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Optimization of Forward Lighting: Visibility and Headlamp Performance Along High-Speed Curves

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Abstract

A field study to characterize the impact of headlamp intensity on visual detection of small targets when entering high-speed curves was conducted. The results demonstrate that the relationship between headlamp intensity and visual performance depends upon the target's location and the amount of light on the target. A small but statistically significant effect of tracking task location indicates the importance of knowing where subjects are looking during such studies, but do not undermine the general trends that are found in similar studies, as long as the results are not interpreted as precise predictors of visual performance in the field.

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

CONTENTS

ABSTRACT

A field study to characterize the impact of headlamp intensity on visual detection of small targets when entering high-speed curves was conducted. The results demonstrate that the relationship between headlamp intensity and visual performance depends upon the target's location and the amount of light on the target. A small but statistically significant effect of tracking task location indicates the importance of knowing where subjects are looking during such studies, but do not undermine the general trends that are found in similar studies, as long as the results are not interpreted as precise predictors of visual performance in the field.

INTRODUCTION

This report describes a static field study to explore the role of headlamp luminous intensity and observer viewing location on forward visibility, focusing upon high-speed curve scenarios. The objective of the present study was to explore the impacts of target location and reflectance, headlamp illumination, and location of a secondary tracking task on detection of small targets located along the periphery of high-speed left- and right-hand curves. Research previously conducted by the authors (Van Derlofske et al., 2001, 2002; Bullough et al., 2006) utilized fixed viewing and tracking task locations while measuring the detection of targets illuminated by vehicle headlamps. While it has been shown that the observer's gaze location (e.g., either fixed or free) does not significantly impact perceptions of discomfort glare in the context of oncoming headlamps (Bullough et al., 2003), the impact of different viewing locations, especially upon the entrance of a curve while driving, on target detection is not well understood.

BACKGROUND

The use of new headlamp technologies to replace conventional filament based light sources for vehicle forward lighting offer several heretofore unattainable potential areas of improvement:

- The higher luminous efficacies (lumens per watt) of high intensity discharge (HID) light sources can result in increased light output in portions of the forward beam distribution without impacting overall energy use.
- The increased flexibility inherent through the use of advanced forward-lighting systems (AFS) means light levels can increase or decrease in specific regions of the beam distribution to account for special driving situations such as entering curves, inclement weather, or driving in pedestrian-rich environments.
- The durability and flexibility of solid-state, light emitting diode (LED) light sources permits them to be readily switched on and off and adjusted in luminous intensity through current control with no moving parts.

These potential areas of improvement will need to be benchmarked against existing vehicle beam distributions to determine impacts on areas such as forward visibility, discomfort glare, and driver satisfaction.

Previous research has demonstrated that increased forward illumination in the peripheral regions of the forward beam distribution, such as those often resulting from the use of HID headlamps, can result in shorter response times and increased detection probabilities of objects located along the edges of roadways (Van Derlofske et al., 2001, 2002). Using similar experimental methods, Bullough et al. (2006) showed that swiveling existing headlamp beam patterns while entering low-speed, left- and right-hand curves resulted in higher illuminances on targets placed along the curve edges and therefore resulted in shorter response times and greater probability of detecting targets within 1000 ms.

With regard to LED light source technologies, Dyble et al. (2005) demonstrated that using pulse-width modulation to reduce light output of white phosphor-based LED sources resulted in very little color shifts, compared to direct current reductions. Pulse-width modulation can be readily achieved in vehicle lighting systems and has an advantage over filament based sources in that dimming LEDs in this way does not appreciably shift the chromaticity or color appearance, whereas dimming filament sources will result in increased relative long-wavelength output and a yellower color appearance.

