Evaluation of High Intensity Discharge Automotive Forward Lighting

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Abstract

An experimental field investigation is described that compares the off-axis visual performance of HID forward lighting systems with comparable halogen systems to determine the relative visual effects of HID lighting. This has been accomplished for European beam patterns; North American beam patterns are currently being examined. The goal of the investigation is to determine if the higher off-axis intensity levels combined with the spectral properties of HID lamps provide any benefits to visual performance over conventional tungsten halogen lamps.

In this study three current production European headlamp systems, one HID and two halogen, are compared. These systems are used to illuminate a fixed scene. Subjects perform a visual tracking task, cognitively similar to driving, while, simultaneously, small targets located at various angles in the periphery are activated. Subjects release a switch upon detection and reaction times and missed signals are measured.

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 numbers of missed signals. The results are compared to a model that predicts visibility at nighttime (mesopic) light levels. Potential implications of the results on driving safety and on the development or refinement of forward lighting standards are discussed.

Introduction

In the United States and in Europe, automotive forward lighting must adhere to specifications regarding the luminous intensity distribution along the forward direction of view. These specifications ensure that the vehicle forward lighting allows for safe, comfortable driving at night without causing glare to oncoming drivers. Historically, tungsten, and then tungsten halogen, filament lamps have been used in headlamp systems to achieve these lighting standards.

In the early 90's high-intensity discharge sources were developed for vehicle forward lighting systems. HID lamps employ gas discharge rather than an incandescent filament to produce light. They offer the advantages of greater light output, higher luminous efficacy, and longer life than conventional systems using halogen lamps.[1]

Typically HID lamps produce two to three times more luminous flux than comparable halogen lamps. In general, most of this extra flux is distributed at larger angles creating a wider beam. HID headlamps also have a different spectral power distribution (SPD), being discharge rather than graybody sources. These SPDs tend to be shifted more toward the shorter visible wavelengths compared to the SPDs of tungsten halogen headlamps.

As HID headlamps increase in popularity, so do questions on their relative benefits and drawbacks. While incidental reports from drivers may indicate increased glare from HID headlamps there is also evidence of increased visual performance and safety as well. In 1999 Hamm and Steinhart reported on a static field experiment comparing visual detection thresholds of a small, low contrast target with halogen and HID headlamps.[2] From the study results, Hamm and Steinhart calculated the relative benefit, in terms of detection time and distance, provided by the HID headlamps, due to their greater light output.

Until now the impact of HID headlamps on off-axis vision was still unknown. Off-axis vision is important for driving in detecting edge-of-roadway hazards, such as pedestrians and animals, as well as providing a feeling of comfort. The properties of HID lamps may make them ideal for improving off-axis vision. As stated above, the width of an HID beam typically exceeds the width of a halogen beam pattern. This results in more peripheral light. HID lamps also produce light with different spectra than halogen lamps. While driving at night, off-axis human vision is in the mesopic response range. The mesopic range lies in-between the photopic (high light levels) and scotopic (almost no light) ranges. In this response region the eye's sensitivity shifts towards shorter wavelengths. At mesopic light levels off-axis vision is enhanced (faster reaction times, larger detection range) by the use of a lamp more closely matched to the shorter wavelength sensitivity range.[3][4] In combination, these factors may endow HID headlamps with greater nighttime off-axis visual performance that may translate into greater driving safety.

Methods

Experimental geometry

This experiment was designed to measure off-axis visual performance under different vehicle frontlighting systems. Three headlamp systems were used, one HID system and two halogen systems, all considered relatively "high quality" lighting systems and all having beam patterns corresponding to European standards. The HID system employed a Philips DS2 lamp. The measured illuminance distribution for the HID headlamp system is shown as an isolux diagram in Figure 1. The halogen A system employed an H7 Philips lamp. The measured illuminance distribution for the halogen A headlamp system is shown as an isolux diagram in Figure 2. The halogen B system employed an H4 Philips lamp. The measured illuminance distribution for the halogen B headlamp system is shown as an isolux diagram in Figure 3.

