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Visual Performance and Safety Benefits of Adaptive Driving Beam Headlighting Systems

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Abstract

Current standards for vehicle headlighting systems specify two distinct headlight beam patterns: a low beam when driving in the presence of other nearby vehicles, and a high beam when there is not a concern for producing glare to other drivers. Adaptive technologies such as curve/bending headlight systems with steerable or swiveling headlights may contribute to increments in safety according to the Highway Loss Data Institute, but isolating the effects of lighting among other factors can be very difficult. Recent analyses suggest that visual performance improvements from adaptive curve headlighting systems might contribute to reducing nighttime crashes along curves by 2%-3%. More advanced systems such as adaptive driving beam (ADB) systems that reduce high-beam headlamp intensity in the direction of oncoming and preceding drivers are not currently permitted in the U.S. The purpose of this study is to analyze visual performance benefits and to quantify the potential for nighttime crash reductions associated with ADB headlighting systems. Before ADB systems could be allowed on roads in the U.S., it is important to have information describing their potential for nighttime crash reductions. The results from the present analyses could help inform discussions about the potential safety impacts of ADB headlighting systems in the U.S.

Keywords: ....headlights, safety, adaptive driving beam, glare, visual performance, visibility

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ABSTRACT

Current standards for vehicle headlighting systems specify two distinct headlight beam patterns: a low beam when driving in the presence of other nearby vehicles, and a high beam when there is not a concern for producing glare to other drivers. Adaptive technologies such as curve/bending headlight systems with steerable or swiveling headlights may contribute to increments in safety according to the Highway Loss Data Institute, but isolating the effects of lighting among other factors can be very difficult. Recent analyses suggest that visual performance improvements from adaptive curve headlighting systems might contribute to reducing nighttime crashes along curves by 2%-3%. More advanced systems such as adaptive driving beam (ADB) systems that reduce high-beam headlamp intensity in the direction of oncoming and preceding drivers are not currently permitted in the U.S. The purpose of this study is to analyze visual performance benefits and to quantify the potential for nighttime crash reductions associated with ADB headlighting systems. Before ADB systems could be allowed on roads in the U.S., it is important to have information describing their potential for nighttime crash reductions. The results from the present analyses could help inform discussions about the potential safety impacts of ADB headlighting systems in the U.S.

INTRODUCTION

The present-day requirements for vehicle headlighting in the U.S. are based on standards developed by the Society of Automotive Engineers,[1] which give the required photometric performance of low and high beam headlighting patterns. Vehicles are required to have a set of low- and high-beam headlights that conform to these specifications. These specifications stipulate minimum and maximum luminous intensities produced by each type of beam pattern at several different angular directions from the headlight.

Thus, these specifications define the static performance of headlights. Adaptive headlighting systems are beginning to appear on vehicles, including some vehicles commercially available in the U.S. One example is curve-based headlighting, in which the low-beam headlighting system "bends" or "swivels" based on input such as that from the steering wheel, to direct the headlighting beam pattern toward the direction of steering when entering roadway curves. Such systems are allowed in the U.S. because the overall beam pattern does not change with these systems. Instead, the entire beam pattern moves horizontally relative to the direction of travel.

Some evidence exists, from reports published by the Highway Loss Data Institute (HLDI),[2-5] that curve lighting systems do have a beneficial impact on improved safety. HLDI measured safety in terms of the frequency and amount of insurance claims for property damage and personal injuries. Curve lighting systems tend to produce more light along roadway curves, and empirical evidence[6,7] suggests that reaction times to targets located along roadway curves are shorter when headlights swivel in the direction of the curve.