When approaching a curve entrance, it is probably reasonable to assume that the average driver viewing location would be biased toward the direction of the curve. For this reason, a tracking task location that results in a driver's eye gaze location straight ahead, as used in earlier research studies (e.g., Bullough et al., 2006) might not be representative of what is experienced in the real world. With respect to discomfort glare from oncoming headlamps, Bullough et al. (2003) measured subjects' ratings of discomfort while they were instructed to either maintain a fixed viewing location, or while they were permitted to gaze freely throughout the visual scene. The relative impact of light level and spectrum of the glare source on subjective ratings of discomfort were identical under both sets of instructions. However, it has not been studied whether viewing direction significantly impacts visual performance. Thus, an objective of the present investigation was to study the impact of tracking task location on target detection performance.

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 335 m, corresponding to New York State Department of Transportation design standards for driving at speeds up to 50 mph (80 km/h).

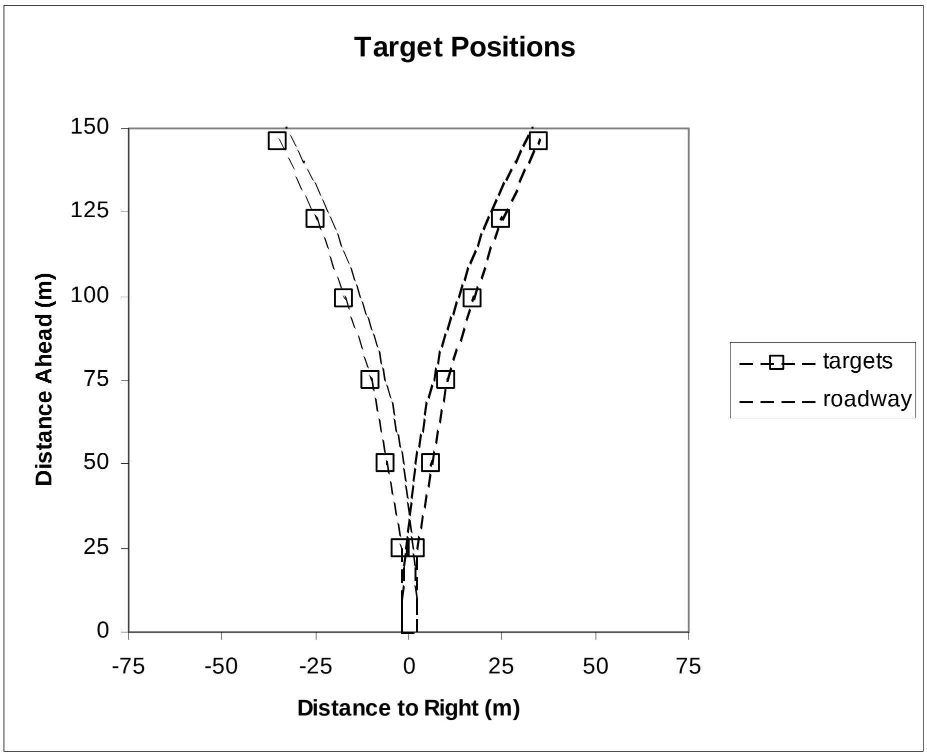

Figure 1. *Layout of roadway curves and location of targets along each side.*

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. The flip dot targets were able to be controlled via personal computer to flip to white with a total flip time of less than 20 ms.

