
Visual Benefits of High-Intensity Discharge Automotive Forward Lighting

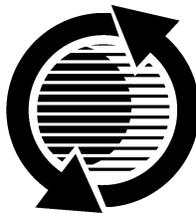
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ABSTRACT

Recent studies have shown that high-intensity discharge (HID) headlamps provide visual benefits to the vehicle operator that may lead to greater nighttime driving safety.[1] This paper is an extension of that work to further examine the role of beam pattern. An experimental field investigation is described that explores the visual performance aspects of HID forward lighting systems meeting North American beam pattern standards.

This study further explores and quantifies the overall benefits of HID systems by direct comparison to conventional halogen systems. It examines and compares two systems producing typical Society of Automotive Engineers (SAE) J1383 beam patterns. Subjects perform a visual tracking task, cognitively similar to driving, while seated in the driver's seat of a test vehicle. Simultaneously, small targets located at various angles in the periphery are activated, with subjects releasing a switch upon detection so that reaction times can be measured. Reaction times greater than 1 second are considered misses.

From the results, comparisons are made among the HID and halogen systems in terms of reaction time to signals at different peripheral angles, and in terms of missed signals. Potential implications of the results on driving safety and on the development or refinement of HID forward lighting systems are also discussed.

INTRODUCTION

BACKGROUND

HID vehicle forward lighting systems produce roadway illumination that can result in enhanced performance of nighttime driving visual tasks compared to standard tungsten halogen systems.[1][2][3][4] These visual benefits, occurring both on and off the visual axis, are likely caused by two factors. HID systems provide more light than conventional halogen headlamps, which in turn may lead to greater visual performance. HID systems

also provide light with a different spectral power distribution (SPD) than halogen systems. The SPD of a typical HID system has proportionally more energy in the short wavelength portion of the visual spectrum. This energy is more efficient at stimulating the rod photoreceptors of the human eye at lower light levels. This becomes particularly important when off-axis nighttime vision applications are considered.

Beam pattern is arguably the most important factor when considering headlamp performance. The forward lighting intensity distribution determines the illuminance onto important visual objects in the roadway scene. The amount of illuminance is typically the primary factor determining visual performance. If light level is above threshold, visual performance is relatively insensitive to object contrast and size.[5] Other factors that affect visibility, such as illumination SPD, usually only play a role in nighttime driving if the illuminance levels are low. For a typical headlamp beam pattern visibility in the central portion of the beam, within $\pm 15^\circ$ of the vehicle axis, is driven by light level. However, on the edges of the beam distribution, other factors such as SPD begin to have a larger contribution to performance.

Worldwide, two conventions are primarily used to govern automotive headlamp performance. In North America standards are followed that are developed by the SAE. Most of the rest of the world follows standards regulated by the Economic Commission for Europe (ECE). Both groups set strict requirements for the central portion of headlamp beam patterns to ensure that vehicle forward lighting allows for safe, comfortable driving at night without causing glare to oncoming drivers.

The light distribution at the edge of the headlamp beam pattern depends on which convention is followed and is not very well defined. However, off-axis or peripheral vision is crucial to driving safety. Peripheral vision is important to hazard object detection, negotiating curved roadways, and nighttime driving comfort.[1][3]

HID headlamp systems produce more light than traditional halogen systems.[6] Due to the strict

requirements in the central part of the beam this light is often directed towards the edge of the beam. Therefore HID systems often provide superior off-axis visual performance.[1][2] However, in previous research only ECE beam patterns were used. Until very recently HID headlamp systems with SAE type beam patterns did not exist. With the growing acceptance of HID headlamps in North America HID systems are now being produced with SAE beam patterns. It is expected that these systems will show the same general trending as that shown for the ECE HID systems, but if visual benefits do occur, the exact magnitude of them have not been shown.