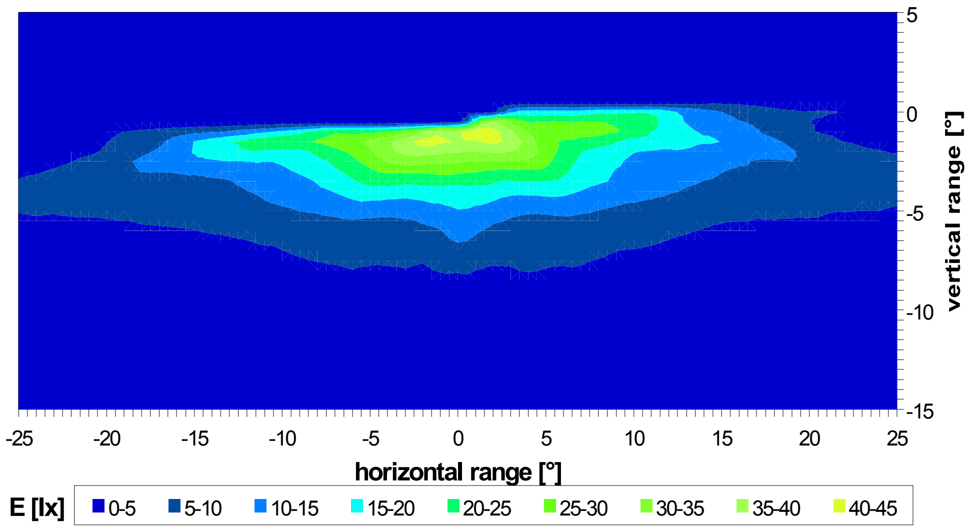

Figure 1. Illuminance distribution of HID test headlamp system.

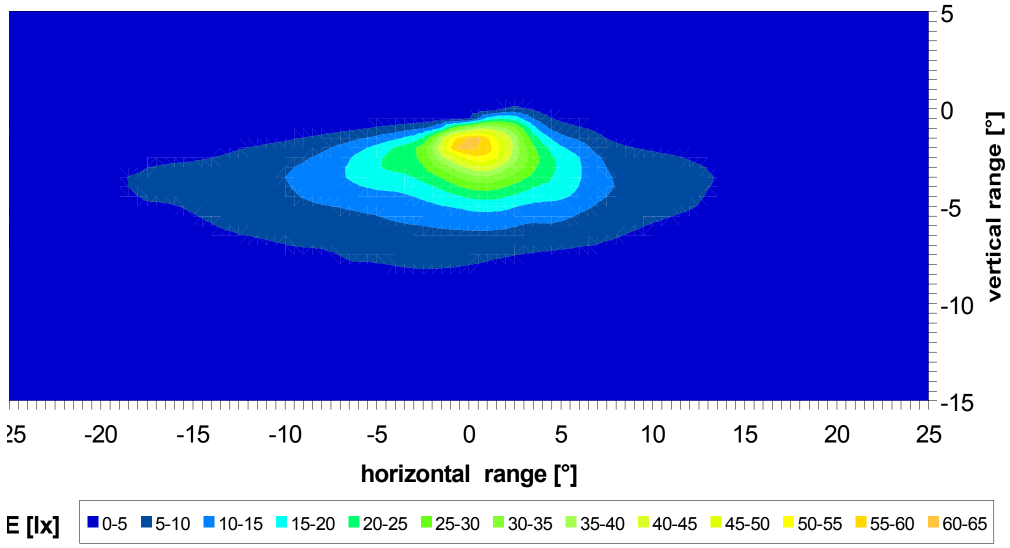

Figure 2. Illuminance distribution of halogen A test headlamp system.