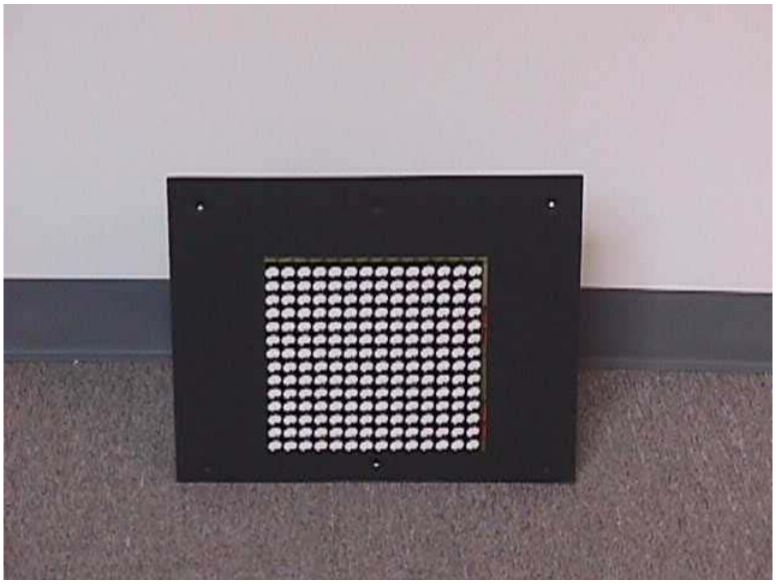

Figure 2. *Flip dot target.*

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 3), in which subjects continually adjusted a visual display of a bar graph made up of LEDs to reduce the bar graph to zero.

This tracking task was positioned in one of two locations: either straight ahead (at a nominal forward angle of 0°) or at a visual angle (approximately 7.2°) between the second- and third-closest targets, on the right-hand side for the right-hand curve and on the left-hand side for the left-hand curve.

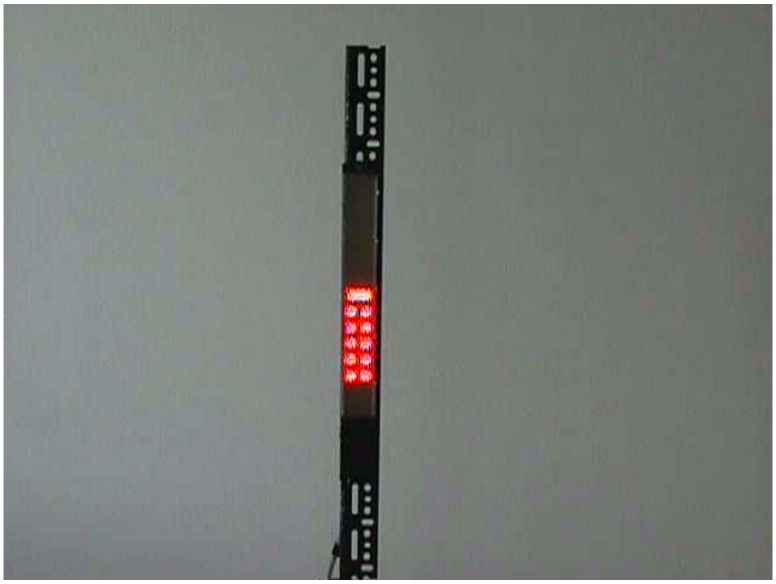

Figure 3. *LED tracking task.*

Subjects sat in the driver seat of a 1995 black Mercury Tracer passenger car parked at the entrance of the curve. In front of the car, a rack containing a set of HID low beam headlamps was mounted. These headlamps were aimed to SAE specifications at the start of each experimental session and 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.