HID headlamps systems also produce light with a different spectral power distribution than halogen systems. The SPD produced by HID lamps has relatively more energy in the short wavelength region of the visual spectrum. At nighttime driving light levels the eye is adapted such that the rod photoreceptors play a more dominant role in off-axis vision. The eye's response is a mixture of rod and cone photoreceptor responses. This is the mesopic adaptation region. Since the rod photoreceptors are more sensitive to light of shorter wavelength, HID illumination may be more efficient under these conditions. It has been shown that, depending on the visual conditions, light spectrum can moderately or greatly impact efficiency.[7][8]

In the previous studies mentioned and in the SAE beam pattern study described here the role of spectrum is not known. The effect measured is a combination of both spectrum and light level. It is important to know the relative proportion of each on visual performance. If HID spectrum results in a large proportion of the visual benefits produced than this would be a justification for the higher color temperature of the lamps. If the spectrum of HID systems plays a small role, then possibly the chemistry of the lamp can be altered to reduce the relative short-wavelength content. This question will be addressed in future research studies.

SCOPE OF PAPER

The goal of this paper is to report the results of a field investigation exploring the relative off-axis visual performance of HID headlamps compared to standard tungsten halogen. It is divided into three main sections. The first reviews the experimental methods employed in the study. This includes a description of the experimental geometries, procedures, and subjects used.

The second section presents the experimental results. This includes both reaction time and number of missed signals as a function of target location and target contrast.

The last section analyzes the data. Potential implications of the results on driving safety and on the development or refinement of forward lighting standards are discussed.

METHODS

EXPERIMENTAL GEOMETRY

This experiment was designed to measure off-axis visual performance under different vehicle frontlighting patterns. As an extension of previous research, the experimental methodology used was very similar to that reported by the authors in the related earlier study.[1] This was done so that the research results can be directly compared and analyzed together.

Two headlamp systems were used, one HID system and one halogen system. Both headlamps were "high quality" lighting systems from the same make and model of automobile. Both systems had beam patterns corresponding to SAE J1383 standards.

Two target contrast levels, ~100% and 50%, were used to examine the effect of contrast on visual performance. Subjects were shown off-axis targets lit with the test headlamps and asked to respond as soon as the target was seen. If no response was given within 1 sec the target was considered missed. This process was repeated four times for each target for each of the 12 subjects. The subjects' reaction times and numbers of missed signals were recorded.

These experiments were performed in the field in order to increase application validity. A disused runway at Schenectady County Airport in Scotia, NY was chosen as the study location. This location offered a straight, flat, paved surface with little stray light. The tarmac is asphalt and exhibited reflection characteristics similar to a typical roadway surface.

The experimental geometry, shown in Figure 1, is as follows. The subject sits in the driver position in a stationary test vehicle. A tracking task is placed 15m away from the front of the test vehicle directly in the subject's line of sight. Six targets are placed at a constant distance of 60m from the vehicle. The targets have a 5° angular separation, with four to the right of the driver and two to the left. In both directions the targets start at 2.5° from the line of sight. This geometry results in targets at the angular positions shown in Figure 1, where negative angles indicate to the left of the driver and positive to the right.

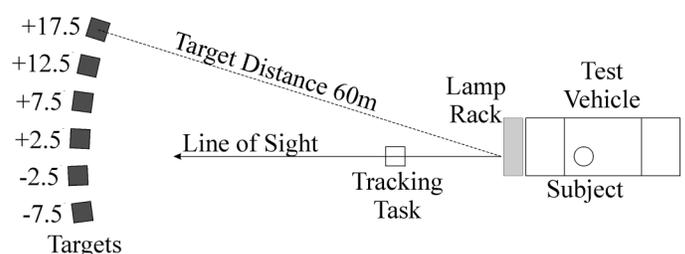


Figure 1. Schematic diagram of experimental geometry.

The headlamp systems were placed on a buck or rack in front of the car. The subject could not see the rack from

the driver's position so it appeared the lighting was from the vehicle. Headlamps were mounted at the correct vehicle height and separation. The HID system was powered directly from the test vehicle battery. The halogen systems were powered by a DC power supply running from the test vehicle battery. A power supply was used to ensure the voltage remained constant. Care was taken to aim the headlamps to the line of sight every time they were mounted on the rack or adjusted. Aiming was performed visually 10m from the lamps.