Figure 1. Driver's view of a prototype adaptive driving beam system with reduced light output toward an oncoming vehicle.[8]

Another form of adaptive vehicle lighting that has been evaluated in many recent research studies[8-16] is the adaptive driving beam (ADB), sometimes also called a "glare-free" high beam or a "matrix beam" system. An ADB system allows a driver to use the high beam headlights at all times. This might produce unacceptable discomfort glare,[17] but ADB systems reduce glare to oncoming and preceding drivers by selectively dimming a portion of the high beam pattern in the angular regions around other vehicles and their drivers (see Figure 1). Dimming can occur through mechanical means such as baffles, or through solid-state control such as a matrix array of light sources like light emitting diodes (LEDs). As a result, drivers approaching ADB systems are exposed to light levels much lower than would normally be produced by conventional high beam headlights, while drivers using them have high-beam levels of forward illumination throughout the rest of the field of view, levels which of course are beneficial to forward visibility. In a series of nighttime outdoor field experiments, Skinner and Bullough[8] demonstrated that visibility when using a prototype ADB system was comparable to that under high beam headlights, while disability and discomfort glare for oncoming drivers were comparable to that experienced when facing low beam headlights.

ADB headlighting systems have not been used on vehicles in the U.S. because the modified high-beam beam pattern results in a pattern of illumination that does not conform with either the high- or the low-beam performance standards.[1] There is therefore no empirical safety data to support whether or not such systems would be beneficial to safety and thus, possibly considered for allowable use on vehicles. The present report summarizes a study to analyze visual performance impacts of ADB systems using a validated model of visual performance that has been linked to improvements in nighttime crash safety, providing initial evidence that could be helpful in assessing whether ADB systems might be expected to provide beneficial impacts on safety compared to conventional vehicle headlighting systems.

VISUAL PERFORMANCE MODELING

Several different models of visual performance exist that can be used to quantify the speed and accuracy of visual processing under various luminous conditions. One of these is the relative visual performance (RVP) model,[18] which evaluates visual performance as a function of:

- Light level
- Target contrast
- Target size
- Observer age

RVP values range from zero at the threshold for the visual recognition of an object, to values greater than one. An RVP value of one corresponds to the visibility of a reference visual task (i.e., reading black printed text on white paper under office light levels) consisting of large, high contrast objects under high light levels. Values greater than one are possible, but are not likely to increase much higher than this value because under such conditions, speed and accuracy will have reached a nearly-asymptotic level of performance. Higher light levels, greater contrast, or larger object size would not substantially improve speed and accuracy of visual processing once a plateau has been reached.[18]

This RVP model was developed under a wide range of light levels, which ranged from mesopic (i.e., nighttime lighting conditions) to photopic (i.e., daytime lighting conditions). According to the RVP model, the speed of visual processing (RT, or reaction time [in ms]) is linearly related to the RVP value based on to the following relationship:

$$RVP = 1.42 - 0.00129\ RT \qquad \text{(Eq. 1)}$$

Supporting the use of the RVP model is the fact that it has been validated in a number of nighttime driving situations. In one nighttime outdoor field study of pedestrian crosswalk lighting configurations, Bullough et al.[19] measured pedestrian identification times under different fixed lighting systems and found these times to be linearly and negatively correlated with RVP values calculated from the photometric characteristics of the lighted scenes (see Figure 2).

Similarly, Bullough and Skinner[20] measured detection times to targets located along a mock-up roundabout intersection under conventional and swiveling headlighting configurations, in another nighttime outdoor field experiment. The measured reaction times in this study were also negatively correlated with the calculated RVP values.

