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Optimization of Forward Lighting: Headlamp Intensity and Visibility along Curves

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Abstract

A field study to measure peripheral visual performance under various headlamp conditions, including conditions typical of halogen and high intensity discharge (HID) headlamps was conducted. The study simulated an approach of left- and right-hand turns. Targets of varying size were located at different locations along the edges of the curves, and different headlamp illumination conditions were used. Eleven subjects aged 21 to 49 years participated in the study. Reaction times and missed targets were measured. The results were consistent with previously published studies showing a benefit of increased peripheral illumination commonly found in HID headlamps on peripheral detection. Perhaps more importantly, these data can be used to make predictions of peripheral visibility under arbitrary beam patterns as a function of target characteristics and headlamp intensity, and could help identify locations within beam patterns where increased illumination is likely to be beneficial when entering curves. The findings of the present study are consistent with the findings of visual benefits with HID headlamps in earlier studies, in that the configuration with illuminance conditions most representative of HID headlamps resulted in improved target detection for targets located along a curve, over the configuration most closely matching the illuminance profile of halogen headlamps.

Keywords: ....automotive, headlamp, lamp, intensity,
HID, halogen, targets, peripheral, illumination,
visibility, beam, target, field study

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ABSTRACT

A field study to measure peripheral visual performance under various headlamp conditions, including conditions typical of halogen and high intensity discharge (HID) headlamps was conducted. The study simulated an approach of left- and right-hand turns. Targets of varying size were located at different locations along the edges of the curves, and different headlamp illumination conditions were used. Eleven subjects aged 21 to 49 years participated in the study. Reaction times and missed targets were measured. The results were consistent with previously published studies showing a benefit of increased peripheral illumination commonly found in HID headlamps on peripheral detection. Perhaps more importantly, these data can be used to make predictions of peripheral visibility under arbitrary beam patterns as a function of target characteristics and headlamp intensity, and could help identify locations within beam patterns where increased illumination is likely to be beneficial when entering curves. The findings of the present study are consistent with the findings of visual benefits with HID headlamps in earlier studies, in that the configuration with illuminance conditions most representative of HID headlamps resulted in improved target detection for targets located along a curve, over the configuration most closely matching the illuminance profile of halogen headlamps.

INTRODUCTION

This report describes a static field study to explore the role of headlamp luminous intensity on forward visibility, focusing upon left- and right-hand curve scenarios. The data and analyses herein can be used to assess the role of new headlamp technologies, such as high intensity discharge (HID) or light-emitting diode (LED) headlamps and advanced forward-lighting systems (AFS), at contributing to forward visibility as a function of parameters such as illuminance on the target, target size and target location.

BACKGROUND

The use of filament lamps (e.g., incandescent and halogen) for vehicle forward lighting applications for many decades has facilitated the development of standardized headlamp beam patterns such as the low and high beams found on all North American vehicles. With the advent of new lighting technologies, however, such as HID and LED sources, and the introduction of dynamically changing AFS systems on vehicles, the existing beam patterns are perhaps open to new questions.

For example, HID headlamps typically produce on the order of twice the light output as conventional halogen headlamps (Jost, 1995). Meeting the minimum performance requirements for headlamp performance perhaps is easier with this greater amount of light output, but many locations within the headlamp beam are also regulated with respect to the maximum permitted luminous intensity. Thus, luminous flux from HID headlamps is often distributed to locations within the beam that are not strictly regulated. These locations include the peripheral parts of the beam.

Such increases in peripheral light distribution has obvious potential advantages, including improved visibility of objects and pedestrians that might not be located along the roadway but rather, might be located off the edge of the road in the visual periphery. Indeed, a study by Sullivan and Flannagan (1999) demonstrated that the lighted environment impacts pedestrian crashes to a much larger extent than any other type of crash. Since pedestrians are typically (and hopefully) found along the roadway periphery rather than in the center of the road, lighting in the visual periphery probably has a great deal of relevance to pedestrian safety.