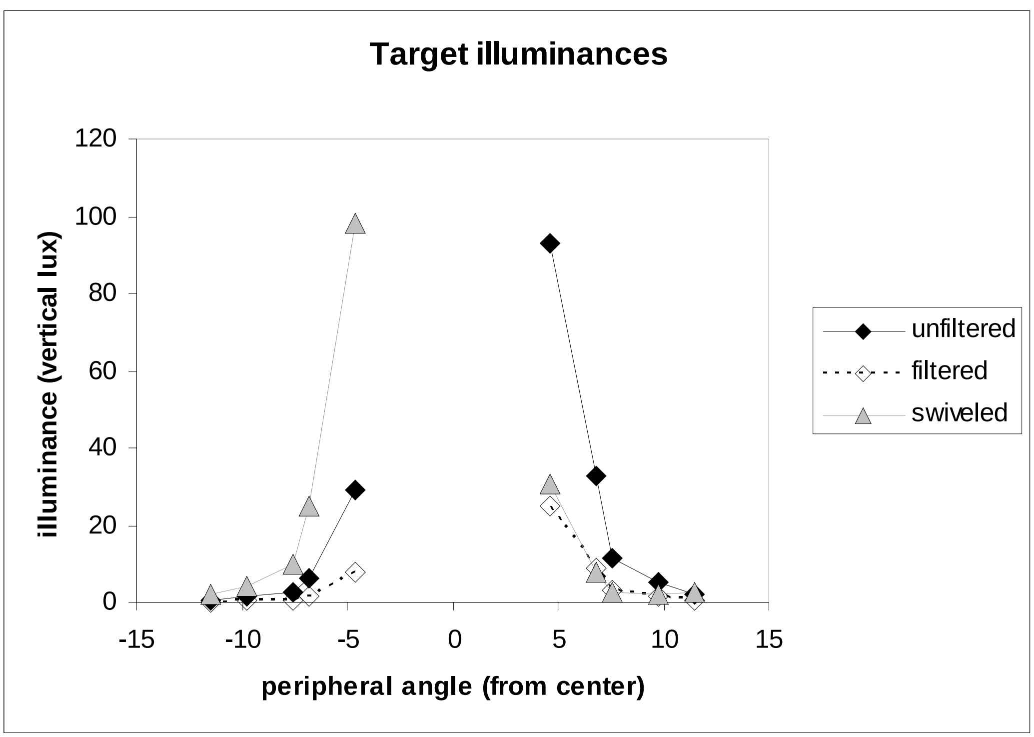

Figure 4. *Vertical illuminances on targets for each headlamp condition.*

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). A third condition consisted of the unfiltered headlamp set with the mounting rack swiveled to the left or right by 10^{o}, to increase light output toward the left or right side. Figure 4 shows the vertical illuminances on the targets for each of the three headlamp conditions.

Subjects

A total of 14 subjects participated in the study. The age range was primarily in the young age range, ranging from 21 to 51 years. All subjects were licensed drivers and had normal or corrected visual acuity.

Procedure

Upon arriving at the experiment location, subjects completed an 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 performed the tracking task and responded to target onsets, presented randomly with a 2 to 4 s random delay, under each headlamp condition and for each curve direction (right or left). Each subject completed three reaction time (RT) trials for each target and each lighting condition (unfiltered, filtered and swiveled). The curve during each nighttime session was set to be either a right- or a left-hand curve. In total, ten subjects completed the left-hand curve trials and eleven completed the right-hand curve trials. Seven subjects completed trials for curves of both sides. The order of all conditions presented to subjects, including the location of the tracking task (at 0^{o} or at 7.2^{o}) was randomized in order to minimize the potential effects of learning on the detection task.

RESULTS

Reaction Times

Figure 5 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 (following a 2- to 4-second delay). The standard deviation values for each mean value are also shown. Observation of this figure shows several trends:

- The targets at the most peripheral angles tend to result in the longest RTs.
- There is a general order whereby the filtered headlamp conditions tend to result in the longest RTs; for left-hand curves, the swiveled conditions tended to result in the shortest RTs, while for right-hand curves, the unfiltered conditions tended to result in the shortest RTs.

