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High-Beam Intensity, Visual Performance and Safety-Related Impacts

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Abstract

It has been understood for many years that driving above certain speeds at night while using low beam headlights can result in insufficient visibility to respond to hazards on the road. As new vehicle headlighting technologies emerge, the practicality of intelligent, adaptive high-beam functions has increased so much that these systems are now commercially available in many parts of the world. These technical developments in turn invite questions about the optimal photometric performance of high beam headlights. One important barrier to the more frequent use of high beam headlighting systems has been concerns about creating glare to the drivers of oncoming and preceding vehicles. If it can be demonstrated that adaptive high-beam control can provide acceptable glare control, it may be possible to question the need for the current limits on the luminous intensity of high-beam headlights. In this report, visual performance analyses are summarized that allow the evaluation of the potential benefits of increased luminous intensity on forward visibility, and potential implications for driving safety are discussed.

Keywords: .... headlights, safety, high beam, visual performance, visibility, adaptive headlights

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ABSTRACT

It has been understood for many years that driving above certain speeds at night while using low beam headlights can result in insufficient visibility to respond to hazards on the road. As new vehicle headlighting technologies emerge, the practicality of intelligent, adaptive high-beam functions has increased so much that these systems are now commercially available in many parts of the world. These technical developments in turn invite questions about the optimal photometric performance of high beam headlights. One important barrier to the more frequent use of high beam headlighting systems has been concerns about creating glare to the drivers of oncoming and preceding vehicles. If it can be demonstrated that adaptive high-beam control can provide acceptable glare control, it may be possible to question the need for the current limits on the luminous intensity of high-beam headlights. In this report, visual performance analyses are summarized that allow the evaluation of the potential benefits of increased luminous intensity on forward visibility, and potential implications for driving safety are discussed.

INTRODUCTION

The objective of vehicle headlighting is to make potential hazards such as pedestrians, vehicle and other objects in and along the roadway visible to drivers. Accomplishing this objective should be done while minimizing glare to the drivers of oncoming and preceding vehicles. It is often assumed that the optimization of forward visibility and glare involves a tradeoff between these two factors. In other words, increases in headlamp intensity to improve forward visibility will simultaneously, but necessarily, increase glare (Perel et al., 1983). Although this is largely true when static low and high beam patterns are used, recent technological developments such as adaptive lighting seem to indicate that a strict tradeoff between visibility and glare can be overcome. The ability for real-time modification of a headlight beam pattern in response to the presence of vehicles along the road, while maintaining high intensity levels throughout the visual scene while reducing the intensity in the direction of other drivers (Skinner and Bullough, 2009; Flannagan and Sullivan, 2011; Neumann, 2014; Bullough, 2014a), is increasingly being demonstrated to improve overall visibility (and safety) for drivers with these systems as well as for the drivers facing them. And, as has been pointed out (Flannagan and Sullivan, 2011), the progress in adaptive systems calls into question the necessity to restrict luminous intensity requirements (such as the 75,000 cd maximum intensity for high beams in North America) for vehicle headlights.

Recently, Rosenhahn et al. (2014) measured observers' ability to detect and recognize targets located 250 m ahead, that varied in shape (rectangle, triangle, or human-shaped) and contrast (C=0.15, C=0.52, or C=0.85), under high-beam headlighting conditions with peak luminous intensities (for each headlight) of 60,000 cd (a typical peak luminous intensity of North American high beam headlights), 116,250 cd, or 227,000 cd (which is close to the maximum permitted peak intensity based on European requirements). Increased headlight intensity resulted in fewer missed targets, with an average of 33% missed targets at the lowest intensity, 20% missed targets for the intermediate intensity, and 9% missed targets for the highest intensity value. The shape of the target had little impact on detection. This is not unexpected, since all of the targets subtended similar visual angles (Rea and Ouellette, 1991). Additionally, targets with lower contrast were less frequently detected, and target detection was easier than target recognition.