In the context of HID headlamps, for example, a number of researchers have investigated the potential for these lamps to improve visibility owing to their greater light output in the peripheral region. Hamm and Steinhart (1999) compared HID and halogen headlamps in terms of detection distance of small targets located throughout the field of view, finding longer detection distances with HID headlamps. Because Hamm and Steinhart did not control the gaze location of the subjects in their study it is not known whether the target detection in that study was mediated by peripheral vision. Van Derlofske et al. (2001, 2002) compared reaction times and detection probability of small targets in combination with a tracking task that ensured that targets were located in the visual periphery. Van Derlofske et al. compared halogen and HID headlamp sets conforming to European (Van Derlofske et al., 2001) and North American (Van Derlofske et al., 2002) standards. In both studies the HID headlamps both produced more peripheral light and resulted in improved peripheral visual performance relative to the halogen headlamps.

Using the raw data from the studies by Van Derlofske et al. (2001, 2002), Bullough (2002) and Bullough and Van Derlofske (2004) developed a technology-independent model of peripheral target detection based on illuminance on the target, target reflectance and target location. This model incorporates the "plateau and escarpment" principle whereby once a near maximal level of visual performance is achieved; further increases in light level will have negligible impacts on increasing visual performance (Rea and Ouellette, 1991).

The context for the studies by Hamm and Steinhart (1999) and by Van Derlofske et al. (2001, 2002) was visibility while driving along a straight road. In order to provide additional information about the role of headlamp intensity on visibility, a field study of peripheral target detection was conducted simulating approaches into left- and right-hand curves. In order to provide additional data that could be used in modeling forward visibility of an arbitrary forward lighting beam pattern, the study also modulated target size (rather than reflectance as had been employed in the studies by Van Derlofske et al. [2001, 2002]).

METHODS

Location and Scenario

The study was conducted along an unused runway at Schenectady County Airport in Scotia, N.Y. Two roadway curves (turning to the left and to the right) were delineated along the asphalt surface of the runway, as shown in Figure 1. The inner radius of each curve was 30 m, corresponding to New York State Department of Transportation design standards for collector roads at low to moderate driving speeds.