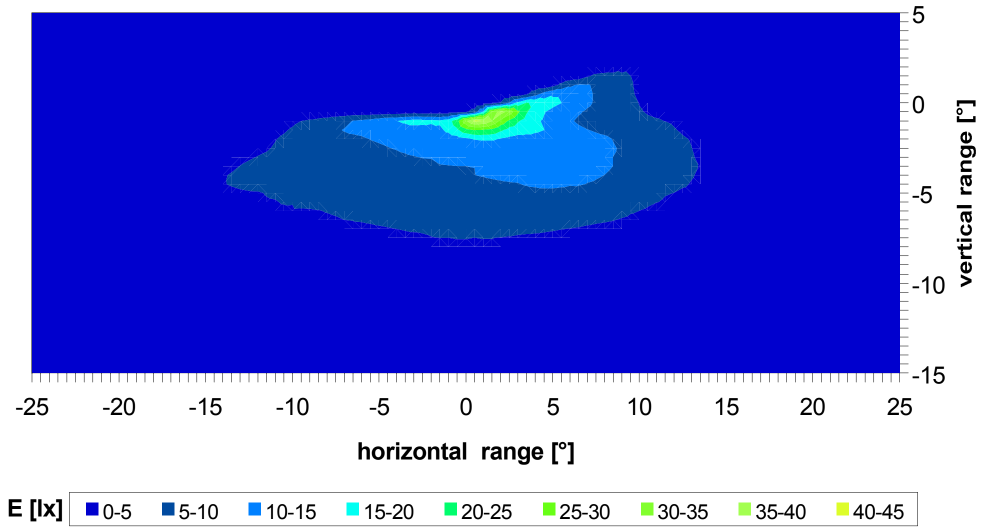

Figure 3. Illuminance distribution of halogen B test headlamp system.

In addition, two target contrast levels were used to examine the effect of contrast on visual performance under these conditions. 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 many times and the subject reaction times and numbers of missed signals were recorded.

In order to increase application validity, this experiment was performed in the field. 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 4, 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 contestant distance of 60m from the vehicle. The targets have a 5^o angular separation, with four to the right of the driver and two to the left. In both directions the targets start at 2.5^o from the line of sight. This geometry results in targets at the angular positions shown in Figure 4, where negative angles indicate to the left of the driver and positive to the right.

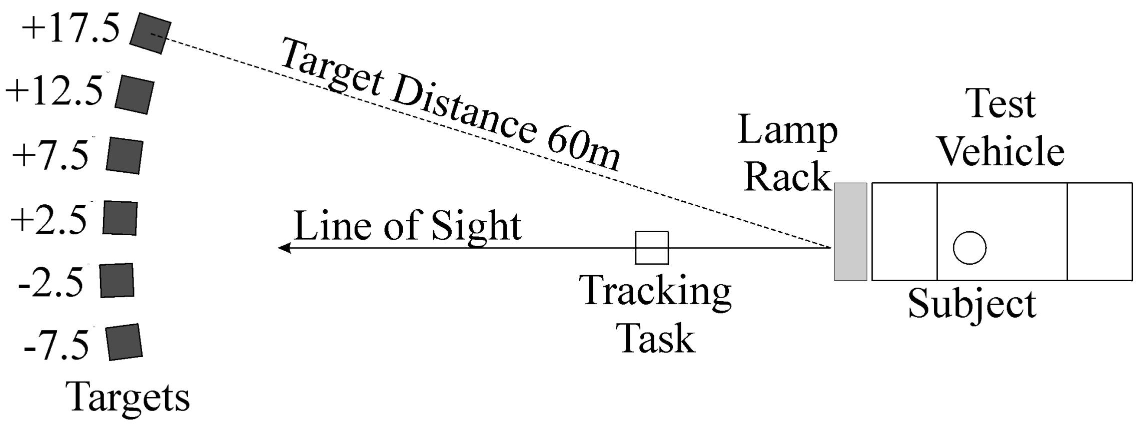

Figure 4. Schematic diagram of experimental geometry.

