Accident Analysis and Prevention 99 (2017) 44–50

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Drivers' detection of roadside targets when driving vehicles with three headlight systems during high beam activation

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ARTICLE INFO

Article history:
Received 13 April 2015
Received in revised form
19 September 2016
Accepted 21 September 2016
Available online 18 November 2016

Keywords:
Vehicle lighting
Crash avoidance technology
Nighttime driving performance

ABSTRACT

A previous open-road experiment indicated that curve-adaptive HID headlights driven with low beams improved drivers' detection of low conspicuity targets compared with fixed halogen and fixed HID low beam systems. The current study used the same test environment and targets to assess whether drivers' detection of targets was affected by the same three headlight systems when using high beams. Twenty drivers search and responded for 60 8 × 12 inch targets of high or low reflectance that were distributed evenly across straight and curved road sections as they drove at 30 mph on an unlit two-lane rural road. The results indicate that target detection performance was generally similar across the three systems. However, one interaction indicated that drivers saw low reflectance targets on straight road sections from further away when driving with the fixed halogen high beam condition compared with curve-adaptive HID high beam headlights and also indicated a possible benefit for the curve-adaptive HID high beams for high reflectance targets placed on the inside of curves. The results of this study conflict with the previous study of low beams, which showed a consistent benefit for the curve-adaptive HID low beams for targets placed on curves compared with fixed HID and fixed halogen low beam conditions. However, a comparison of mean detection distances from the two studies indicated uniformly longer mean target detection distances for participants driving with high beams and implicates the potential visibility benefits for systems that optimize proper high beam use.

1. Introduction

Thirty percent of U.S. traffic fatalities involving passenger vehicles during 2014 occurred in dark and unlit conditions, while the most recent National Household Travel Survey indicates that only 10% of passenger vehicle miles traveled are driven between 9 p.m.–6 a.m. (Insurance Institute for Highway Safety, 2016). Poor driver visibility is likely to have contributed to such nighttime crashes, although other factors such as fatigue, impairment, and driving too fast for conditions have also been implicated in these crashes. Efforts to improve driver visibility with advanced headlight technologies may work to reduce crashes in dark, unlit conditions.

The current paper describes an experiment that assessed driver differences in visual target detection performance associated with curve-adaptive HID headlights relative to fixed HID or halogen headlights during high beam driving conditions. Curve-adaptive headlights swivel with steering input to project the beam further ahead in curves than fixed, non-swiveling headlights. The basis for the assessment of target detection performance with curve-adaptive headlights stemmed from the Highway Data Loss Institute's (HLDI) analyses of insurance crash claims data that indicated that vehicles with curve-adaptive headlights were associated with lower claim frequencies than the same makes without curve-adaptive headlights (HLDI, 2011a,b; HLDI, 2012a,b).

The headlight system installed in the test vehicle allowed activation or deactivation of the curve-adaptive feature by pressing a button by the instrument display panel. This permitted the parsing of effects of the swiveling nature of curve-adaptive headlights from the HID headlight source and allowed comparisons relative to a "baseline" fixed halogen headlight system. The ability to test differences in detection performance as a function of light source (HID versus halogen) was appealing because the light produced by HID and halogen sources differ in ways that might affect visual performance. For example, HID light sources generally have a higher scotopic (associated with rods and night vision) to photopic (associated with cones and vision in lighted conditions) ratio. Thus, a light source with higher scotopic-photopic ratio provides better nighttime visibility than an equally powered light source with a lower ratio (Eloholma et al., 2005; Rea et al., 2004). Further, the lighting configurations differed across manufacturers included in the HLDI

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http://dx.doi.org/10.1016/j.aap.2016.09.021
0001-4575/

analyses of insurance claims. For example, the non-curve-adaptive Acura vehicles used fixed HID headlights, whereas the non-curve-adaptive Mazda and Volvo vehicles were fixed halogen headlights. Curve-adaptive halogen headlights were not available in the test vehicle or in other vehicles in the U.S. fleet when the study was conducted.

The experiment was conducted on a rural two-lane road with straight and curved sections. A previous experiment used the same test environment and a different sample of drivers to assess differences across the same three headlight configurations during low beam driving conditions (Reagan et al., 2015). However, the test environment represented conditions for which high beams were designed (i.e., no street lighting, low traffic volume, possible presence of deer and other wildlife). Research indicates that a majority of drivers do not activate their high beams in dark, unlit conditions when they are isolated from other traffic (see Hare and Hemion, 1968; Iragavarapu and Fitzpatrick, 2012; Sullivan et al., 2003; Mefford et al., 2006; Reagan et al., 2016). Recent observational studies provided point estimates of high beam use rates of isolated vehicles from ranging from 18 to 42%.

