TLA 2011-01

A Transportation Lighting Alliance Report

Daytime Use of Automotive Headlamps During Inclement Weather: Safety and Conspicuity

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December 2011

Lighting Research Center

Rensselaer

Technical Report Documentation Page

Report number TLA2011-01

Report title/subtitle .... Daytime Use of Automotive Headlamps During Inclement Weather: Safety and Conspicuity

Report date .... December 2011

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Performing organization .... Lighting Research Center (LRC), Rensselaer Polytechnic Institute
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Transportation Lighting Alliance 2011 members .... Automotive Lighting, Hella, OSRAM Sylvania, Philips Lighting, Visteon

Notes .... (none)

Abstract

The goal of this report is to provide information regarding the potential crash safety benefit of driving during the daytime in rainy weather with headlamps switched on, evaluated by comparing the incidence of fatal, multiple-vehicle crashes in states with "wipers-on, headlamps-on" legislation. Data for seven states were assess individually and were pooled to identify statistically reliable reductions in the proportion of rainy-weather crashes during the daytime compared to clear-weather crashes and nighttime crashes. Differences in the apparent magnitude of the associations between daytime and dawn/dusk periods were consistent with differences predicted by a model of daytime vehicle conspicuity, suggesting that the mechanism for a potential safety benefit is through increasing conspicuity of other vehicles during rainy weather.

Keywords: .... headlamp, weather, safety, conspicuity

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ABSTRACT

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INTRODUCTION

An issue of widespread concern among drivers in the U.S. is the use of automotive headlamps during inclement weather in the daytime, and whether there are any safety benefits in terms of reduce likelihood of crashes when they are used (Kingery and Bullough, 2010; Bullough, 2011). This issue has led to the proposal and enactment of many state laws requiring the use of vehicle headlamps whenever conditions also require the use of windshield wipers (Kingery and Bullough, 2010), such as rain, sleet or snow.

In the present report, a study of crash statistics is summarized in which the types of crashes likely to benefit from the daytime use of automotive headlamps during inclement weather, namely, multiple-vehicle crashes, were assessed for several states recently enacting this type of "wipers-on, headlamps-on" legislation. Daytime crashes in clear weather, and nighttime crashes in rainy weather were used as controls for the statistical analyses because headlamps would not typically be used during clear daytime weather, and headlamps would be used at night in rainy weather, regardless of a "wipers-on, headlamps-on" law.

In addition, in order to understand the mechanisms of conspicuity (increased "attention-getting" properties) underlying any possible benefits of "wipers-on, headlamps-on" legislation, a psychophysical model of vehicle conspicuity was used to compare how conspicuous a vehicle with its headlamps on is compared to one without headlamps switched on.

BACKGROUND

Drivers in the U.S. are particularly concerned with their ability to see and to be seen when driving during inclement weather conditions such as rain, sleet and snow. A survey of newspaper articles from the five-year period spanning 2004-2009 showed that many stories that discussed vehicle headlamps and visibility described their use during poor weather (Kingery and Bullough, 2011). Figure 1 shows a breakdown of visibility related concerns with headlamps identified from that report.