The headlamp systems were placed on a rack in front of the car. The subject could not see the rack from the driver's position, so it appeared that the lighting came from the vehicle. Headlamps were mounted and aimed at the correct vehicle height and separation. Aiming was performed visually using a screen at 10m.

The tracking task used consisted of an LED "bar graph". This was a vertical column of LEDs that mimicked a moving bar graph. 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.

The targets used in this experiment were 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. [5][6] The illuminance levels were measured at the targets each time the headlamps were mounted.

Figure 5 shows the average target illuminance as a function of angular target position. Each point represents the average illuminance measurement with the error bar length equal to twice the standard deviation. Note that at 2.5^{o} all three headlamps produce approximately the same illuminance. However, as the angle increases the HID lamp provides significantly more illuminance. At 17.5^{o} the illuminance from the HID headlamp is an order of magnitude greater than that produced by the halogen lamps. Also note that the halogen A headlamp produces less illuminance at larger angles than the halogen B headlamp.

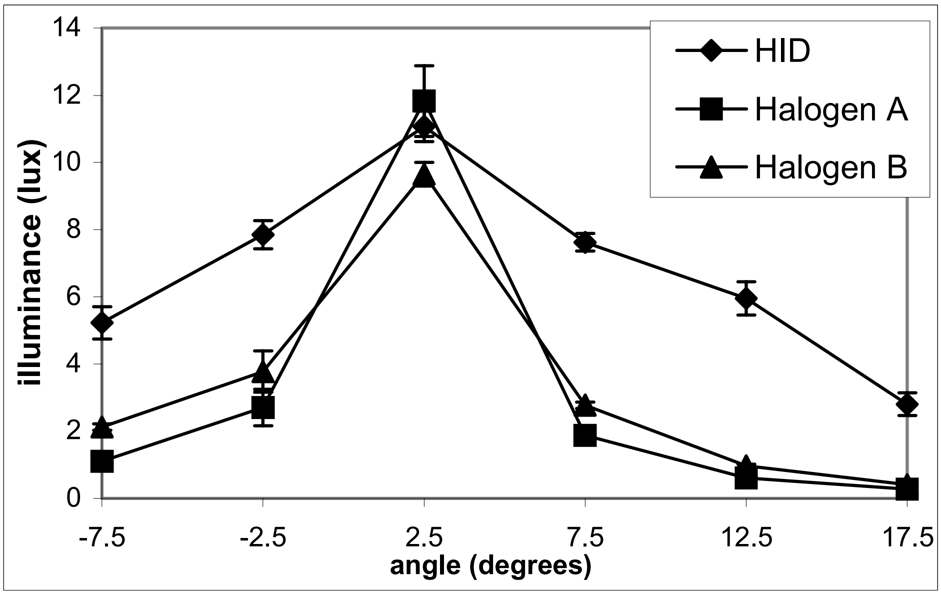

Figure 5. Plot of average target illuminance.

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%.

Procedure

The experiment was conducted as follows. 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.

Targets were presented to the subject in a random order at random time intervals. Subjects were asked to release a switch when a target was seen. If the subject did not respond in one second to the target presentation, it was considered a missed signal. 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. Care was taken to randomize the order of headlamps and target contrast levels presented. This was done to counterbalance any order effects.

Subjects

Twelve subjects were used in total. Six subject were less than 30 years old and six were over 50 years old. This age grouping ensured a relative sample of the driving population and allowed analysis of age related effects. Each subject was tested to ensure they had at least 20/20 corrected acuity and no color blindness.

Results

Reaction Times

Figure 6 shows reaction time versus target location for the high contrast target case. The y-axis shows reaction time in milliseconds. The x-axis shows target location in degrees. Each reaction time data point is the average of all subjects, 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 impact of target location on reaction time was found to be statically significant for these data ($p<0.01$).