Conventional high beam patterns project further and wider than low beams, so one might expect that curve-adaptive high beams would have a negligible effect on drivers' visibility. However, high beam headlights typically have more intensity in the center than on the edges, so redirecting the higher intensity further into curves could benefit visibility. Published research on driver visual performance in open road driving conditions with adaptive curve high beam headlights is lacking.

2. Methods

2.1. Experimental design

The experimental design was a repeated measures factorial design. The independent variables were headlight system (curve-adaptive HID, fixed HID, fixed halogen), target reflectance (high or low), curve direction (left or right), curve type (no curve, gradual curve, sharp curve), and target placement (inside of curve, outside of curve or no curve). Although headlight system order was counterbalanced, headlight system order (first, second, third trip) was included as a factor to test for potential learning effects, and vehicle speed at time of response button press was included as a covariate. The test road was a 4-mile span of a rural two-lane collector road without street lighting in Stanardsville, VA. Additional site selection criteria included the presence of many curves throughout the route and low traffic volume. The presence of curves was essential to analyze the effects of curve-adaptive headlights on a visual search task, whereas a high flow of road traffic would complicate target detection performance and make it difficult to study high beam use. To complete each headlight condition, participants made one 8-mile round trip of the route.

There were 30 high reflectance and 30 low reflectance targets for each headlight condition. Targets were placed at specified locations with recorded GPS coordinates such that targets of each reflectance level were distributed evenly across the roadway variables of curve direction, curve type, and target placement on curve.

The participants' task on each drive was to search for and press the response button as soon as they were sure they saw a target. When participants pressed the response button, the vehicle instrumentation captured the distance between the vehicle and the oncoming target. The research team measured the maximum visibility distance for each target during daylight hours. This involved placing a 6-inch miniature traffic cone wrapped in high-visibility yellow material with retro-reflective tape at the target's exact location and then computing the maximum straight-line distance when a researcher driving/sitting in the driver seat of the test vehicle could see the cone. The maximum visibility distance for each target was then adjusted for any changes in the vertical roadway profile that could block the light falling on the target. Finally, maximum visibility distance was capped at 200 m as this was the maximum distance at which the miniature traffic cone could be seen on a flat, straight test track at night when using high beams. The dependent measure used for analysis was the ratio of observed response distance to maximum visibility distance.

2.2. Participants

Chesapeake IRB reviewed and approved the research protocol; this independent firm complies with federal regulations associated with human subjects research, including ethical treatment of participants. Twenty participants (10 male and 10 female) with valid driver's licenses completed the study. Participation was restricted to 30–50 year-old drivers. Participant age ranged from 30 to 49 with a mean age of 42 (SD = 5.7 years) years old, and the mean number of years licensed was 26. Participants passed visual screening tests (Snellen acuity scores of 20/50 or better; Rabin contrast sensitivity test with range = 0.6–2.0). Given the objective of assessing the performance of drivers who drive at night, the screening process included questions relevant to nighttime driving. Nine participants reported driving at night at least 1–2 times per week; 8 reported they drove at night most days of the week, and 3 indicated they typically drove every night of the week. Nineteen of the 20 reported that they did not have trouble seeing at night, whereas 8 participants reported they worry about crashing at night more than the day. Thus, our sample represents experienced drivers with no apparent visual impairment who typically drive at night.

2.3. Materials

The two test vehicles were 2013 Mazda 3 sedans. One had HID headlights, and the other had fixed halogen headlights. As noted above, the vehicle with HID headlights had a button to the left of the steering wheel that turned the curve-adaptive feature on or off. When the curve-adaptive headlights are on and the vehicle is traveling over 25 mph, the headlight to the inside of the curve swivels with steering input up to 15°. Post-experimental testing of the curve-adaptive HID, fixed HID and fixed halogen high beam headlamp systems indicated that the mean distances at which each produced 5 lx illumination were 134 m, 134 m, and 165 m, respectively, on straight roads and 67 m, 59 m, and 58 m, respectively, across an average of four curves. In these tests the lux meter was placed on the left edge of a two-lane road.

A 2012 Mazda 3 served as the training vehicle for the participants. The instrumentation for measuring target detection performance included a response button attached to the steering wheel, GPS equipment, and 3 cameras (one aimed at the forward roadway, one aimed at participants' face, and one aimed at the steering wheel and response button). A microphone also recorded audio. The 8×12 inch targets were aluminum, with half painted a high-reflectance gray (*M* reflectance = 0.38) and half painted a low-reflectance grey (*M* reflectance = 0.10). The target size and shape were selected because they were similar to the standard target size specified by the Illuminating Engineering Society for use in testing roadway lighting (see Adrian, 1987), and similarly sized targets were used in target detection research of a prototype curve-adaptive headlight system (McLaughlin et al., 2004). The lower reflectance value was selected to approximate dark apparel commonly worn by pedestrians, whereas the higher reflectance represented a medium light gray.