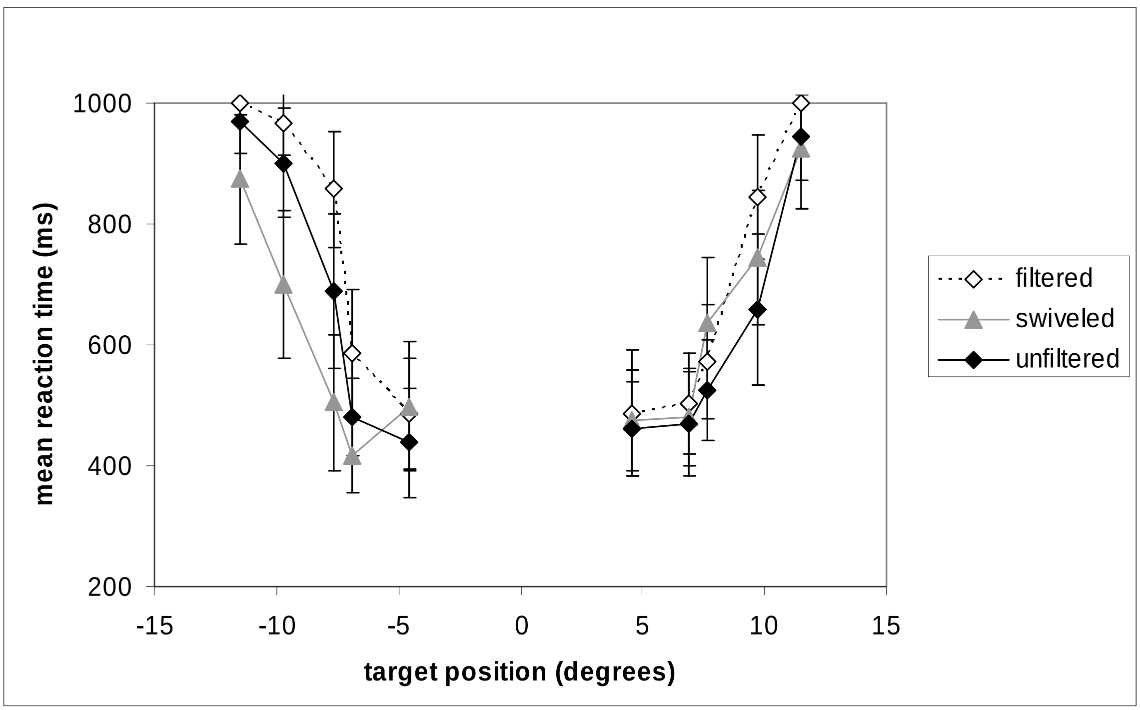

Figure 5. *RTs for each target location and headlamp condition.*

For the targets on the right-hand curve, a repeated-measures analysis of variance (ANOVA) was conducted. Lighting condition, target location and tracking task location all were shown to have statistically significant ($p<0.05$) main effects on RT. In addition, there were statistically significant two-way interactions between target location and lighting condition ($p<0.05$) and between target location and tracking task location ($p<0.05$).

For the targets on the left-hand curve, a repeated-measures ANOVA revealed statistically significant ($p<0.05$) effects of lighting condition and target location on RTs, as well as a statistically significant two-way interaction between these factors, but there was not a statistically significant effect of tracking task location.

Missed Targets

Figure 6 shows the percentage of missed targets for each condition, plotted in a manner similar to that in Figure 5.