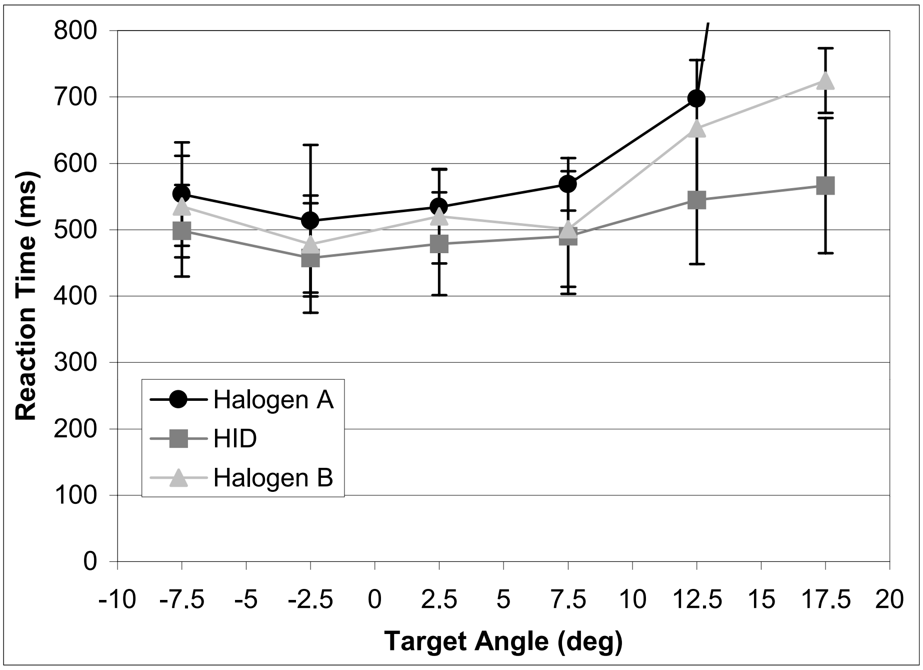

Figure 6. Average reaction times for high contrast targets.

Several things are evident from the graph in Figure 6. Generally, reaction time is lowest at the small angle targets where illuminance is highest. Reaction time increases as the target angle increases and the illuminance decreases.

For the high contrast condition, reaction times for all three headlamps are statistically similar at small target angles. As the target angle increases the reaction times for each headlamp type begin to separate. This is particularly evident at the 12.5° and 17.5° target locations. The halogen A headlamp produces the longest reaction times at these target locations and the HID headlamp system produces the shortest reaction times. In fact at 17.5° all target presentations were missed for the halogen A system and the HID system produced reaction times that are ~150ms less than that produced by the halogen B system.

Figure 7 shows a plot of reaction time vs. target location for the 50% contrast target case. Each reaction time data point is the average of all subjects, 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 impact of target location on reaction time was found to be statically significant for these data ($p<0.01$).

