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On-road experiment to assess drivers' detection of roadside targets as a function of headlight system, target placement, and target reflectance

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ABSTRACT

Adaptive headlights swivel with steering input to keep the beams on the roadway as drivers negotiate curves. To assess the effects of this feature on driver's visual performance, a field experiment was conducted at night on a rural, unlit, and unlined two-lane road during which 20 adult participant drivers searched a set of 60 targets. High- ($n = 30$) and low- ($n = 30$) reflectance targets were evenly distributed on straight road sections and on the inside or outside of curves. Participants completed three target detection trials: once with adaptive high-intensity discharge (HID) headlights, once with fixed HID headlights, and once with fixed halogen headlights. Results indicated the adaptive HID headlights helped drivers detect targets that were most difficult to see (low reflectance) at the points in curves found by other researchers to be most crucial for successful navigation (inside apex). For targets placed on straight stretches of road or on the outside of curves, the adaptive feature provided no significant improvement in target detection. However, the pattern of results indicate that HID lamps whether fixed or adaptive improved target detection somewhat, suggesting that part of the real world crash reduction measured for this adaptive system (Highway Loss Data Institute (HLDI), 2012a) may be due to the differences in the light source (HID vs. halogen). Depending on the scenario, the estimated benefits to driver response time associated with the tested adaptive (swiveling HID) headlights ranged from 200 to 380 ms compared with the fixed headlight systems tested.

1. Introduction

Traffic safety professionals anticipate substantial benefits from emerging technologies that actively support avoidance of motor vehicle crashes (Jermakian, 2011). Such systems include those that alert drivers via auditory, visual, or tactile displays to lane departures and potential forward collisions and those that provide vehicle control inputs. Examples of this latter class include lane keeping assistance and automatic emergency braking systems. Still other emerging crash avoidance technologies include back-up cameras and sensors as well as the focus of the current effort, advanced headlamp systems. Although there is agreement that crash avoidance technologies have great potential to prevent or mitigate crashes, and experimental research has found that the systems can benefit driver performance in ways that could reduce crashes (e.g., drawing attention to forward roadway after alert (Wege et al., 2013)), the association between the improvements in driver performance and crash risk is not well established.

The current gap in knowledge about crash reductions associated with specific technologies results in part from the slow turnover of the vehicle fleet and the limited availability of advanced systems. Early generation systems typically are offered only as optional features in luxury makes and models. In recent years, these systems have become available in more moderately priced vehicles, making them available to a larger segment of the driving population. For example, the 2014 Honda Accord and Ford Fusion models both are available with forward collision and lane departure warning systems, among other safety technologies. However, drivers who want these technologies still must purchase optional packages or trim levels that can add significantly to the purchase price.

It has been difficult to study the effects of crash avoidance technologies on crashes using databases of police-reported crashes, given the small number of vehicles with collision avoidance systems and the difficulty of determining whether vehicles are equipped with the technologies. However, analyses of insurance collision claims are providing early information on the relationship between crashes and crash avoidance technologies. HLDI receives automobile insurance data that represent about 80 percent of the U.S. automobile market. To study the effects of

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crash avoidance systems, HLDI has worked with several vehicle manufacturers to obtain vehicle identification numbers for vehicles with specific features and then match these data with vehicles in its insurance databases. HLDI assessed the effects of several collision avoidance systems on the frequency and severity of insurance collision claims (e.g., HLDI 2012a,b; IIHS, 2014). The analyses compared a system installed in vehicles of a given year, make, and model with vehicles of the same year, make, and model without the system. The analyses controlled for vehicle exposure (insured vehicle year), location (zip code where vehicle is garaged), and several characteristics of the driver rated to the vehicles in the study such as age, sex, marital status, and the insurance carrier's ratings of risk.

HLDI reported a consistent reduction in insurance claim frequency for vehicles with adaptive headlights (HLDI 2011a,b, 2012a,b). In this paper, the term "adaptive headlights" describes headlight systems that swivel horizontally to follow the steering input as drivers negotiate curves. HLDI identified robust reductions for property damage liability claims, which is insurance coverage for damage that an at-fault driver causes to another vehicle or property. Property damage liability claims decreased significantly ($p < 0.05$) for three of the four manufacturers studied, and vehicles with adaptive headlights produced by the fourth manufacturer showed a similar trend. Comparisons of collision claim frequencies also indicated reductions for each of the four manufacturers' vehicles with adaptive lighting, although only one manufacturers' collision claims indicated a significant safety benefit for these headlight systems. Fig. 1, which was adapted from the HLDI reports cited above, displays the percentage decreases in the rates of collision claims and property damage liability claims observed for vehicles with adaptive headlights relative to the same model vehicles with fixed (i.e., non-swiveling) headlights.