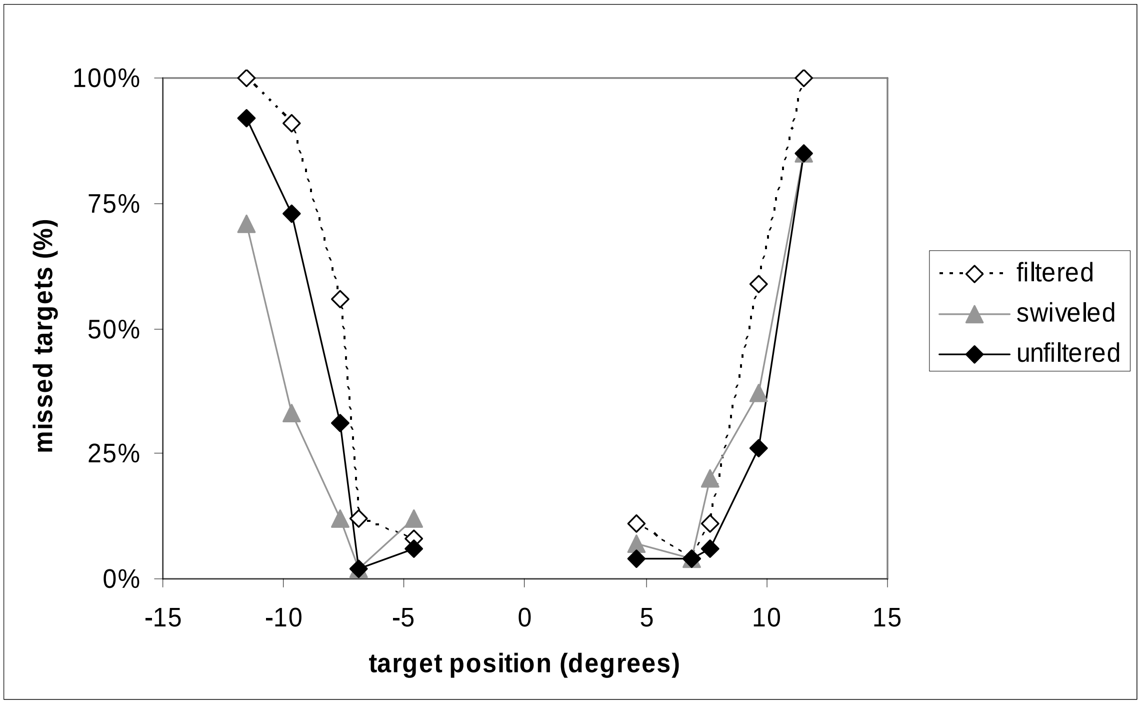

Figure 6. *Missed targets for each target location, target size and headlamp condition.*

The trends are very similar as those for RT; in fact, the RT values and missed target percentages in Figures 5 and 6 are highly correlated with each other (r^2=0.96). Using a repeated-measures ANOVA for the right-hand-curve conditions, target location, lighting condition and tracking task location all were shown to have statistically significant ($p<0.05$) main effects on missed targets. In addition, there were statistically significant interactions between target location and lighting condition ($p<0.05$), and between target location and tracking task location ($p<0.05$). A statistically significant three-way interaction was found among lighting condition, target location and tracking task location.

A repeated-measures ANOVA for the left-hand curve conditions revealed statistically significant ($p<0.05$) main effects of lighting condition and target location on missed targets, The two-way interaction between these factors was also found to be statistically significant.

DISCUSSION

The data in Figures 5 and 6 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 high-speed curves. As with previously reported data (Bullough et al., 2006), such data could be used to predict the relative impact of different headlamp light source technologies (e.g., halogen and HID). As both Figures 5 and 6 illustrate, differences among conditions producing different amounts of forward illumination are smallest for targets closest to the line of sight and closest to the observer, where their larger size makes them more readily detected. Only for more distant targets does a clear separation among the lighting conditions become more apparent on RTs (Figure 5) and missed target percentage (Figure 6).