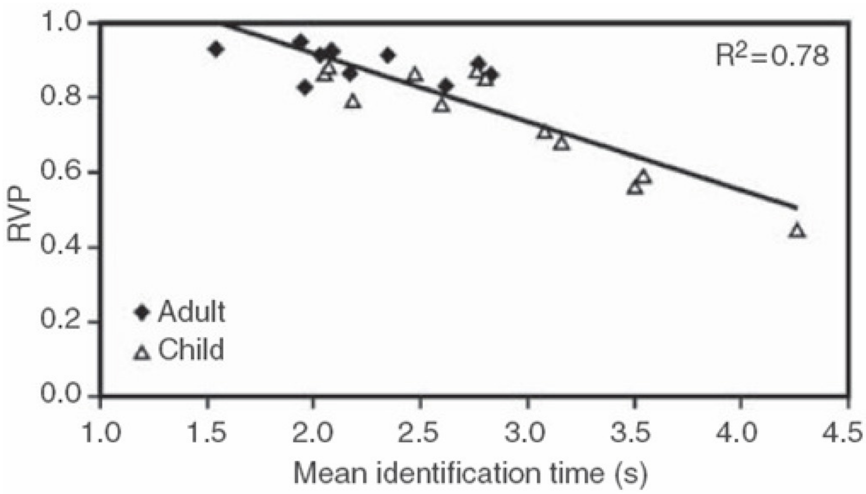

Figure 2. Calculated RVP values and pedestrian identification times measured under different crosswalk fixed lighting conditions, for simulated adult-and child-sized pedestrians.[19]

Although shorter visual reaction times would, in theory, provide drivers with additional time in which they could make defensive driving maneuvers when approaching a roadway hazard such as a pedestrian, it is not necessarily a given that improved visual performance would result in increased safety. To address this potential shortcoming, Bullough et al.[21] compared visual performance increments under roadway intersection lighting relative to when roadway lighting was not present, for four different intersection types (signalized or unsignalized intersections, and rural and urban/suburban locations). It was found that the visual performance increments were strongly correlated (r^2=0.93) with nighttime crash frequency reductions for the same intersection types, using crash data for state highway intersections in the state of Minnesota (Figure 3).

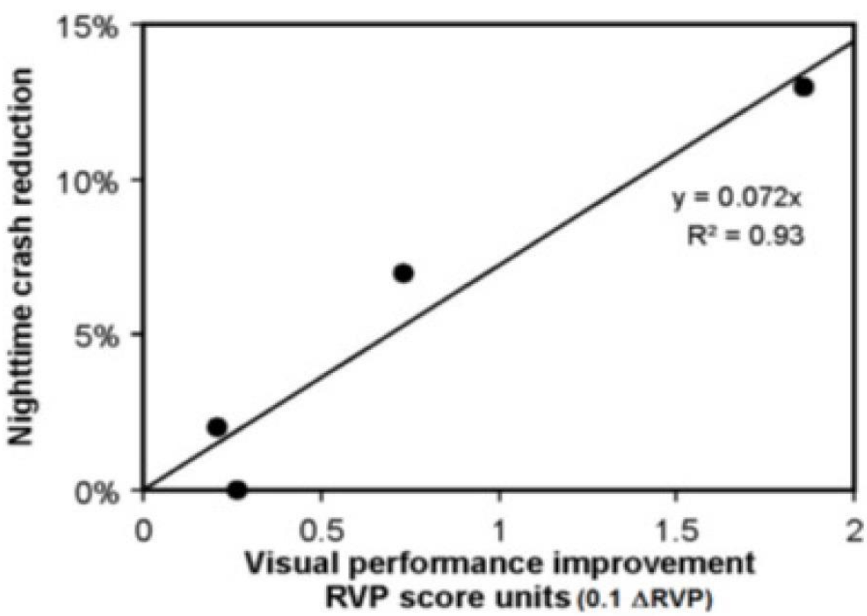

Figure 3. The relationship between RVP improvements from lighting and nighttime crash reductions for different intersection types.[21]

The relationship that is shown in Figure 3 suggests that improvements in visual performance associated with lighting for nighttime driving are related to the potential for lighting to reduce the likelihood of nighttime crashes. It provides a basis for predicting the safety benefits of various lighting configurations, and not only retrospectively identifying when safety improvements occurred after changes in lighting. Critically, the studies mentioned above included the visibility impacts of both fixed roadway lighting and of vehicle lighting, both as sources of illumination in the field of view and as potential glare sources that might reduce forward visibility. Therefore, the relationship in Figure 3 is used in the present paper as a provisional transfer function relating visual performance increments from ADB headlighting systems with the possible safety benefits from such lighting systems.