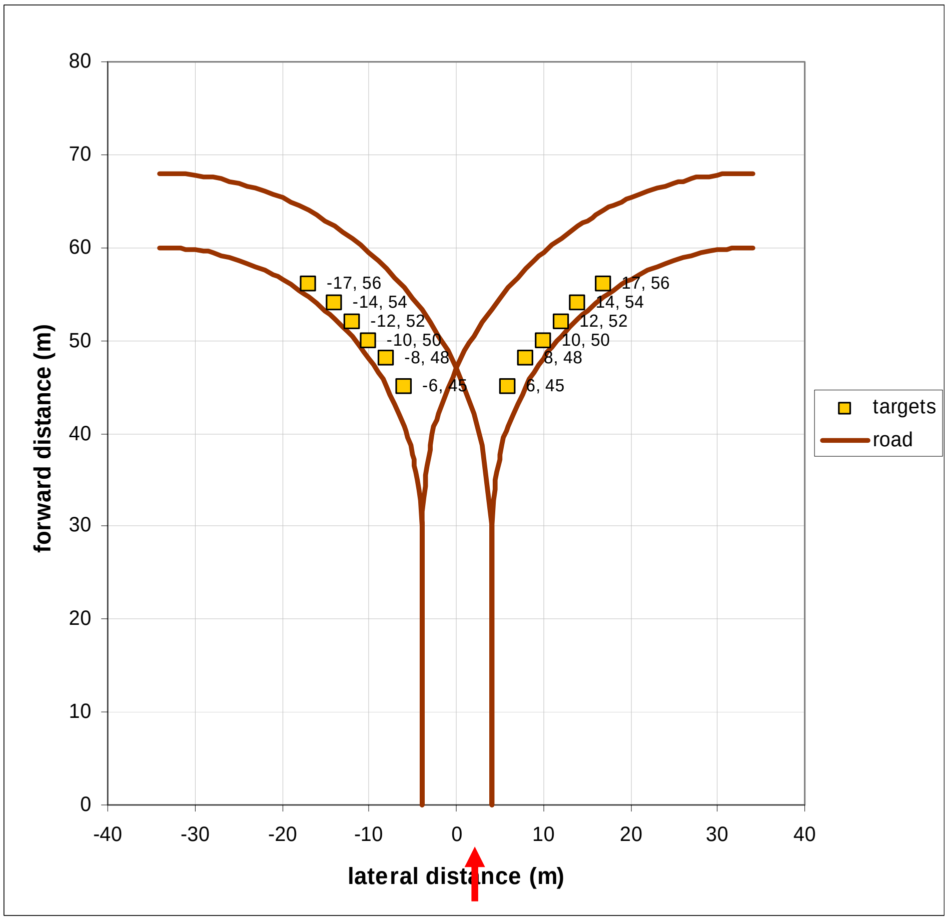

Figure 1. *Layout of roadway curves and location of targets along each side. The arrow at the bottom of the figure shows the location of the subjects performing the experiment. Starting with the centermost targets, the angles of the targets from the centerline are 7.6°, 9.5°, 11.3°, 13.0°, 14.5° and 16.9°. The angles from the line of sight when subjects were viewing the tracking task, starting with the centermost targets, are 1.9°, 3.7°, 5.6°, 7.3°, 8.8° and 11.1°.*

Apparatus

The small targets consisted of 14 x 14 square arrays of small, white flip dots (Figure 2) such as those used in changeable message signs. The square area of the area measured 20 cm along each side. The average reflectance of the array, including the black space between the flip dots, was 0.4. Through computer control some of the targets could be set to display only the 7 x 7 square area on the lower left face of the target, others were masked (when needed) with an "L"-shaped black baffle that occluded the upper- and right-three-quarters of the target. The flip dot targets were able to be controlled via personal computer (Figure 3) to flip to white with a total flip time of less than 20 ms.

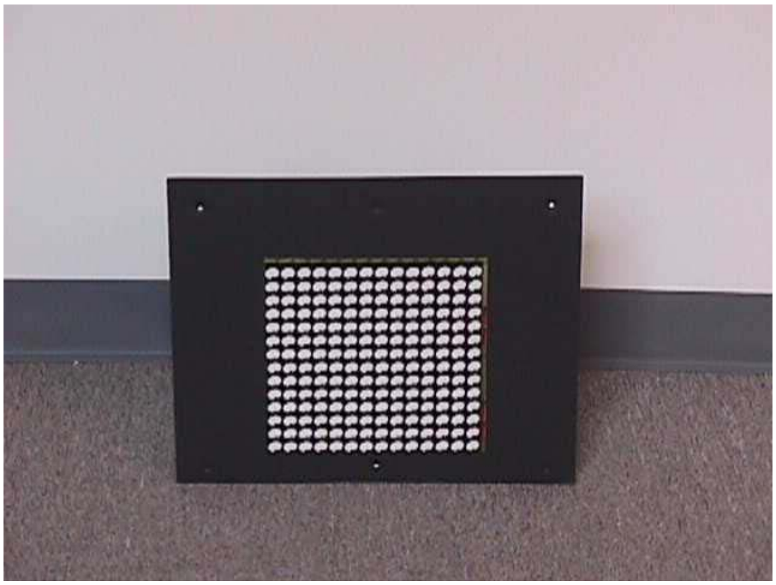

Figure 2. *Flip dot target.*

Figure 3. *Flip dot targets connected to personal laptop computer.*

The targets were placed along the left- or right-hand curve, and connected to the personal computer running Labview software through a control box that contained a microprocessor that could measure the time (within 1 ms resolution) between the onset of the target and the press of a button on another small box held by the experimental subjects. This subject box also contained a knob that permitted control of an LED tracking task (Figure 4), in which subjects continually adjusted a visual display of a bar graph made up of LEDs to reduce the bar graph to zero.