Bullough et al. (2013) proposed a method for evaluating lighting conditions using a model known as the relative visual performance (RVP) model (Rea and Ouellette, 1991). In this model, the speed and accuracy for detecting and identifying potential hazards in and along the roadway while driving is assessed. The RVP model was developed based on target detection and numerical verification tasks that were conducted under a wide range of light levels (spanning the mesopic and photopic ranges), sizes, and contrast values. Negative RVP values indicate when a target can be seen but it cannot be recognized. An RVP value of 0 corresponds to the threshold for identification or recognition; an RVP value of 1 corresponds to a reference condition with very high levels of visibility, like those experienced when reading large, high-contrast printed text under office lighting levels. The RVP model also predicts visual response times to targets under the specified lighting conditions. As Bullough (2014b) has summarized, RVP model quantities are strongly correlated with visual response times (Bullough et al., 2012), visual detection distances (Bullough and Skinner, 2009), and real-world nighttime crash frequency reductions (Bullough et al., 2013) in a number of studies. Interestingly, an RVP value of 0.8 has been found in many studies to correspond to the point at which a driver would start to brake or perform another corrective maneuver in response to a potential roadway hazard. Under the assumption that adaptive driving beams could reduce glare from intense headlight patterns toward other drivers, the RVP model is used as a metric in the present report to assess the effects of a range of high-beam headlight peak intensities on forward visibility of targets with similar characteristics as the ones used by Rosenhahn et al. (2014) in their recent field experiment.

METHOD

For distances ranging from 600 m to 20 m in front of a driver, the solid angular size (in steradians) of a 1 m x 0.5 m target was determined. Three contrast values of C=0.85 (H), C=0.52 (M) and C=0.15 (L) were used, and the background luminance was calculated from the peak headlight intensity (60,000 cd, 116,250 cd, or 227,000 cd) assuming a background reflectance of 6%, as used in the experiment conducted by Rosenhahn et al. (2014). Using these data, RVP values corresponding to each distance (between 600 m and 20 m) for a driver ages 30 years old were calculated. Additionally, the distances at which each of the targets would be predicted to become just detectable, just recognizable (RVP=0), and at which a driver might begin to brake or begin another avoidance maneuver in response to a roadway hazard (RVP=0.8), were calculated.

RESULTS

Figure 1 shows the RVP values (when RVP was greater than or equal to zero) plotted as a function of the viewing distance, for each combination of high-beam headlight peak intensity and target contrast (denoted L, M or H). Similar to the experimental results from Rosenhahn et al. (2014), higher intensities and higher target contrasts were predicted to result in improved visibility. Table 1 shows the maximum distances, for each combination of headlamp intensity and target contrast, where the target was just detectable, just identifiable (RVP=0), and at which a driver might initiate a braking or other avoidance maneuver (RVP=0.8).

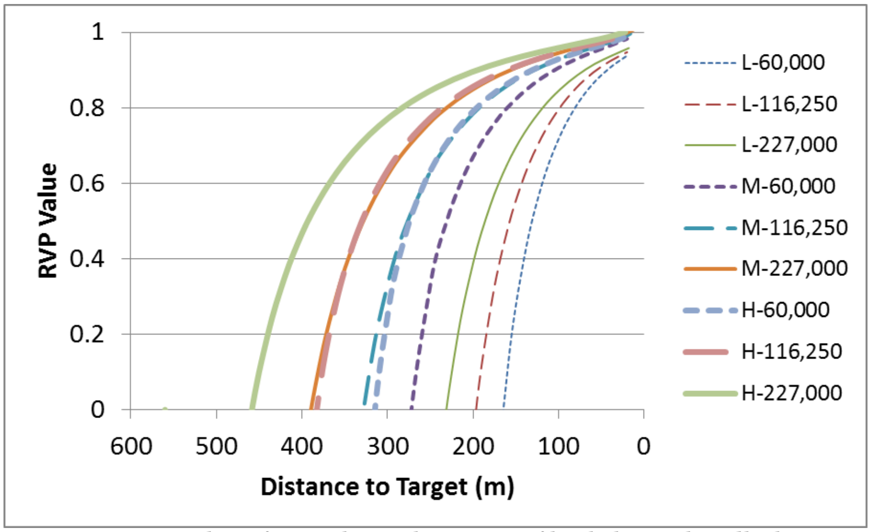

Figure 1. RVP values for each combination of high-beam headlight intensity (60,000 cd, 116,250 cd, or 227,000 cd) and target contrast value (L, M or H), plotted as a function of the distance to the target.

