0.01 level. There is essentially no difference for the older subjects. However, the young subjects averaged 0.04 second slower in the far peripheral location.

TABLE 15

MEAN RESPONSE TIME IN SECONDS AS A FUNCTION OF PERIPHERAL LOCATION AND SUBJECT AGE

Subject Age	Peripheral Location	
	Near	Far
Young	0.44	0.48
Old	0.58	0.57

Discussion

The results of this investigation provide evidence that the LED HMSL has a significant advantage over the conventional incandescent HMSL in terms of the response time of following drivers. The rise-time characteristics of the two types of lamps led to an expected response time difference of about 0.14 second. Under the conditions of this test that were most favorable for viewing light signals, the LED units provided a response time advantage slightly greater than expected, about 0.20 second. Under less favorable conditions (e.g., viewing at a distance, high-intensity illumination on the lamp surface) the attention-getting properties of the LED units appear to be less affected than those of the incandescent units, and the response-time advantage increased to about 0.30 second.

The shorter response time of 0.2 – 0.3 second associated with the LED HMSL translates (at 55 mph [88 km/h]) to a 16 to 24 ft (4.9 to 7.4 m) reduction in stopping distance. This is a significant safety benefit.

The fact that the response time advantage enjoyed by LED signal lamps is greater than would be predicted based on their rise-time characteristics suggests that they have greater conspicuity than incandescent sources of the same intensity. This greater conspicuity may be attributable to the LED's brief rise-time. That is, a lamp that quickly reaches maximum output may have better attention-getting characteristics than one that takes a longer time to reach maximum output.

The results also indicate that the shape of the unit has no effect on subject response time. In addition, it seems clear that the reaction-time advantage of the LED units tested cannot be attributed to the fact that they were significantly brighter than the incandescent units when briefly energized.

CONCLUSIONS

The purpose of the study described in this report was to evaluate the acceptability and possible response-time advantage of HMSL's using LED technology. The results of the two studies carried out suggest that the LED HMSL would be acceptable to the driving public and would make it possible for following drivers to respond to brake signals in significantly less time.

REFERENCE

Fujita, T., Kouchi, T., Takahashi, K. and Kashiwabara, H. Development of LED High Mounted Stop Lamp. Paper presented at the 1987 SAE Congress, Detroit, Michigan. February 23-27, 1987.

APPENDIX A – RATING FORMS

FORM 1

Subject Number __________ Date ____________________

Name ________________________________ Day ____ Night ____

Years Driving Experience ____________ Lamp Number ________

	Much Better	Better	About the Same	Worse	Much Worse
1. Compare this HMSL to others you have seen in terms of the ease with which you could see it.					
2. Taking all factors into consideration (visibility, effectiveness, appearance, etc.), how do you think this HMSL compares with others you have seen?					

3. If rank of 1 and 2 differs, ask why.

	Very Much Like	Like	Don't Care	Dislike	Very Much Dislike
4. How would you feel about having this unit on your car?					

5. General Comments:

FORM 2

Subject Number _______

	Best		Worst
	3	2	1
Please rank the three HMSL units from best to worst in terms of visibility.			
Rank in overall preference, taking all factors into account.			

Other than shape, did you notice any differences between the three HMSL's or between the HMSL's and the stock lamps?

APPENDIX B – SUMMARY OF SUBJECT COMMENTS

Standard Lamp

Day

Because it is brighter he tended to focus on the HMSL and less on other lamps such as the turn signal.

This unit is only slightly brighter than the stock lamps on the car.

Less attractive than other units she has seen.

Likes it a lot better than the wide LED lamp.

Doesn't like appearance.

Looks much like other units he has seen. Has about the same brightness as the stock lamps on the car.

Appearance is a problem. Unit looks cheap.

Thinks it might cause glare at night.

Unit offers better visibility than the brake lamps on this vehicle.

The HMSL looks brighter (than the stock lamps on the car) when following at a distance.

Night

The unit is too bright, it is distracting.

Utility of this unit should be pretty good.

Not as bright as the square LED unit.

Almost exactly the same as standard units on cars today.

The unit is too small.

This unit looks the same as others he has seen. It is small, and somewhat on the dim side.

This unit was easier to see than other units. Not as distracting as the square LED HMSL. Wasn't as scared to get close to the lead car.

Stands out due to shape compared to the stock lamps on the car.

The unit is uniform in brightness, which sets it apart from the regular taillights.

Reminded him of most other lamps he has seen. Color and rise-time are the same as other lamps.

Square LED Lamp

Day

Looks brighter than the standard HMSL and the stock lamps on the car.

Color different from standard HMSL and other lamps on the car.

Thinks it would be more effective than the standard lamp.

More easily seen than low-mounted brake lamps on the car.

Looks the same as the standard HMSL.

Too bright close up.

At a distance noticed sharp, square image. Up close it is almost irritating. It dominated the visual field.