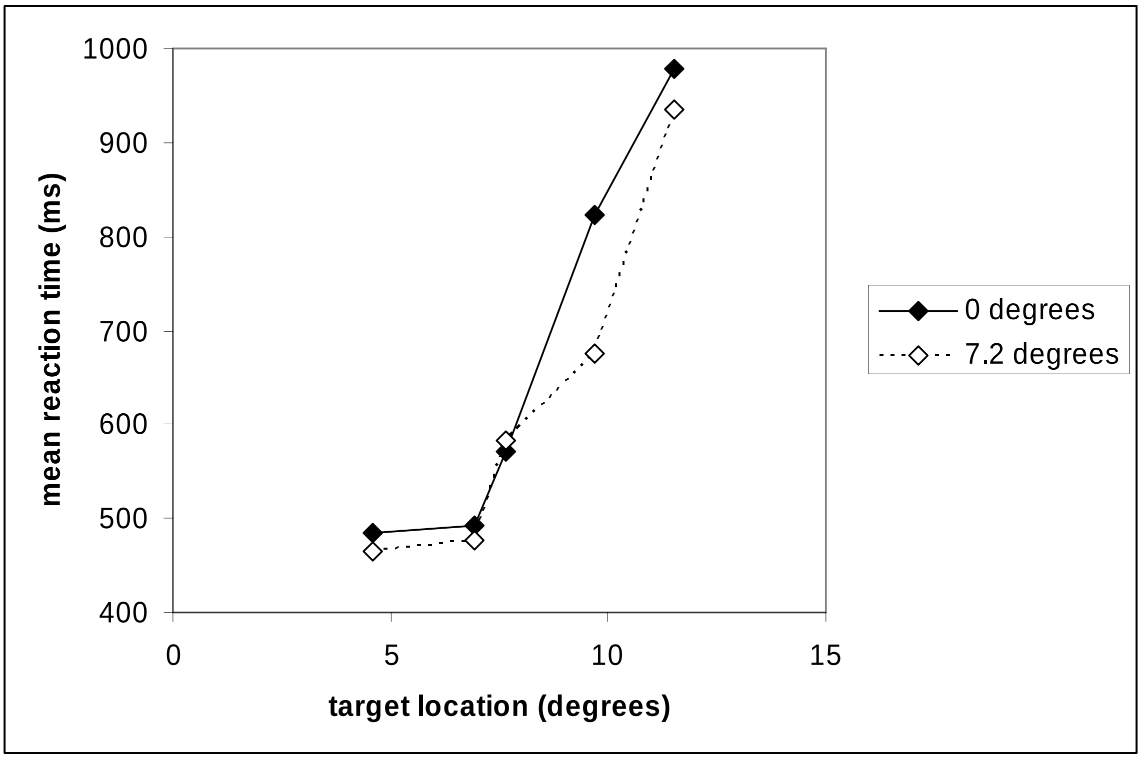

Figure 7. *Illustration of interaction between tracking task location (either 0° or 7.2° from the line of sight) and target location on RTs.*

Interestingly, there was a reliable effect of tracking task location on RT and missed targets for the right-hand curves only, but not for the left-hand curves. Figure 7 illustrates that the tracking task location had little impact on RTs for the closest targets (Figure 8 shows the same trend for missed targets), but the location of the tracking task did affect RTs (Figure 7) and missed targets (Figure 8) for the more distant and off-axis targets. For both RT and missed target responses, moving the tracking task toward the direction of the curve improved target detection performance, as might be expected, since the targets would be closer to the line of sight under these viewing conditions. Yet no such effect was found for the left-hand curves, where the effect of the tracking task location was negligible. Why was this difference found?