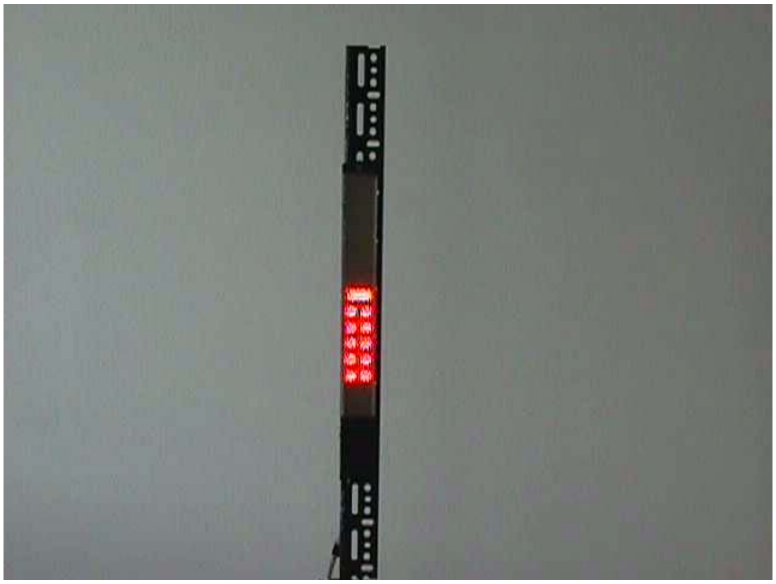

Figure 4. *LED tracking task.*

Figure 5. *Test vehicle and headlamp rack.*

Subjects sat in the driver seat of a 1994 gray Hyundai Excel parked 30 m from the entrance of the curve. In front of the Excel, a rack containing a set of HID low beam headlamps was mounted (Figure 5). These headlamps were aimed to SAE specifications at the start of each experimental session. They met the SAE requirements for low beam headlamp illumination. The unfiltered headlamp conditions consisted of the headlamps aimed in this manner, with no filtering of the lamps.

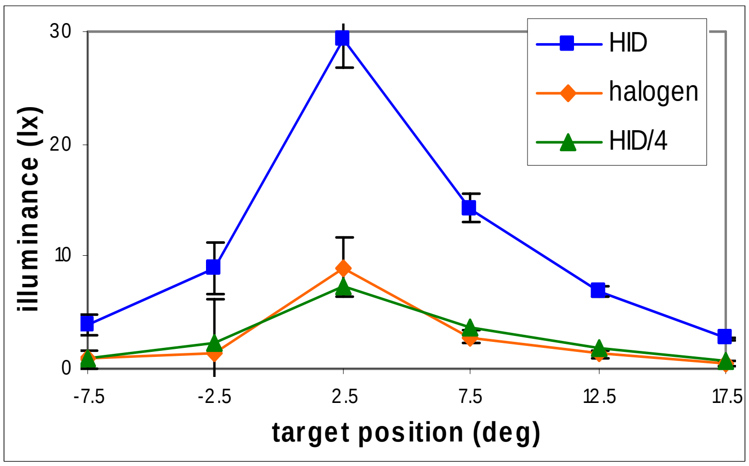

Figure 6. *Comparison of illuminances from unfiltered HID headlamps (squares), halogen headlamps (diamonds) and filtered HID headlamps (triangles).*

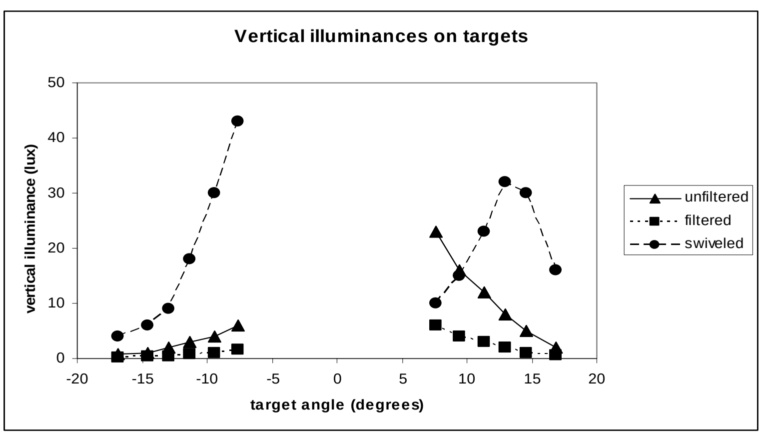

Figure 7. *Vertical illuminances on targets for each headlamp condition.*

A filtered condition was also used, incorporating a neutral density filter placed over the headlamp lens, which reduced the output from the headlamps to about one-fourth of full output. This filtering reduced the output of the HID headlamp set to an output in the peripheral region typical of halogen headlamps used in an earlier study (Van Derlofske et al., 2002) as shown in Figure 6. A third condition consisted of the unfiltered headlamp set with the mounting rack swiveled to the left or right by 10°, to increase light output toward the left or right side. Figure 7 shows the vertical illuminances on the targets for each of the three headlamp conditions.