The tracking task used consisted of an LED "bar graph". This was a linear series of LEDs that mimicked a moving bar graph. The LEDs start lit in the middle and light a random distance up or down. The subject has a knob controlling the LEDs and is instructed to turn them off till they reach the center again. Once the center is reached the LEDs light in a random direction again. The subject is asked to perform the tracking task throughout the experiment. This ensures that the subject's line of sight is fixed and targets are presented off-axis.

Figure 2 shows the targets used in this experiment. They are a 7"x7" grids of "flip dots". The flip dots are small 0.5" diameter electromagnetic disks that are white on one side and black on the other. When a current is applied the disks flip completely within 20ms, showing the white or black face. The dimensions and relative position on the targets were constructed to match other studies of roadway visibility. [9][10]

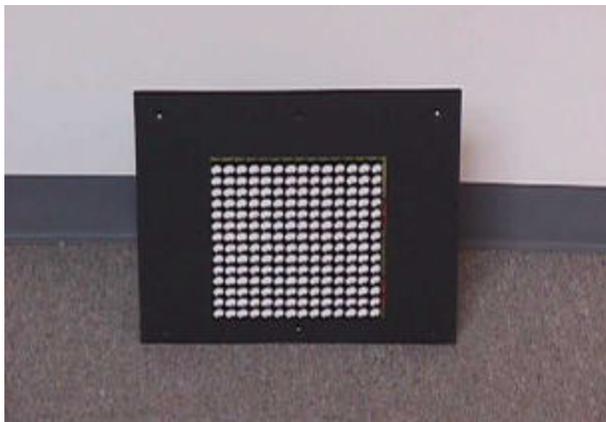


Figure 2. Flip dot target.

Changing the target contrast was accomplished by placing neutral density filters over the targets. Neutral density filters were used so the light spectrum would be minimally affected. For high contrast the target was used with no filter. The lower contrast condition was accomplished by placing a 0.15 optical density filter mounted on glass substrate over the target. This resulted in a contrast level of ~50%. The filters were placed over the target at an angle so that any light reflected from the filter would not return to the subject.

The illuminance levels were measured at the top and bottom of the targets each time the headlamps were mounted. Figure 3 shows the average target illuminance

as a function of angular target position. The study was performed over two sessions; each point represents the average of two sets of top and bottom illuminance measurements with the error bar length equal to twice the standard deviation. Note that although the HID system produces significantly more light at all angular positions, particularly 2.5°, it was found through goniometric measurement that the beam meets SAE J1383 standards.

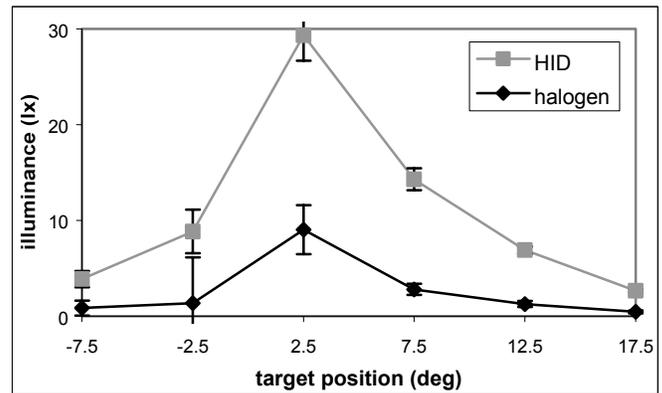


Figure 3. Plot of average target illuminance.

PROCEDURE

Subjects were asked to sit in the driver's position with the scene already illuminated. Subjects did not see which lamp system was being used. Once seated the subject was given a control box. It contained a knob to control the LED tracking task and a reaction time switch.

After a trial run to get acquainted with the controls the actual test was started. The subject held the reaction time button down while performing the tracking task. Targets were presented in a random order at random time intervals. Subjects were asked to release the reaction time button when a target was seen. If the subject did not respond in one second to the target presentation it was considered missed. The reaction time and number of missed signals was automatically recorder by a computer. In one data collection period each target was presented to the subject four times.