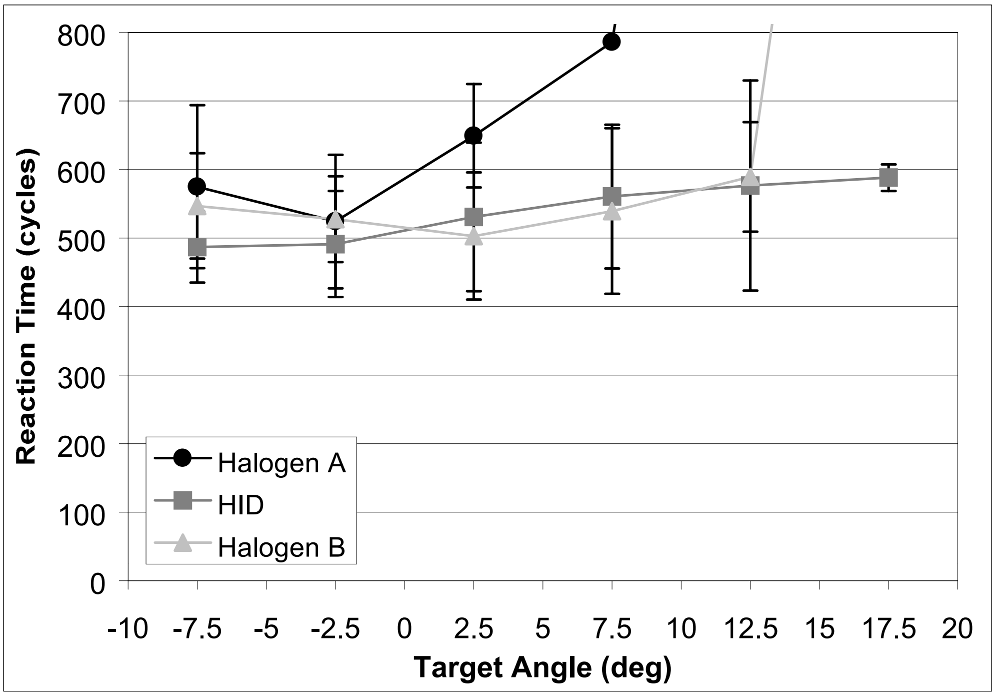

Figure 7. Average reaction times for 50% contrast targets.

Overall reaction times have increased compared to the high contrast case. However, once again the same general trends are seen as in Figure 6. Reaction time increases with target angle and decreasing target illuminance. However, for the lower contrast case, this trending is more severe and the separation between reaction times produced by the different headlamp types is larger.

At only 2.5° there is a significant separation between reaction times for the Halogen A lamp and the other headlamp systems. By 12.5° all signals are missed for the halogen A headlamp. This is consistent with the narrow beam pattern observed for the halogen A headlamp.

The halogen B and HID headlamps produce similar reaction times through 12.5°. However, as seen in the next section, the halogen B lamp is producing significantly more missed signals so the variation and error of the remaining reaction time data is greater (fewer samples). At 17.5° there is significant separation with the halogen B system producing only missed signals and the HID headlamps still resulting in reaction times under 1 second.

Missed Signals

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

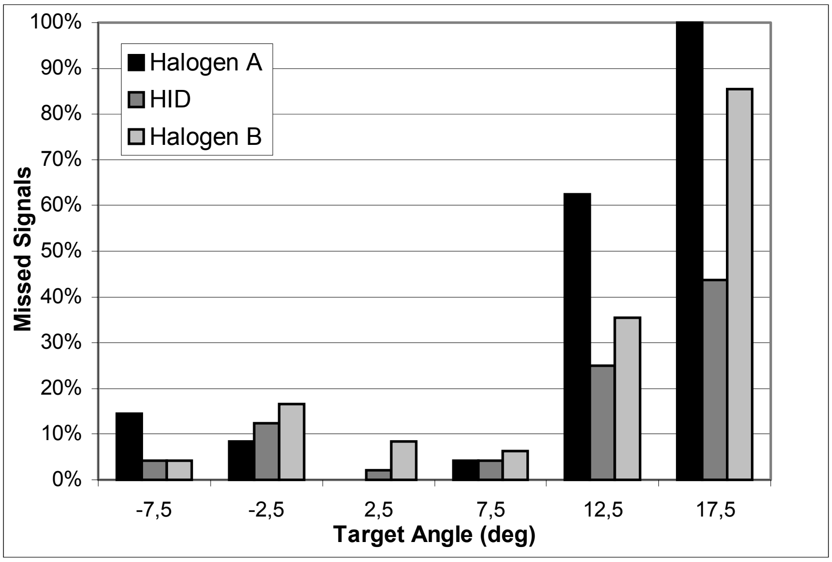

Figure 8. Percent missed signals for high contrast targets.

The same general trends as seen in the above reaction time graphs are present in Figure 8. For all headlamps, at small angles few targets are missed.

The missed targets shown in figure 7 from –7.5° to 7.5° are experimental noise. As the target angle increases, and the target luminance decreases, the number of missed signals increases.