Subjects

Eleven subjects participated in the study, consisting of eight males and three females. The age range was primarily in the young age range, ranging from 21 to 49 years. All subjects had normal or corrected visual acuity.

Procedure

Upon arriving at the experiment location, subjects completed the informed consent form and the experimental methods were described to them. After having a chance to practice the tracking task and the target response method, each subject in a given experimental session (three to four subjects participated in three nighttime sessions held August 18, August 26 and September 23, 2004) performed the tracking task and responded to target onsets, presented randomly with a 2 to 4 s random delay, under each headlamp condition, for each target size, and for each curve direction (right or left). Each subject completed three reaction time (RT) trials for each target under each of 12 conditions (3 headlamp conditions x 2 target sizes x 2 sides). The order of conditions was randomized and counterbalanced in order to minimize the potential effects of learning on the detection task.

RESULTS

Reaction Times

Figure 8 shows the mean RTs of all of the subjects for each condition, as a function of the angular distance of each target from the line of sight, using negative angles for the left-hand side and positive angles for the right-hand side. The maximum RT was 1000 ms; after this time, the next target onset was presented. A typical standard deviation for each condition is also shown. Observation of this figure shows several trends:

- RTs to the large targets (filled symbols) are shorter than to the small targets (open symbols).
- There is a general order whereby the filtered headlamp conditions result in the longest RTs and the swiveled conditions the shortest.
- The targets at the most peripheral angles tend to result in the longest RTs.

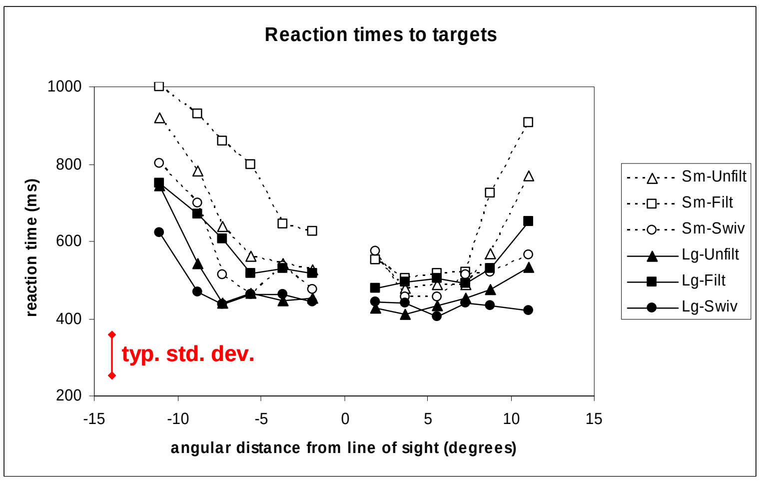

Figure 8. *RTs for each target location, target size and headlamp condition.*

Using a repeated-measures analysis of variance (ANOVA), target size, target location and headlamp condition all were shown to have statistically significant ($p<0.001$) main effects on RT. In addition, there were statistically significant interactions between target size and headlamp condition ($p<0.05$) and between target size and target location ($p<0.001$), whereby differences among the headlamp conditions and among the target locations were smallest for the largest targets. Figure 9 shows the main effects on RT.