The data collection periods were repeated within two groups of six subjects. Each subject performed the experiment with one headlamp type and the targets at one contrast level. The contrast level was then changed, either higher or lower, and each subject performed the experiment again. After each subject in the group performed the experiment for one headlamp type at both contrast levels the headlamp system was changed and the process repeated.

Care was taken to randomize and counterbalance the order of headlamps and target contrast levels presented to each group of subjects. This was done to counterbalance any order effects. Four each study, in total, four data collection periods were completed by

each subject, two headlamp types and two target contrast levels. In each data collection period 24 data points were collected (4 for each target). So, for each subject 96 data points were collected.

SUBJECTS

Twelve subjects were used in total. The subjects ranged in age from 23 years to 51 years, with an average age of 33 years and a standard deviation of 10 years. Each subject was tested to ensure they had at least 20/20 corrected acuity and no color blindness.

RESULTS

REACTION TIMES

Figure 4 shows reaction time versus target location for the high contrast target case. The y-axis shows reaction time. Each reaction time data point is the average of all subjects and the error bar length corresponds to twice the standard deviation. Reaction times that exceed the scale correspond to targets where no reaction time data points were collected (all targets were missed). The impacts of target location and lamp type on reaction time were found to be statistically significant for these data ($p < 0.01$).

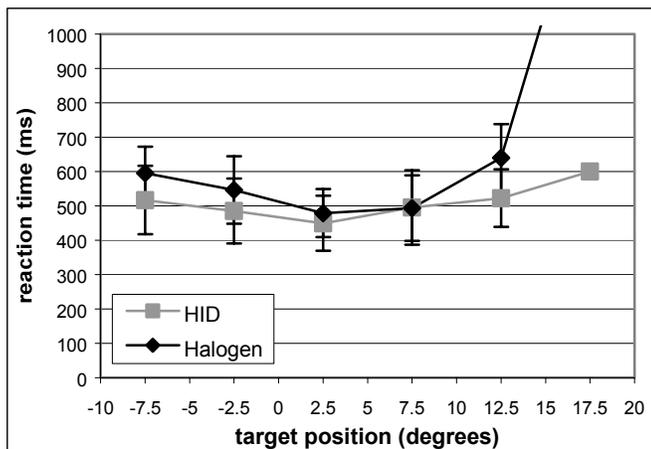


Figure 4. Average reaction times for high contrast targets.

Several trends can be seen from the plotted data in Figure 4. Reaction time is shortest at the small angle targets where illuminance is highest. Reaction time increases as the target angle increases and the illuminance decreases. However, the reaction times for HID illuminated targets do not increase as rapidly as those under halogen illumination. The HID system produces significantly lower reaction times at higher angles than the halogen system.

The data shown in Figure 4 can be directly compared to the high contrast reaction time data reported earlier.[1] However, each reaction time point represents the average subject reaction time for those targets seen. Missed targets were not weighted into the reaction time values. This has the effect of making the reaction time values dependent on a smaller number of samples. For

large angle targets, where the number of missed signals is large, the reported values for reaction time may be the average of only one or two samples. To overcome this artifact the reaction time was recalculated with missed signals averaged in with a value of 1200ms. This is an arbitrary reaction time value, above the 1000ms cutoff, used for comparison. The results of the reaction time recalculation can be seen in Figure 5.

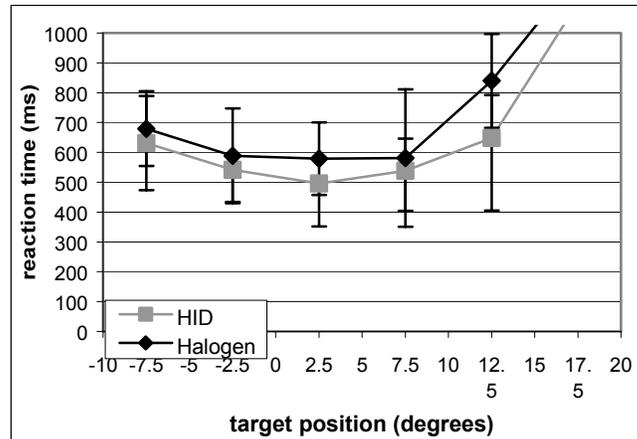


Figure 5. Average reaction times for high contrast targets with missed signals averaged in at 1200ms.