A similar approach was previously used by Bullough[22] in evaluating adaptive curve lighting systems such as those evaluated by HLDI.[2-5] Using reaction time data from outdoor field studies of curve-based vehicle lighting configurations for high and low speed curves, and relating these in turn to RVP values determined from conventional vehicle lighting scenarios, Bullough[22] estimated that curve lighting systems could result in nighttime crash reductions between 3% and 4% for low speed (sharp) curves, and between 1% and 2% for high speed (shallow) curves.

APPLICATION TO ADAPTIVE DRIVING BEAM SYSTEMS

As mentioned previously, Skinner and Bullough[8] measured driver response times to targets located ahead of a vehicle when using a prototype ADB system that dimmed the beam pattern in a 3°-wide section of the beam in the vicinity of an oncoming vehicle. The prototype served as the observer's forward headlighting system and also as the oncoming headlight system in a separate experiment in order to measure the impacts on disability glare. Measurements of reaction times to the onset of targets were made in comparison to low-beam headlights as the forward illuminant and as a source of glare.

Figure 4 shows measured reaction times to targets when forward illumination was provided by low beam headlights and by the prototype ADB system set to reduce the illuminance 5° to the left, which represents the location of an oncoming vehicle 50 m ahead on a two-lane road. Except at the 5° location where the light level was dimmed, reaction times were shorter under the prototype ADB system, averaging 640 ms. Under the low beam headlights, the response times were longer, averaging 758 ms.

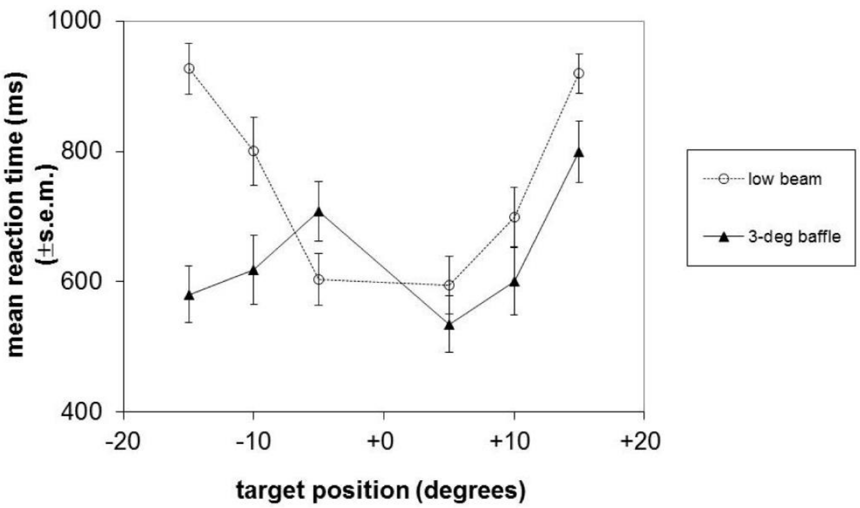

Figure 4. Average reaction times to targets positioned at various angular locations under low beam and under the prototype ADB headlight system.[8]

Figure 5 shows reaction times measured with low beam headlights as the forward illuminant, in the presence of oncoming glare located 5° to the left of the line of sight, which could either come from low-beam or from the prototype ADB headlights dimmed toward the observer's viewing location. Because the light level from the prototype ADB system used by Skinner and Bullough[8] was slightly higher than that from the low beam headlights they used, the reaction times in the presence of the prototype ADB system were slightly longer than in the presence of the low beam headlight system. The average reaction time in the presence of the prototype ADB system was 836 ms; the average response time in the presence of low beams was 763 ms.