Response	Peak Intensity	Distance for Target Contrast:		
		Low	Medium	High
Detection	60,000 cd	225 m	323 m	351 m
	116,250 cd	269 m	401 m	445 m
	227,000 cd	315 m	485 m	548 m
Identification	60,000 cd	164 m	272 m	313 m
	116,250 cd	196 m	327 m	382 m
	227,000 cd	231 m	389 m	458 m
Initiate Braking	60,000 cd	80 m	160 m	196 m
	116,250 cd	98 m	193 m	236 m
	227,000 cd	118 m	230 m	282 m

Table 1. Distances for three different visual responses to each combination of headlight intensity and target contrast value.

At a distance of 250 m, which was used by Rosenhahn et al. (2014) in their study, increasing the headlight intensity from 60,000 to 227,000 cd resulted in a decrease in the RVP-based visual response time from infinity (i.e., undetectable under a headlamp intensity of 60,000 cd) to 1.43 s for low-contrast targets; from 0.85 s to 0.51 s for medium-contrast targets; and from 0.61 s to 0.45 s for high-contrast targets. Using the transfer function relating visibility (RVP) and safety (nighttime crash reductions) developed by Bullough et al. (2013), these visual response time reductions correspond to nighttime crash frequency reductions (for crashes involving hazards located 250 m ahead) of 15% for high-contrast hazards, and of 31% for medium-contrast hazards. Since RVP is undefined for the low-contrast hazard at the lowest headlamp intensity, it is not possible to estimate a corresponding nighttime crash frequency reduction value for the low-contrast targets. It should be noted, however, that what is not yet known is the absolute number of crashes that would be caused by a driver not being able to see a hazard located 250 m ahead along the roadway.

However, the information in Table 1 can be used to identify whether the distance at which a driver might initiate braking after detecting and identifying a hazard (where RVP=0.8) are short enough to present a possible safety issue. For dry and wet asphalt pavement and for vehicle tires in good condition (Jones and Childers, 1993), one can estimate the stopping distance of a passenger vehicle for the three different driving speeds listed in Table 2. In several cases, indicated by shaded cells in Table 2, the stopping distances are equal to or exceed distances in Table 1 at which RVP=0.8, when drivers might be expected to start a braking or other avoidance maneuver upon seeing a roadway hazard.

Driving Speed	Stopping Distance (Dry)	Stopping Distance (Wet)
80 km/h	36 m	63 m
100 km/h	56 m	98 m
120 km/h	80 m	142 m

Table 2. Vehicle stopping distances for dry and wet pavement at several driving speeds. Shaded cells indicate stopping distances that are equal to or longer than distances in Table 1 at which drivers might initiate braking maneuvers to possible hazards.

DISCUSSION

The analyses detailed in the previous section of this report suggest that increases in allowable high-beam headlight peak intensities from a typical North American value (such as 60,000 cd) to much higher values could have meaningful impacts on safety. It should be noted that Kloeden et al. (1999) analyzed crashes involving roadside hazards, and found that most of these types of crashes occurred during the nighttime (with a much higher rate of incidence in wet conditions), and they recommended reducing speed limits to no more than 110 km/h along rural roadways, when vehicle headlights would be likely to be the only source of illumination. The recommendations from Kloeden et al. (1999) and the results from the present analyses are largely in agreement. Since it is now technologically feasible to mitigate glare within a portion of a headlight beam pattern facing other drivers on the road, the present results indicate, as suggested by Flannagan and Sullivan (2011), that there could be room for improvement in the specification of maximum intensities for high beam headlights without creating undue worry about increasing glare unacceptably to other drivers.

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