The effect of the addition of missed signals to the reaction time analysis can be seen by comparing Figures 4 and 5. In both graphs it is evident that the HID system results in a lower reaction time values, particularly for the large angle targets. However, for the reaction times with the missed signals included the difference in reaction times become more evident at some locations. This indicates that at these locations the number of missed signals was significant.

Figures 6 and 7 show reaction time versus target location for the 50% contrast target case. Figure 6 shows the average reaction time with no weight given to the missed signals while Figure 7 shows reaction time with missed signals included. Reaction times are shown for both headlamp types. The impacts of target location and lamp type on reaction time were found to be statistically significant for these data ($p < 0.01$).

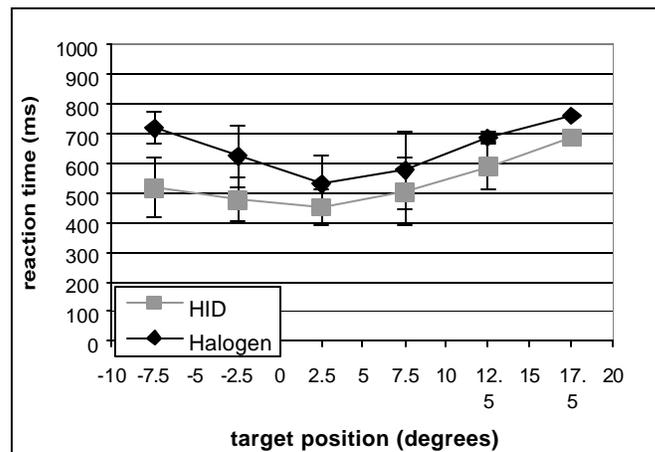


Figure 6. Average reaction times for 50% contrast targets.

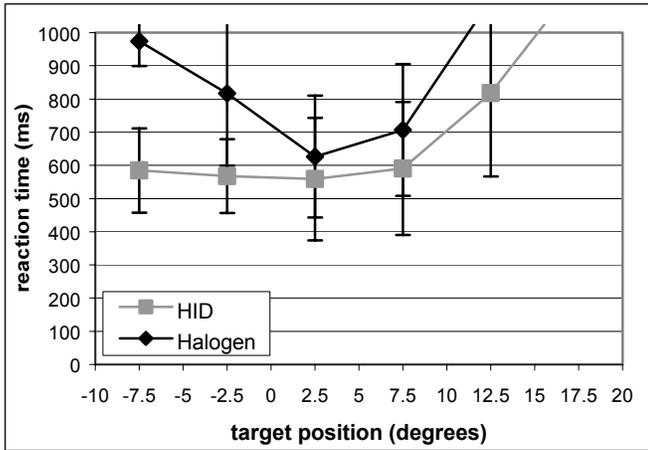


Figure 7. Average reaction times for 50% contrast targets with missed signals averaged in at 1200ms.

As expected for lower contrast, overall reaction times have increased compared to the high contrast case. Once again the same general trends are seen. Reaction time increases with target angle and decreasing target illuminance. However, for the lower contrast case, this trending is more severe. Also for the 50% contrast case, the effect of including missed signals in the reaction time calculation is significant. In Figure 7 large differences in reaction times can be seen between the HID and halogen systems, particularly at large angles. This is due to the much greater number of missed signals under halogen illumination.

MISSED SIGNALS

Figure 8 shows a plot of missed signals vs. target location for the high contrast target case. The yaxis corresponds to the percentage number of totals targets missed. Each target is presented 4 times to the 12 subjects for a total of 48 possible target presentations to miss. The x-axis shows target location in degrees.