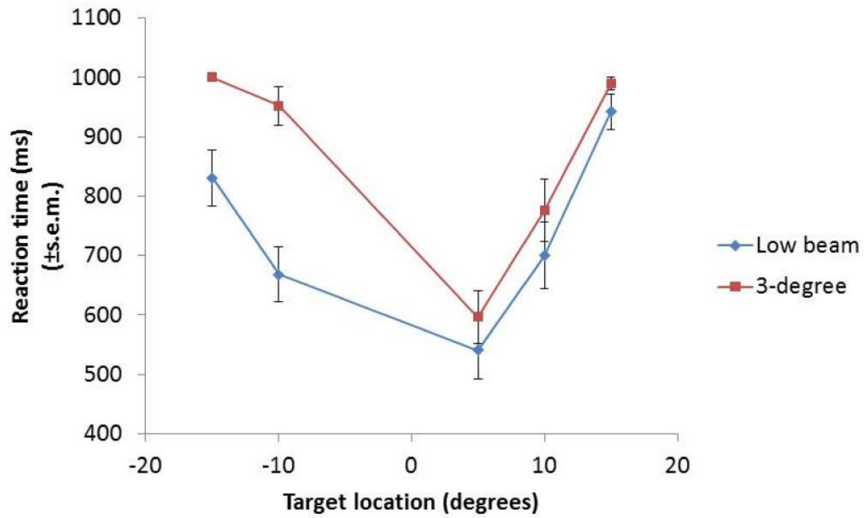

Figure 5. Average reaction times to the onset of targets in the presence of low beam headlights and in the presence of the prototype ADB system evaluated by Skinner and Bullough.[8]

Using the functional relationship between visual reaction times and RVP values described above by Equation 1, one can estimate the RVP values corresponding to the average response times in the study by Skinner and Bullough[8] for forward visibility and for oncoming disability glare. For forward visibility, the RVP values are:

- Low beam headlights: RVP = 0.45
- Prototype ADB system headlights: RVP = 0.60

The net RVP change for forward visibility under the ADB system (relative to low beam headlights) is +0.15 RVP units. For oncoming disability glare, the corresponding RVP values are:

- Oncoming low beam headlights: RVP = 0.40
- Oncoming prototype ADB headlights: RVP = 0.34

The net RVP change for oncoming disability glare in the presence of the prototype ADB headlight system (relative to conventional low beam headlights) is −0.06 RVP units. Combining the forward visibility benefit described above with the oncoming disability glare penalty for adaptive high beam systems, the overall net change is +0.09 RVP units, a benefit relative to low beam headlights.

DISCUSSION

Using the provisional transfer function in Figure 3 between visual performance increments associated with lighting and nighttime crash frequency reductions (in which each 0.1 RVP unit increase from lighting corresponds to a 7.2% nighttime crash frequency reduction), the overall net visual performance benefit of +0.09 RVP units associated with adaptive high beam systems (relative to low beams) corresponds to a nighttime crash frequency reduction of 6.7%.

This potential nighttime crash reduction value (6.7%) is roughly the same order of magnitude as nighttime crash frequency reductions associated with roadway intersection lighting on state highways in Minnesota.[21] This finding suggests that if the use of ADB systems were to become commonplace, requirements for fixed overhead lighting systems could perhaps be reduced.

Currently, however, the photometric requirements for vehicle headlighting in the U.S. do not allow adaptive systems that change the beam pattern so that all of the performance specifications[1] for either a low beam or a high beam headlamp are met. One *possible* approach to specifying performance might be to allow a headlamp beam pattern to meet *either* the low or high beam performance specifications at any given location and at any given time. For example, the system could meet high beam performance specifications except when an oncoming or preceding vehicle was present, and could then meet the low beam specifications in a limited angular region (e.g., a 3° diameter) around that other vehicle.

It is also important to note that the visual performance analysis summarized in the present report was based on the performance of the specific prototype ADB system developed and evaluated by Skinner and Bullough.[8] Other systems would likely have different performance characteristics, particularly in terms of oncoming disability glare, but the visual performance analysis approach and provisional transfer function should still be a practical way to formulate hypotheses for the safety benefits of such forms of adaptive vehicle headlighting systems.

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