These analyses led to experiments to understand the aspects of driver's performance that may underlie such real-world crash reductions associated with adaptive headlights. The goal of the study described below was to assess differences in drivers' roadside target detection performance as a function of conventional or adaptive headlights. More specifically, a field experiment was completed on a public road to measure target detection performance associated with driving vehicles having fixed (i.e., standard, non-swiveling) halogen headlights, fixed high-intensity discharge (HID) lights, and adaptive HID lights.

There are few previous studies of the effects of adaptive lighting on target detection. McLaughlin et al. (2004) completed an on-road experiment with volunteer drivers to compare a prototype swiveling HID headlight with a fixed HID headlight. In the first experiment, the authors demonstrated increased detection distance with the adaptive system for left curves but a disbenefit for

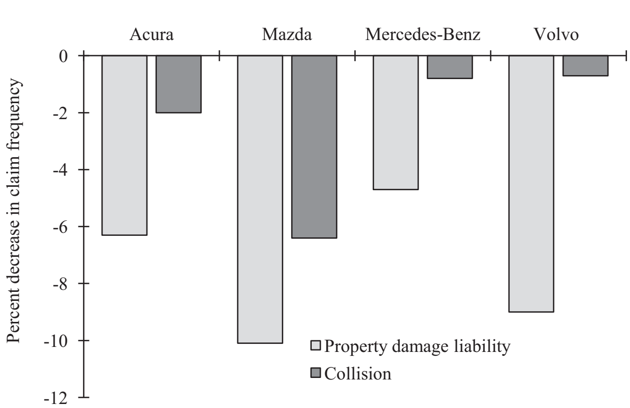

Fig. 1. Effects of adaptive headlights on property damage liability and collision insurance claims.

right curves. After a revision of the algorithm to improve the swiveling feature of the headlights based on the first study's findings, McLaughlin et al. (2004) completed a second experiment that indicated the algorithm's adjustment eliminated the disbenefit for right curves and preserved the advantage of swiveling lamps for left curves. The authors' conclusion emphasized the importance of both photometric and volunteer driver testing in varied road conditions to gain the best insights about the effects of adaptive headlights. More recently, Bullough and Skinner (2009) reported visibility benefits with swiveling headlights using a more static test environment in which participants identified targets placed at different points on a roadway curve. The current field experiment was comparable with McLaughlin et al. (2004) in that participants drove on a public road. However, additional research questions were incorporated in the current study to gain further insights about the benefits of adaptive headlights to visual performance.

In sum, the goals of the study were to separate the effects of fixed and adaptive headlights on roadside target detection during unlit nighttime roadway conditions. Additionally, we sought to distinguish between the target detection performance of drivers viewing the road scene with fixed halogen headlights and fixed HID headlights relative to adaptive HID headlights. In general, fixed HID headlights project more light than fixed halogen headlights (e.g., Sivak et al., 2005), and HID light sources are more conducive to scotopic (night) vision than halogen light sources (e.g., Eloholma et al., 2005; Rea et al., 2004). Such findings suggest that drivers in the current study would identify targets from further away with fixed HID headlights than fixed halogen headlights. Finally, based on the nature of the adaptive headlights and previous research (e.g., McLaughlin et al., 2004), drivers were expected to identify targets from further away with adaptive HID lighting than both fixed headlight systems.

2. Methods

2.1. Experimental design

A repeated measures factorial design was developed that required 3.5 h over two or three nights per participant. The experimental task was to drive three trials, each consisting of the same 8-mile round trip on a pre-identified route on a rural road near Charlottesville, Virginia. During each trial, drivers searched for as many as 60 roadside targets and pushed a button on the steering wheel when they first spotted a target.

2.1.1. Independent variables

The independent measures included trials with three headlight types (fixed halogen, fixed HID, and adaptive HID), target reflectance (high or low), target placement (inside or outside of curve), side of road (left or right), curve direction (left, right, or none), and road curvature (straight, gradual curve, or sharp curve). The road curvature variable classified road segments based on curve radius: sharp curves (<150 m), gradual curves (150–270 m), and straightaways (>270 m). The headlight trial order was counterbalanced to control for potential learning effects. Fifteen high-reflectance targets were painted light gray (40 percent reflectance), while 15 low-reflectance targets were dark gray (10 percent reflectance). These 30 targets were evenly distributed across the roadway variables listed above (see Table 1). Because one trial consisted of one northbound and one southbound leg along the test road, participants encountered each target twice for a total of 60 targets per trial.

2.1.2. Dependent variables

The primary measure recorded by the instrumentation suite was the distance from the nearest target ahead of the vehicle at the