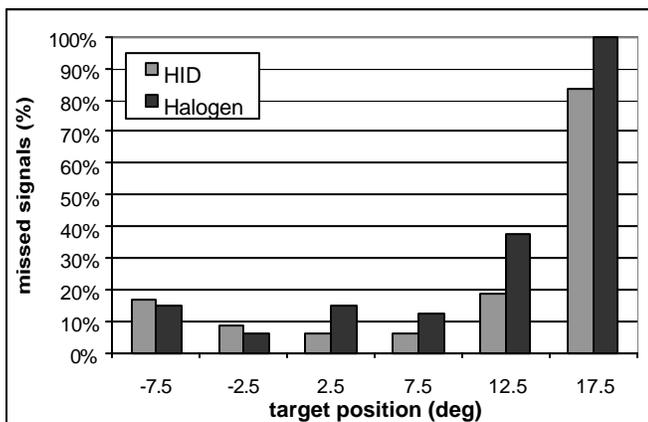


Figure 8. Percent missed signals for high contrast targets.

For all headlamps, at small angles few targets are missed. The number of missed signals is only significant for the 12.5° and 17.5° targets. The number of missed signals at these target locations does vary between the

headlamps used. The HID lamp has the least amount of missed signals. The halogen headlamp approximately twice as many missed signals at 2.5°. At 17.5° the halogen system results in all of the signals being missed.

Figure 9 shows a plot of missed signals verses target location for the 50% contrast target case. The yaxis corresponds to the percentage number of totals targets missed. Each target is presented 4 times to the 12 subjects for a total of 48 possible target presentations to miss. The x-axis shows target location in degrees.

As expected the total numbers of missed signals have increased over the high contrast case. However, the same general trends are seen again. As with reaction time, the trending is more severe with the 50% contrast targets. The numbers of missed signals increases more rapidly as the target angle increases. At only -2.5° and 7.5° the number of missed signals starts to significantly increase.

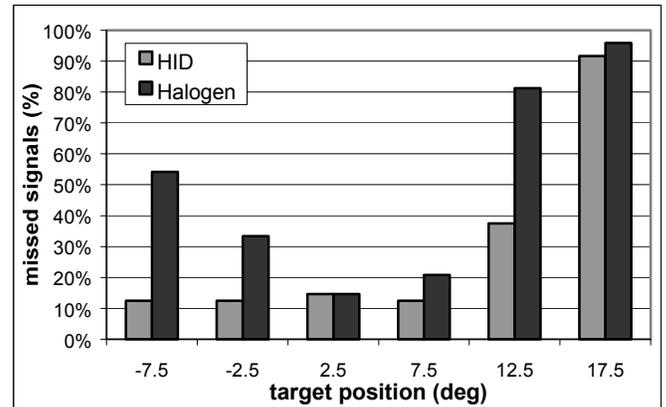


Figure 9. Percent missed signals for 50% contrast targets.

Once again the increase in missed signals is not equal for both headlamp types. The HID lamp shows the least amount and the slowest increase of missed signals. This is particularly true at 12.5° and -7.5°.

DISCUSSION

As in previous research that examined ECE beam patterns, the results of this study indicate that for these representative headlamp systems HID illumination provides relative visual benefits for off-axis vision. An increase in visual performance over conventional halogen systems is seen in both reaction time and number of targets seen. Under HID illumination, subjects had shorter reaction times and fewer missed signals at larger angle targets.

Lowering target contrast increases the total reaction time and the total number of missed signals at all visual angles. This effectively narrows the visual performance beam pattern. Although the HID headlamps result in performance that also decreases with contrast level, this decrease is not as rapid as with the halogen systems tested. Therefore the magnitude of difference between the HID system performance and the halogen system

performance increases as the contrast decreases. In other words the relative visual benefits of the HID system increases for lower contrast targets.

CONCLUSIONS

This study was performed to further explore the relative benefits for off-axis vision of HID forward lighting systems over standard tungsten halogen systems. It was shown that, as in the case of ECE beam patterns, HID headlamps producing SAE beam patterns do produce greater off-axis visual performance than traditional halogen systems due to their increased light output and SPD. The magnitude of the increase in performance differed slightly from that seen with the ECE beam pattern. This difference depends on the off-axis angle and the beam pattern.

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