The increase in missed signals does vary among the headlamps used. The HID lamps show the least amount and the slowest increase of missed signals. Halogen A headlamps produce a significant number of missed signals at only 12.5°, more than twice as much as the HID headlamps produce. At 17.5° the halogen A lamps results in all of the signals being missed. Missed signals also increase rapidly, more than double, for the halogen B headlamp between 12.5° and 17.5°.

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

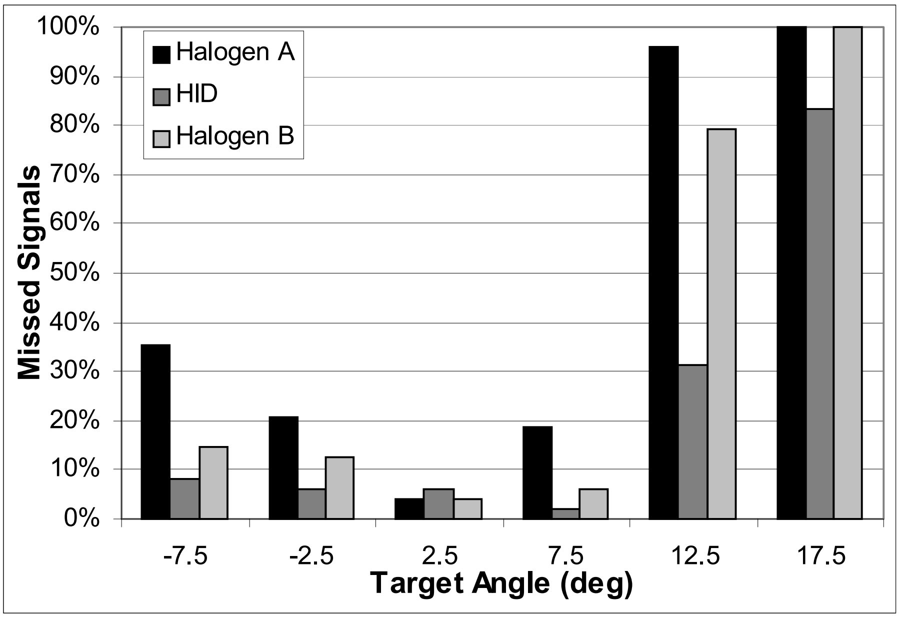

Figure 9. Percent missed signals for 50% contrast targets.

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 than with the high contrast case. The numbers of missed signals increases more rapidly as the target angle increases and the target illuminance decreases. At only 2.5^{o} in both directions the number of missed signals start to significantly increase. By 17.5^{o} degrees all targets are missed for all of the headlamps except for the HID.

Once again the increase in missed signals is not equal for the three headlamp types. The HID lamps show the least amount and the slowest increase of missed signals. This is particularly true at 12.5^{o}, where the halogen A lamps produce almost three times as many missed signals and the halogen B produce more than twice as many missed signals.

Discussion

The results of this study indicate that for these representative headlamps the HID system provides relative visual benefits for off-axis vision. The increase in visual performance is evident 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. This trend occurs regardless of subject age.

Another way to examine these data is to look at subject response as a function of target angle and illuminance, without regard to lamp type used. This approach ignores any light source spectral effects but is still useful for exploring the increasing effects of target contrast at decreasing illuminance levels. Figure 10 shows subject response, both reaction time and missed signals, for the 2.5° and 7.5° targets as a function of target illuminance. This includes the targets both to the passenger's and driver's sides.

For the 2.5° targets, shown on the top row of Figure 10, it is evident that contrast has minimum effect on performance. These targets have relatively high levels of illuminance. The reaction times show no noticeable variation over the illuminance range and the number of missed signals increases slightly with decreasing illuminance. However, little separation is seen between the two contrast levels. This indicates that for higher light levels at small visual angles target contrast is less important.