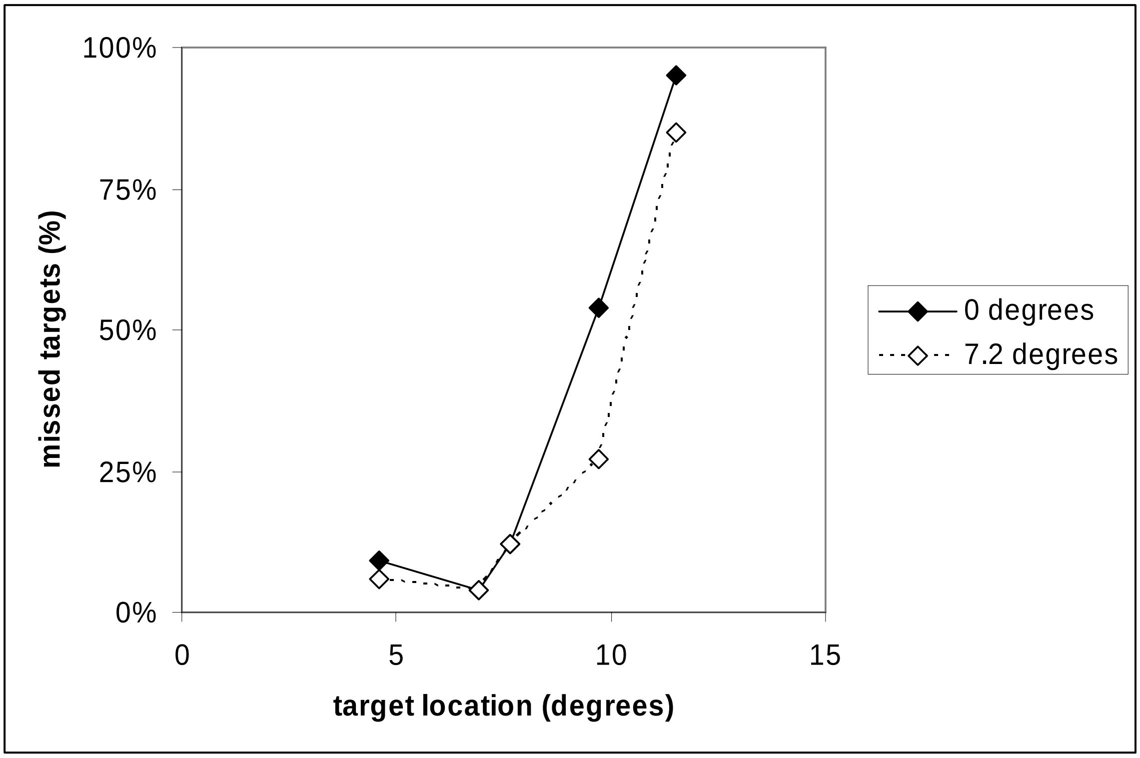

Figure 8. *Illustration of interaction between tracking task location (either 0° or 7.2° from the line of sight) and target location on missed targets.*

One possible reason could be that all headlamp systems designed for roadways where driving is done along the right-hand lane produce their maximal illuminances toward the right-hand side (at least in North America, where this study was performed, and in most other countries). This might have produced a bias among subjects in the present study to look toward the right-hand side of the experimental road and therefore to be more sensitive to changes in the visual task in this portion of the field of view. Further, the location of maximum headlamp intensity for two out of the three lighting conditions (filtered and unfiltered) would have been among the targets on the right-hand curve but not on the left-hand curve, because of the inherent left-right asymmetry in headlamp beam patterns. This so-called "hot spot" could have served to attract attention toward the right-hand side of the visual scene, again possibly making subjects more sensitive to changes in illuminance on the targets along this side of the scene.

Certainly, this speculation must be confirmed experimentally before it could be accepted as a conclusion rather than a preliminary hypothesis. Nonetheless, it should be recalled that the impact of the tracking task location on visual detection of small targets was relatively small in comparison with the effects of overall light level and of the location of the targets of interest. This may support the use of a single tracking task location in future studies to measure visual performance, recognizing that the response measures are relative comparisons among lighting conditions and not absolute predictors of target detection performance.

CONCLUSIONS

The present results build upon the results of previously reported studies using similar methodologies (Van Derlofske et al., 2001, 2002; Bullough et al., 2006) to demonstrate the impact of headlamp intensity on target detection performance. They illustrate that the relationship between headlamp intensity is weakest for targets closest to the driver and closest to the line of sight, and becomes stronger as targets move away from the observer and further from the line of sight. Modification of headlamp beam patterns through swiveling of low beam headlamp distributions at a fixed angle of 10° toward the side of the curve probably "overshoots" high-speed curves toward the right-hand side, but will increase illumination along left-hand, high-speed curves. A small but statistically significant effect of tracking task location indicates the importance of knowing where subjects are looking during such studies, but do not undermine the general trends that are found in similar studies, as long as the results are not interpreted as precise predictors of visual performance in the field.

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