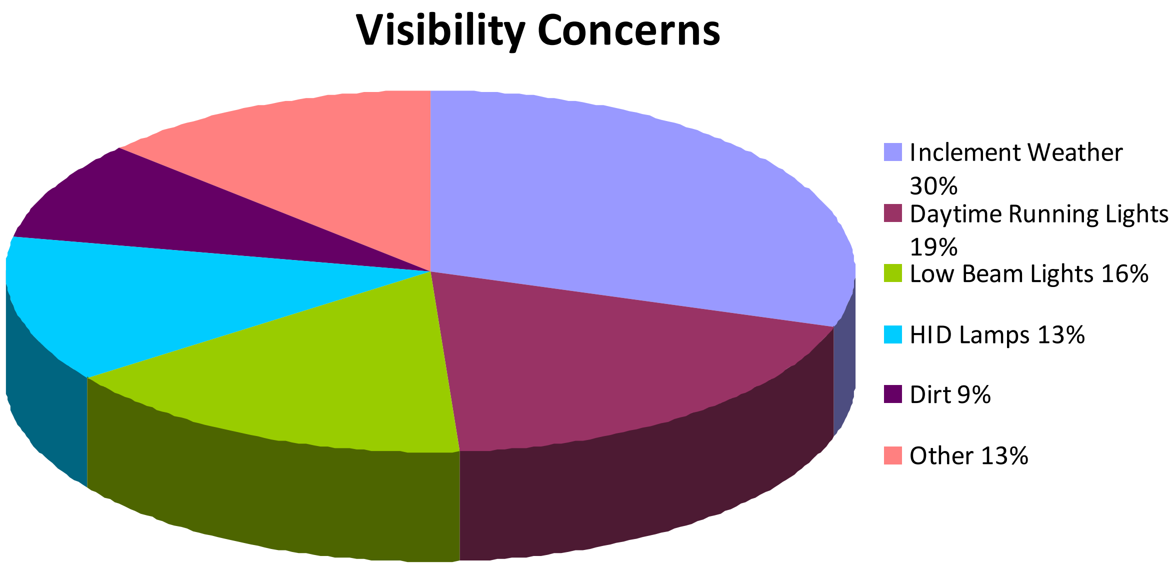

Figure 1: Concerns Related to Visibility from Headlamps

Among those news stories, a common issue pertained to the proposal or enactment of so-called "wipers-on, headlamps-on" legislation, which would require drivers to switch on their headlamps whenever their windshield wipers needed to be used. A majority of U.S. states currently have such legislation and several states are currently debating such laws. A common question in policy debates is whether "wipers-on, headlamps-on" laws have any reliable impact in terms of reduction of crashes, and a review of the literature found no evidence for or against this notion.

To address whether such legislation could be linked to crash safety, an analysis of crash data from the Fatality Analysis Reporting System (FARS) database maintained by the National Highway Traffic Safety Administration (NHTSA) was conducted (Bullough, 2012) to assess whether the incidence of multiple-vehicle, daytime crashes in rainy weather was reduced relative to other periods of the day and other weather conditions, in states that had recently passed such legislation. In addition, since the illumination from headlamps would not be likely to assist in forward visibility while driving during the daytime regardless of weather conditions (Rea et al., 2010), a psychophysical model of the daytime conspicuity of vehicles (Morita et al., 1995) was used to assess predicted ratings of conspicuity under daytime and dawn/dusk periods with and without headlamps on.

WIPERS-ON LEGISLATION AND CRASH SAFETY

Fatal crash data were evaluated from NHTSA's FARS database (Bullough, 2012) for seven states in the U.S. (California, Kansas, Maine, Maryland, Missouri, Pennsylvania, and Virginia) that had recently established wipers-on, headlamps-on laws between 1998 and 2007, and for which there was at least three years of crash data before and after enactment. No more than five years before or after enactment was used.

Multiple-vehicle crashes were divided by time of day (either daytime, dawn/dusk or nighttime) and by weather condition (clear or rainy weather; all other weather conditions such as fog, snow, or sleet were excluded). Data from each state corresponding to "before" and "after" enactment of wipers-on laws were considered separately and pooled together. Only multiple-vehicle crashes were considered because the use of headlamps in daytime should not influence forward visibility (Rea et al., 2010) that might influence single-vehicle crashes such as run-off-the-road crashes.

State	Period	Daytime		Dawn/Dusk		Nighttime	
		Clear	Rainy	Clear	Rainy	Clear	Rainy
California	Before (2001-2005)	[a]4009	190	[b]282	25	2621	166
	After (2006-2009)	2792	83	210	5	1958	102
Kansas	Before (2002-2006)	567	39	39	7	225	16
	After (2007-2009)	248	21	14	3	112	13
Maine	Before (1994-1997)	167	17	6	3	39	6
	After (1998-2002)	241	20	18	2	37	5
Maryland	Before (1994-1997)	561	68	35	6	307	31
	After (1998-2002)	723	85	26	5	414	54
Missouri	Before (2000-2004)	1251	146	0	0	569	75
	After (2005-2009)	1092	123	5	0	513	58
Pennsylvania	Before (2002-2006)	1623	191	100	10	782	108
	After (2007-2009)	892	106	59	8	410	48
Virginia	Before (1994-1997)	[c]759	60	44	3	389	31
	After (1998-2002)	1054	35	52	3	440	29
Pooled Data	Before	[d]8937	711	[e]506	54	4932	433
	After	7042	473	384	26	3884	309