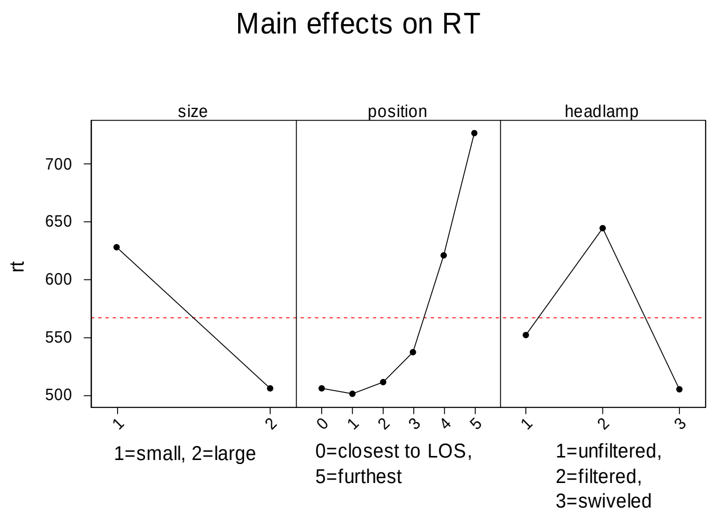

Figure 9. *Main effects of target size, target position and headlamp condition on RT.*

Missed Targets

Figure 10 shows the percentage of missed targets for each condition, plotted in a manner similar to that in Figure 8.

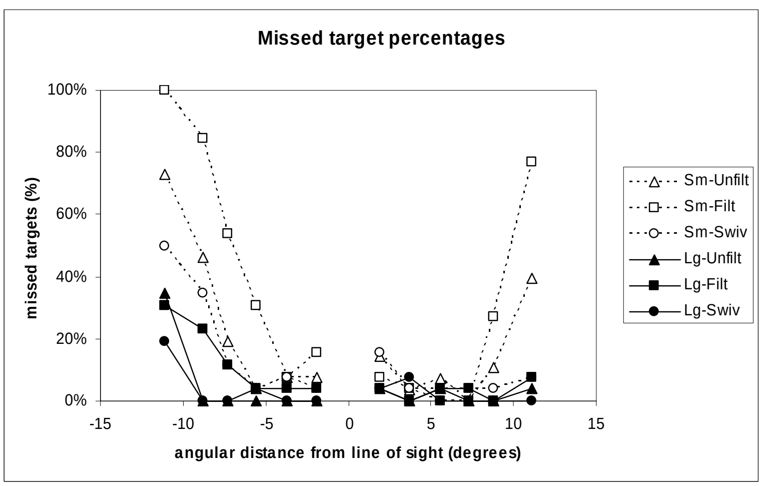

Figure 10. *Missed targets for each target location, target size and headlamp condition.*

The trends are very similar as those for RT. Using a repeated-measures ANOVA, target size, target location and headlamp condition all were shown to have statistically significant ($p<0.001$) main effects on missed targets. In addition, there were statistically significant interactions between target size and headlamp condition ($p<0.01$) and between target size and target location ($p<0.001$), whereby differences among the headlamp conditions and among the target locations were smallest for the largest targets. Figure 11 shows the main effects on missed targets.

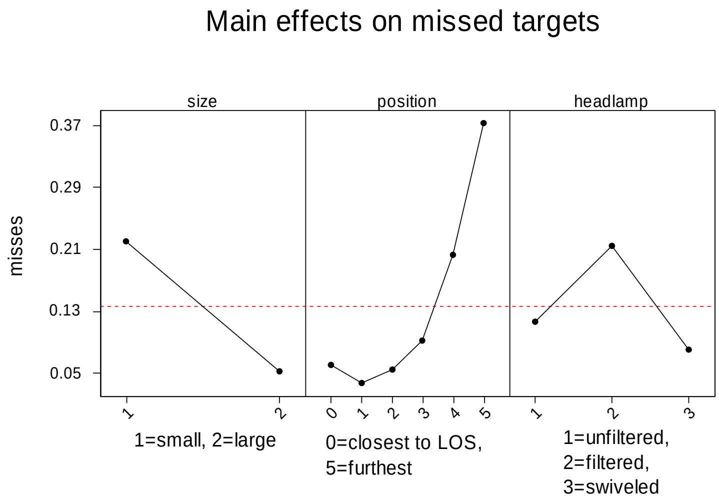

Figure 11. *Main effects of target size, target position and headlamp condition on missed targets.*

DISCUSSION

Technology Context

The data in Figures 8 through 11 demonstrate the potential for headlamp beam patterns with greater amounts of light in the peripheral region to improve visibility of targets in driving scenarios involving entering curves. Such data can be used to predict, for example, the relative impact of the halogen and HID headlamp beams used by Van Derlofske et al. (2002) in earlier studies involving straight-road conditions, because the peripheral light output of the filtered headlamp condition so closely matches the peripheral light output of the halogen headlamp as illustrated in Figure 6. Based on these data it would also be expected that the HID system used by Van Derlofske et al. (2002) would result in improved peripheral visual detection relative to the halogen system also used by Van Derlofske et al. (2002).

