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Determining the potential safety benefit of improved lighting in three pedestrian crash scenarios

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Abstract

The influence of light level was determined for three pedestrian crash scenarios associated with three adaptive headlighting solutions—curve lighting, motorway lighting, and cornering light. These results were coupled to corresponding prevalence data for each scenario to derive measures of annual lifesaving potential. For each scenario, the risk associated with light level was determined using daylight saving time (DST) transitions to produce a dark/light interval risk ratio; prevalence was determined using the corresponding annual crash rate in darkness for each scenario. For curve lighting, pedestrian crashes on curved roadways were examined; for motorway lighting, crashes associated with high speed roadways were examined; and for cornering light, crashes involving turning vehicles at intersections were examined.

In the curve analysis, lower dark/light crash ratios were observed for curved sections of roadway compared to straight roads. In the motorway analysis, posted speed limit was the dominant predictor of this ratio for the fatal crash dataset; road function class was the dominant predictor of the ratio for the fatal/nonfatal dataset. Finally, in the intersection crash analysis, the dark/light ratio for turning vehicles was lower than for nonturning vehicles; and the ratio at intersections was lower than at non-intersections.

Relative safety need was determined by combining the dark/light ratio with prevalence data to produce an idealized measure of lifesaving potential. While all three scenarios suggested a potential for safety improvement, scenarios related to high speed roadway environments showed the greatest potential.

Keywords: Pedestrian collisions; Visibility; Conspicuity; Ambient light; Daylight saving time; Adaptive headlighting

1. Introduction

In previous work, the influence of natural light level on crash risk was found to differ across various scenarios. For example, strong effects of natural light level were found in pedestrian crashes (Sullivan and Flannagan, 2001) and rear-end collisions involving trucks (Sullivan and Flannagan, 2004) using an analysis of crash frequency across daylight saving time transitions. This method is intended to isolate the effect of light level from other factors (e.g., fatigue, alcohol use, driver demographics) that are typically confounded with light level when day–night comparisons are made (Ferguson et al., 1995; Sullivan and Flannagan, 1999, 2002), providing a relatively pure assessment of the influence of light level on crash risk. The purpose of the present analysis is to examine the role of ambient light level in crash scenarios associated with some of the major forms of adaptive headlighting that have been proposed, thereby providing estimates of the potential safety benefits from this technology. Adaptive headlighting is also referred to as adaptive lighting, or as adaptive front lighting systems (AFS). This new class of automotive lighting includes a variety of ideas about how the distribution of forward lighting might be designed to adjust dynamically to meet the changing demands of the driving environment.

In contrast to prior analyses, we will determine the potential benefit of curve lighting, motorway lighting, and cornering lighting using scenarios tailored to each of these three forms of adaptive headlighting. Curve lighting, which has already been introduced on several vehicles, directs light to follow horizontal curves, allowing a driver to see farther down the road. It is especially effective for short-radius curves (Sivak et al., 2005). The analysis scenario for curve lighting compares the effect of light level on dark/light crash risk on curved roads and straight roads.

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Motorway lighting increases forward visibility on high-speed, limited access or divided roadways by modifying a conventional low-beam light distribution to project more light further down the road. On such roadways, there is both greater need for seeing distance because of the higher speeds and diminished glare to opposing drivers because of greater lateral separation. We will evaluate the potential safety benefit of motorway lighting by examining how the variables that differentiate motorways or highways from other roads (posted speed, function class, trafficway characteristics, lanes, and rural versus urban locale) affect the relative risk in darkness. Finally, we will examine the potential benefit of cornering lighting, which is intended to illuminate the side of the roadway during acute turning maneuvers. For cornering lighting, we will examine the effect of natural light on the frequency of pedestrian crashes at intersections when a vehicle is turning.