[a] $p = 0.0002$; [b] $p = 0.003$; [c] $p = 0.00004$; [d] $p = 0.003$; [e] $p = 0.04$.

Table 1. Multiple-vehicle, fatal crash data corresponding to different times of day (daytime, dawn/dusk, nighttime) and different weather conditions (clear, rain) for periods before and after enactment of wipers-on, headlamps-on legislation, for seven states.

Fisher's exact test was used for the data from each state and for the pooled data (Table 1) to assess whether there were statistically significant ($p<0.05$) one-tailed interactions consistent with the hypothesis that the relative proportion of rainy-weather multiple-vehicle fatal crashes was reduced relative to clear-weather crashes for each time of day, after the wipers-on legislation was enacted. The shaded cells in Table 1 indicate statistically reliable interactions.

For the pooled data, there were significant interactions during the daytime and dawn/dusk periods of the day, but no significant interactions were ever identified for the nighttime periods, an important control condition since headlamp use should not have changed at night before and after the enactment of wipers-on legislation. There was, however, a small but non-significant reduction in the proportion of multiple-vehicle, rainy-weather fatal crashes at night.

Using this non-significant change in multiple-vehicle rainy-weather fatal crashes during the nighttime as a control, the data in Table 1 suggest that the wipers-on legislation was associated with a reduction in fatal rainy-weather multiple-vehicle crashes during the daytime of approximately 7%, and a reduction during dawn and dusk times of about 30%, a reduction that is more than four times larger than that during daytime.

VEHICLE CONSPICUITY

Of course, the crash data in Table 1 are correlational, not causative. They are, however, entirely consistent with the concept that vehicle headlamps, in addition to serving to provide drivers with visibility at night (Bullough et al., 2008), increase vehicle conspicuity during the daytime, and perhaps even more so during dawn and dusk periods.

One vehicle lighting application that is similar to the use of headlamps during rainy weather in the daytime is the use of daytime running lights (DRLs). Crash statistics regarding the potential of DRLs to reduce daytime crashes is generally favorable (Elvik et al., 2004), although there can be substantial variance among individual studies as to the direction and magnitude of safety effects (Wang, 2008). Because a substantial proportion of the daytime it is not raining but rather is clear (e.g., sunny, partly cloudy, cloudy), with visibility conditions general optimal (Akashi et al., 2007), vehicles will usually be very conspicuous to other drivers even if DRLs are not used.

During rain, overall visibility is reduced compared to clear weather (Satterthwaite, 1976; Bhise et al., 1981; Hautière et al., 2009), and the impact of DRLs might be expected to be larger and possibly more consistent than during clear weather. This might be particularly true during periods of dawn and dusk, when the conspicuity of vehicles with their headlamps switched on, operationally defined by ratings of their visibility, is consistently greater than that of the same vehicles during the rest of the daytime (Morita et al., 1995).

It seems likely that this is caused by the higher contrast between the surrounding roadway surface and the vehicle lighting systems. In addition, unlike DRLs, using headlamps during rainy weather as required by many states in the U.S. also results in position (rear tail) lamps being on. Morita et al. (1995) evaluated the conspicuity of vehicles in the daytime with only their amber clearance lamps switched on, and while the measured visibility ratings were lower than for vehicle with headlamps on, they still indicated that there was an overall benefit over vehicles with no lights on. Since position lamps have lower intensities than clearance lamps (Bullough et al., 2007), they should result in lower conspicuity than vehicles with clearance lamps, but should still be more conspicuous than vehicles with no lights on at all.