For the 7.5 ° targets, shown on the bottom row of Figure 10, it is evident that contrast is beginning to have a greater effect on performance. As the illuminance levels on these targets decreases performance in both reaction time and number of missed signals gets worse. In addition, separation is beginning to be seen between the two contrast levels, with the low contrast targets performing worse than the high contrast targets. This is particularly evident in the number of missed signals. It is evident that for lower light levels at higher visual angles, low-contrast targets reduce visual performance. This effect will increase in magnitude with decreasing target illuminance and increasing angle.

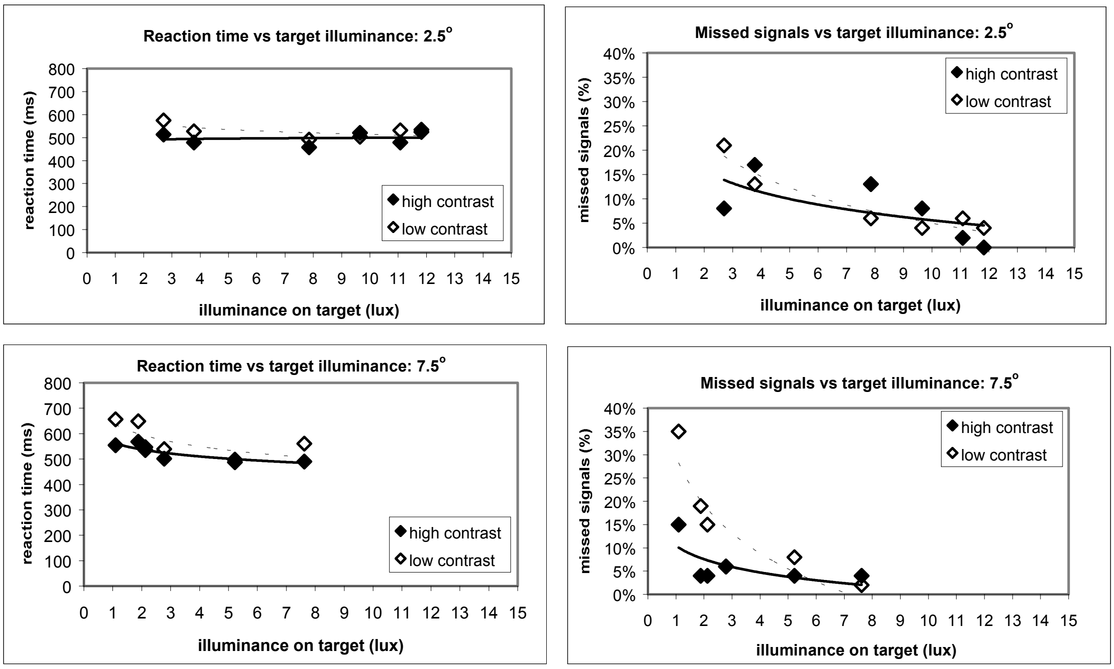

Figure 10. Subject response with target illuminance level and contrast.

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. The relative visual benefits of the HID system increases for lower contrast targets.

It is important to note that in this experiment there are two factors that may be responsible for the increased off-axis visual performance produced by the HID system: higher target illuminance and different light spectra. Since the test beam patterns were not controlled, the illuminance at the targets were as they would be in practice, there is no way to distinguish between the two effects.

Conclusion

In as closely as these systems represent typical headlamp systems, it can be generalized from this study that HID headlamps do produce greater off-axis visual performance than traditional halogen systems due to their increased light output and SPD. The magnitude of the difference in performance depends on the target contrast, target illuminance, and off-axis angle.

It is important to note however that the same properties that allow HID systems to produce greater visual performance may cause them to produce more glare. Further study needs to be performed to quantify the glare aspects of HID systems and weight them against the visual benefits shown here and elsewhere. Only then can decisions on regulations and standards be informatively made on the use of HID forward lighting systems.

Acknowledgments

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