Looks like a high quality unit.

Looks different – dot-matrix appearance – likes that.

Looks brighter (than other units he has seen on the road), but does not glare.

Unit has higher intensity (than other units he has seen on the road) and came on before stock lamps on the car.

Would like this lamp better with softer edges. A rectangular shape would blend in better with the car.

"Real bright."

Was impressed with the fact that it came on faster than the stock lamps; thought that was an advantage.

Was much more prominent than the regular stoplamps on the car.

Feels it is too bright when following closely.

Night

The unit is too bright, it is distracting.

This lamp is redder than the standard HMSL.

Liked this lamp less than during the daytime (reduced one step on questions 1 and 2, stayed the same on question 4). It is too bright when up close. Fine at a distance.

Color different from stock lamps on car.

Unit is more visible – brighter than other units in the test.

Much brighter than other units. Too bright when close for a period of time. It leaves an after image.

He would like this unit if the intensity could be reduced.

This HMSL makes him nervous. Like a police car.

This unit is brighter than others he has seen. It got his attention without taking up the whole back window. Just like other units he has seen elsewhere, but brighter.

Eyes were distracted more to this HMSL than to others she has seen. The color is different, that bothers her.

The high brightness and different shade of red was helpful and not distracting.

Likes "pure" red color.

Likes quick response (i.e., short rise time).

Can see it easily because it was brighter, yet not too bright.

Linear LED Lamp

Day

Width makes it attractive.

It is easy to see when looking to the side.

Doesn't think the design would be as effective (as the square units). May be confused with something else, such as a strip of tape.

Would like it better if shape were more nearly square.

Tended to get lost in the sun glare off the rear deck. Looks more like a novelty item than a stop lamp.

Likes long and narrow appearance. Thinks there is less glare that way.

Pretty, but didn't trigger stop reaction like other HMSL's did. It didn't get his attention at first, but finally found himself fixating on it to an undesirable degree. Thinks it is not as safe.

At times this lamp seemed to come on faster than the stock lamps on the car.

Noted that this unit seemed to come on faster than the stock lamps on the car.

Due to the shape, didn't think it was as visible as other HMSL's he has seen.

The unit is so thin it is difficult to see.

The unit is so different that there was a problem in interpreting what it was.

Night

Liked this unit better at night than during the day (rated one step better on both questions 1 and 2, and went from "dislike" to "like" on question 4).

Liked this unit better than the other two in the test. Less distracting.

Not as bright as the square LED unit. Very visible without being annoying.

Likes the shape. Catches his attention due to the unusual shape.

The unit is so different that you might think it was something other than a car.

Likes appearance. Thinks there is a better chance to see it.

Appears less bright even than some other units on the market. Doesn't glare as much.

Doesn't like the shape. "Looks like a spaceship."

The unit is obnoxious, because it is so bright.

Unit is too bright. So much brighter than other lights on the car that it "mesmerized" her.

Color irritated him.

If following closely he would find the unit irritating.

Liked this unit better at night (increased two scale points on question 1, one scale point on question 2, and went from "dislike" to "don't care" on question 4).

General Comments

Day

The square LED HMSL is brighter than the standard HMSL and the stock lamps on the car. The square and wide LED HMSL's look about equally bright. The standard HMSL is only slightly brighter than the stock lamps on the car.

All three test lamps looked equally bright, but brighter than the stock lamps on the car.

The square LED HMSL was much brighter than the other two units. All three were brighter than the stock lamps on the car.

The two LED units were brighter and sharper than the standard lamp. The two LED units were also brighter than the stock lamps on the car.

These HMSL's did not appear to be as bright as others he has seen.

Liked the wide LED unit best. It is innovative. Its width is an advantage with obstructions in the way.

The HMSL's were brighter than the stock lamps on the car. The wide LED unit seemed to be the brightest.

The two LED HMSL's seemed brighter than the standard HMSL and the stock lamps on the car.

Suggested the regular taillamps should be made using LED technology.

The two LED HMSL's were brighter than the stock lamps on the car, as well as the standard HMSL.

Night

The square LED unit looked brighter and more red than the other two.

All three HMSL units in the test seemed brighter than the stock lamps on the car.

Intensity of the two LED units was higher than the stock lamps on the car. Color was different as well.

The square units (both conventional and LED) were more visible.

The two LED units are brighter than the standard unit.

The two LED units are much brighter than the stock lamps on the car. The standard HMSL is about the same brightness as the stock lamps on the car.

The LED HMSL's were brighter than the other HMSL and the stock lamps on the car.

Noted no differences in the time they came on.

The two LED HMSL's were much brighter than the standard HMSL.

The color and brightness of the two LED HMSL's was different from the standard HMSL and the stock lamps on the car.

Color and intensity of the LED HMSL's are different from the standard HMSL and the stock lamps on the car.

The LED units came on faster.