The data from Morita et al. (1995) on conspicuity resulted in a calculational model they developed to predict a normalized rating of conspicuity of a passenger car with low-beam headlamps switched on, relative to a passenger car without any lights switched on. The model is based on the average luminance of the passenger car ($L_{vehicle}$) for different ambient conditions, plus a contribution to the vehicle's average luminance produced by the headlamps ($L_{headlamps}$), which they estimated to be 1150 cd/m² based on an average luminous intensity of 690 cd per headlamp in the direction of an oncoming driver.

The average passenger car luminance ($L_{vehicle}$) was predicted by the following empirical equation:

$$L_{vehicle} = 22L_{roadway}^{0.67} \quad \text{(Equation 1)}$$

In Equation 1, $L_{vehicle}$ and $L_{roadway}$ are both in cd/m². The luminance of the roadway can be predicted by the horizontal illuminance (E_{horz}) on the roadway assuming a reflectance (ρ) of 0.1 for pavement according to:

$$L_{roadway} = E_{horz}\rho/\pi \qquad \text{(Equation 2)}$$

In Equation 2, E_{horz} is in lx. Taking these values into account, the conspicuity index (CI) of a passenger car with illuminated low-beam headlamps (Morita et al., 1995) is predicted by the following equation:

$$CI = \log[(L_{vehicle} + L_{headlamps})/L_{vehicle}] \qquad \text{(Equation 3)}$$

Thus, knowing the horizontal illuminance from the sky on the roadway, it is possible to determine the CI, as shown below in Figure 1. The CI value for a passenger vehicle without headlamps switched on is defined as zero.

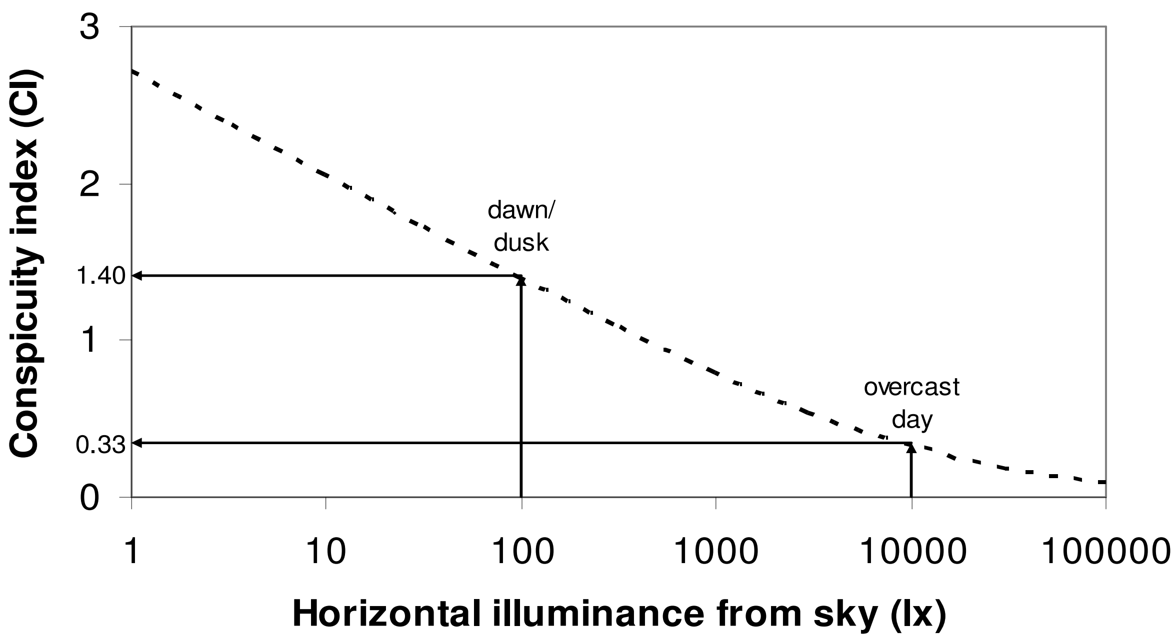

Fig. 1: Conspicuity index (CI) as a function of horizontal illuminance from the sky, based on the model of Morita et al. (1995). Also shown are representative horizontal illuminances (and CI values) from the sky on an overcast day and during dawn or dusk (Rea, 2000).