The data also demonstrate that yet further improvements could be made in peripheral detection performance by turning or swiveling the headlamps in the direction of interest, in a manner analogous to that proposed in certain AFS applications.

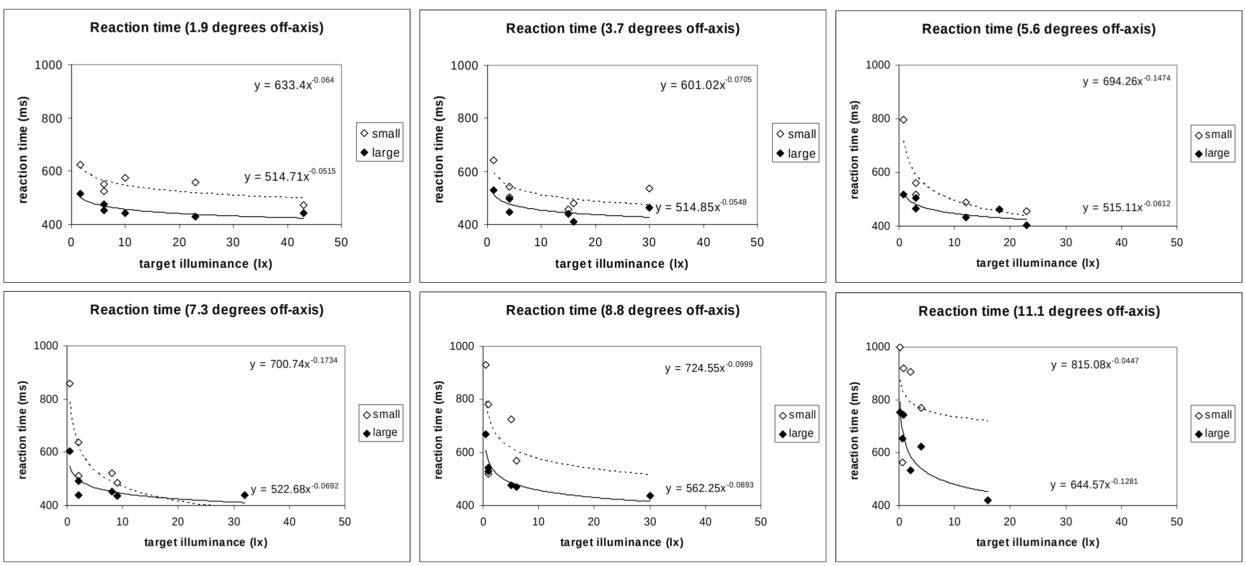

Figure 12. *RT as a function of target illuminance for each target location and target size. Also shown are the best-fitting power functions relating target illuminance to RT.*

Technology-Independent Context

Importantly too, the data presented in this report also provide a basis for comparing any beam distribution to another in terms of peripheral detection along curves. This is because the three different headlamp conditions x two side combinations provide six different illuminances for each visual location in the field of view. In fact it is possible to plot both RT (Figure 12) and missed targets (Figure 13) as a function of target illuminance, for each target location, and for each target size used in the present study.