It should also be noted that the potential crash reductions discussed here do not involve any evaluation of how effective a certain innovation in lighting might be as it is actually implemented. For example, in order for curve lighting to achieve all of the potential crash reduction as quantified here, it would have to be perfect in addressing the problems of darkness that are encountered on curves. That is, the visibility provided by the curve lighting system would have to approximate daylight visibility. How close any specific vehicle lighting system could come to that ideal is not currently known, given the innovative nature of adaptive lighting. We believe it is reasonable to assume that the various forms of adaptive lighting discussed here will improve visibility in the relevant traffic scenarios, and we believe that the potential safety benefits as quantified here are important to consider in developing specific forms of adaptive lighting, but no single analysis can provide a complete assessment of the benefits of all forms of adaptive front lighting.

2. Method

The general method of this analysis is first to determine the degree to which a crash scenario is influenced by natural light using daylight saving time analysis, and then to determine the annual number of crashes in darkness for that scenario. The influence of natural light on crash risk is determined by the dark/light risk ratio—the number of crashes in a certain period of darkness divided by the number of crashes during a comparable period of daylight. A dark/light ratio greater than 1 indicates that darkness is more risky than daylight; a dark/light ratio equal to 1 indicates no difference between dark and light; and a dark/light ratio less than one indicates less risk in darkness. If we suppose that some improvement in artificial lighting at night could create conditions more like daylight, we would expect the dark/light ratio to approach 1. A large dark/light ratio for a certain crash type suggests an important potential for improvement with better lighting. However, to quantify such a potential improvement, it is also necessary to consider the frequency of that crash type. This number provides a measure of how much opportunity there is for crash reduction in each scenario. It is important to recognize that a large dark/light risk ratio coupled with few opportunities may result in a smaller safety benefit than a modest risk ratio coupled with many opportunities. Both risk and frequency must be considered in evaluating potential safety benefits, which are indexed here in terms of potential reduction in crashes.

The following analyses use two principal datasets: the Fatality Analysis Reporting System (FARS) maintained by the National Highway Traffic Safety Administration (NHTSA), which is a complete census of all fatal traffic accidents in the United States; and the North Carolina Department of Transportation Crash dataset (NCDOT), which contains fatal, injury, and property-damage-only crashes. Some data fields in the two datasets are not directly comparable. For example, with respect to locale of the crash, the FARS dataset designates crashes as either URBAN or RURAL, whereas NCDOT also includes a MIXED category. Where possible, these differences have been resolved by grouping crashes into more general categories.

For each dataset, crashes that occurred in the 1 h time window that transitions from dark to light (or light to dark) over the spring and fall daylight saving time (DST) changeover were compiled over several years. The FARS dataset, included crashes from 1987 through 2004 (18 years), while the NCDOT dataset included crashes from 1991 through 1999 (9 years). The interval identified as “dark” began at the local (standard) time of civil twilight, and extended 1 h later. In the spring, this interval transitions from dark to light when the local time is adjusted forward by 1 h. In the fall, this interval was based on the local time of civil twilight after the transition back to standard time. Prior to the fall transition, this interval is identified as “light,” and becomes “dark” after the transition. Note that in North America, the nominally light interval therefore actually extends from about half an hour before to half an hour after sunset. Crashes occurring in this 1-h time window during the 5 weeks before and after the spring and fall DST transition were compiled for this analysis. Only evening transitions were included in this analysis because in the morning light level fluctuates over the 10-week spring and fall calendar windows (for details see Sullivan and Flannagan, 1999, 2002, 2004).

The analysis will first establish which crash types are most affected by light level; these crash types will then be further partitioned based on factors relevant to the various adaptive headlighting scenarios. This analysis extends earlier work (Sullivan and Flannagan, 2001) by using new FARS data and introducing the NCDOT dataset, which contains both fatal and nonfatal crashes. In addition, the analysis also partitions pedestrian collisions by age to assess the extent to which dark/light exposure differences between pedestrian children and other pedestrians may affect the determination of pedestrian risk in darkness.

3. Results

3.1. The effect of ambient light by crash type

A breakdown of the frequency of different fatal crash types during dark and light periods is shown in Table 1, from the FARS DST dataset. Ratios that significantly depart from 1 (where 1 would indicate no difference between dark and light) are shown in Fig. 1. This analysis is consistent with previous analyses