The Illuminating Engineering Society (IES) of North America (Rea, 2000) has published representative illuminance data from the sky for different weather conditions. During rainy weather, the daytime sky is likely to be overcast and during such conditions, the horizontal illuminance can range from near zero to 20,000 lx. For an intermediate daytime illuminance from the sky of 10,000 lx, the resulting CI value is 0.33 (Figure 1). During dawn/dusk periods shortly after sunset or before sunrise, horizontal illuminances from the sky range between 3 and 500 lx. For an intermediate illuminance of 100 lx, the predicted CI value is 1.40 (Figure 1).

The ratio between these representative CI values for dawn/dusk conditions and daytime conditions in rainy weather is 4.3 (1.40/0.33). Interestingly, recalling the estimates of the safety benefit (in terms of fatal, multiple-vehicle crashes) associated with wipers-on/headlamps on legislation in the U.S. from Table 1, these were 30.0% for dawn/dusk periods and 6.8% for daytime periods. The ratio between these values is 4.2 (30.0%/6.8%), very similar to the ratio of CI values based on the model by Morita et al. (1995).

DISCUSSION

The logical role of automotive headlamps in reducing the frequency of fatal, multiple-vehicle crashes during rainy weather in daytime and dawn/dusk periods is supported by two parallel analytical approaches:

- One based on reported fatal multiple-vehicle crash data during different times of day and different weather conditions (Table 1)
- One based on an empirical model (Morita et al., 1995) of conspicuity for vehicles with and without illuminated headlamps during the daytime (Figure 1)

The use of such parallel analysis methods to investigate lighting has been described by Bullough (2010) as essential for a comprehensive understanding of the role of vehicle lighting on safety, and evidence is growing that such an approach is a valid one. In the context of roadway lighting, Bullough and Rea (2011) described the converging results of statistical associations between the presence of roadway intersection lighting (Donnell et al., 2009) and improvements in visual performance (Rea and Ouellette, 1991) associated with roadway intersection lighting systems (Rea et al., 2010). Situations in which lighting improved visual performance the most were the ones for which lighting was associated with the greatest reduction in nighttime crashes (Bullough et al., 2011).

The parallel analyses presented in this paper should, of course, be interpreted with caution. The empirical conspicuity model developed by Morita et al. (1995) is based on subjective ratings of visibility of passenger cars, and not on an objective measure of visual performance. Nonetheless, Janoff (1992) reported that subjective visibility ratings taken under roadway visibility conditions were often highly correlated with visual performance metrics such as visibility level (VL), although whether the relationship is linear or nonlinear is not well understood. Nor is it known to what extent wipers-on, headlamps-on legislation, in the states that have adopted it, is enforced or followed.

As with all correlational analyses, associations among weather, time of day and fatal multiple-vehicle crashes derived from the data in Table 1 could be caused by extraneous variables not assessed directly in the present report. Certainly, if drivers did not actually use their headlamps in states with such legislation when driving in the rain, the hypothesized benefits of headlamps in rainy weather would be illogical. While Krawzak (1995) reported in a news story that a police officer estimated "90 percent of the drivers he sees on the high-speed interstates activate their headlights in the rain," such figures are anecdotal, and levels of compliance with wipers-on legislation has not been systematically documented.

These caveats underlie the importance of independent, converging operations when assessing safety impacts of transportation lighting. Using multiple approaches and analyses can point to a more fruitful way to identify and conduct research about this important topic, and to develop sound estimates of the purported benefits of lighting.

ACKNOWLEDGMENTS

Preparation of this report and the analyses described within were supported by the 2011 members of the Transportation Lighting Alliance (TLA): Automotive Lighting, Hella, OSRAM Sylvania, Philips Lighting, and Visteon.

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