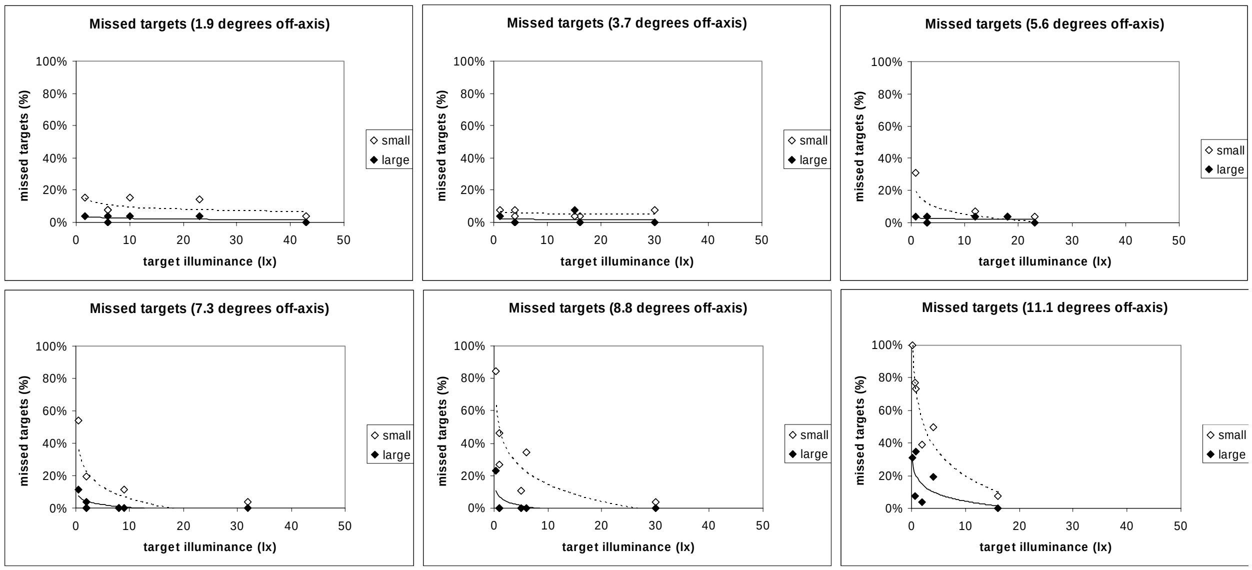

Figure 13. *Percentage of missed targets as a function of target illuminance for each target location and target size. Also shown are the best-fitting logarithmic functions relating target illuminance to missed targets.*

For example, Figure 13 shows the potential impact of increasing illuminance from headlamps from 3 to 6 lx at 3.7° from the line of sight or at 8.8° from the line of sight. For each case, the effect of this doubling of illuminance is very different. Closer to the line of sight (3.7°), visual detection performance has reached an asymptotic condition and doubling the target illuminance would have no impact on either large or small targets. Further from the line of sight (8.8°), there is only a small effect of increasing illuminance on the large targets, but a large impact (from 40% missed targets to 20%) on small targets.

Modeling Context

The data in this report can be used to extend models such as those developed by Bullough (2002) and by Bullough and Van Derlofske (2004) to predict visibility under headlamp illumination as a function of target illuminance, target characteristics and visual angles. Of interest, for example, the effect of target size in this study seems to be similar in magnitude to that of target reflectance in earlier studies by Van Derlofske et al. (2001, 2002). Of course, the target size in the present study was somewhat confounded by the fact that the targets were located at varying distances from the subjects, which gave them different apparent sizes. However, this effect would be true in a realistic driving situation as well; as one approaches an object, it becomes larger in the field of view.

CONCLUSIONS

The data presented in this report clearly show the impact of increasing headlamp intensity in certain regions of the beam pattern at improving visual detection while entering left- and right-hand curves. Such data can be used to compare specific headlamp technologies such as halogen versus HID headlamps. The data can also be used to assess the effect of changing illuminance in specific locations within the beam. It can be seen that when visual performance is near maximum, further increases in headlamp intensity will not substantially improve performance, and could in fact increase potential for creating glare to oncoming drivers. Being able to identify regions of the forward scene where additional light is likely to be of the greatest benefit will be useful for headlamp designers and decision makers considering new beam patterns or dynamically changing patterns.

The changes in target illuminances achieved in this study were comparable to illuminance differences between halogen and HID headlamps that were measured in a previous study (Van Derlofske et al., 2002). In that study, improved detection of peripheral targets in a straight-road driving context was found with HID headlamps, owing to their increased light output at peripheral angles. The findings of the present study are consistent with the findings of visual benefits with HID headlamps in that the configuration with illuminance conditions most representative of HID headlamps resulted in improved target detection for targets located along a curve, over the configuration most closely matching the illuminance profile of halogen headlamps.

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