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James R. Sayer
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The University of Michigan
Transportation Research Institute
Ann Arbor, MI 48109-2150
U.S.A.

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16. Abstract

This study examined the effect that hydrophobic treatment of glass headlamp lenses has on light output when headlamps are exposed to contaminants under naturalistic driving conditions. The hypothesis, *a priori*, was that the water-repelling nature of a glass surface after hydrophobic treatment would aid in minimizing the adhesion, or promote the removal, of contaminants on the lens, thereby leaving light output less affected.

Additional variables of interest included the presence of precipitation, the side of the vehicle the headlamp was on, and whether the headlamp was illuminated during the exposure. The study examined vehicles with glass lenses installed as intended by the vehicle manufacturer. The vehicles were driven on a 155-km route under conditions of active precipitation or no precipitation, and with or without the headlamps on. Subsequent to each drive, measurements of light output were made at eight key test points in the headlamp beam pattern. The headlamps were then cleaned and measured again. In this way, each headlamp served as its own control.

The results indicate that hydrophobic treatment of glass headlamp lenses did not affect light output. However, the presence of precipitation did result in decreased light output below the horizontal cutoff of the beam pattern and increased light output above the horizontal cutoff. This result was especially evident above the horizontal cutoff when the headlamps had been illuminated. The side of the vehicle the headlamp was on did not affect light output.

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CONTENTS

INTRODUCTION

What are Hydrophobic Treatments?

In most automotive applications, hydrophobic treatments are transparent chemical coatings that bind with, and change the surface chemistry of, laminated or tempered glazing to minimize the level of contact between the glazing surface and water that comes into contact with that surface. Hydrophobics cause rain and other accumulated moisture to bead (Figure 1). Aided by airflow resulting from wind and the aerodynamics of a vehicle in motion, beads of water are more readily shed from a hydrophobically treated surface than from a nontreated surface. Hydrophobic coatings have been used for some time in aviation, and have been widely available as car care products. Some hydrophobic treatments for automotive glazing are commercially available for the consumer to apply, while others must be applied by trained personnel. However, hydrophobic treatments have only relatively recently been engineered to resist the wear associated with environmental exposure in order to retain water repellant properties over extended periods.

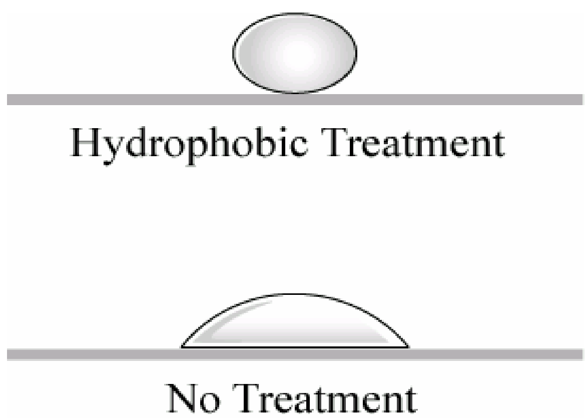

Figure 1. A schematic representation (cross section) of the contact between water and glass with and without hydrophobic.

Previous Research

The application of hydrophobics to automotive glazing has previously been shown to improve driver visual acuity when applied to windshields (Sayer, Mefford, Flannagan, and Sivak, 1997) and rear windows (Sayer and Mefford, 2000), but to have no significant effect on distance judgments when applied to the driver-side window and rearview mirror (Sayer, Mefford, Flannagan, and Sivak, 1999). These three studies are discussed briefly here.

Sayer et al. (1997) reported that the application of a hydrophobic treatment to the windshield of an automobile resulted in significantly improved visual acuity and decreased response time to recognize a simple target. The improvement in response time was, on average, greater than one second. The improvement in visual acuity was also significant (approximately 34% in terms of the minimum visual angle resolved). By way of comparison, visual acuity improved in a treated nighttime condition to approximately the same as performance in an untreated daytime condition. The experimental conditions in the study simulated moderate to heavy amounts of rainfall, with the windshield wipers on at all times, and simulated wind comparable to a moderate traveling speed (58 km/hr).

Sayer et al. (1999) investigated the effects of hydrophobic treatment, when applied to the driver-side window and driver-side exterior rearview mirror, on distance estimation under conditions of simulated rain and wind. The authors reported that there was no significant effect of hydrophobic treatment of the driver-side windows or mirrors, but that one marginally nonsignificant interaction of interest was observed. Specifically, there was a tendency for older drivers to report shorter (more conservative and presumably safer) distance estimates when viewing vehicles through a driver-side window that had received hydrophobic treatment. It was suggested that this tendency, in combination with overrepresentation of older drivers in lane-change/merge crashes, warranted additional examination of the potential safety benefit of applying hydrophobics, particularly to driver-side windows.

Sayer and Mefford (2000) investigated the potential benefits of using hydrophilic and hydrophobic treatments on the rear and side windows of a passenger car. Hydrophilic treatments behave differently than hydrophobics in that they attempt to maximize, or evenly distribute, water's contact with a treated surface through increasing surface tension. Unlike windshields, which are equipped with wipers, or side windows that receive greater airflow across their surface, the rear windows of most passenger cars have neither wipers nor the level of airflow associated with a side window to aid with water removal.

In the first part of their study, Sayer and Mefford conducted an exploratory survey of driver impressions concerning the efficacy of hydrophilic treatments. The second part of the study was an experimental examination of the effects of hydrophilic and hydrophobic treatments on driver visual acuity through the rear window. Visual acuity once again served as a general measure of visual performance. Similar to previous studies by Sayer et al. (1997 and 1999), the study was performed under conditions of simulated rain and airflow—the vehicle was static while water was sprinkled from overhead and air flow was generated using a very large fan. The results suggested that the application of hydrophilic coating to motor vehicle glazing does not present either subjective or objective benefits relative to an untreated condition. However, the results of the visual performance experiment suggested that hydrophobic treatment of the rear window can provide benefit in the form of improved driver vision, similar to previous findings for windshield applications.

The Objectives of the Present Study

The present study investigates the potential benefits of hydrophobic treatment for glass headlamp lenses. Like windshields, headlamps receive significant airflow across their surface that may promote removal of water and contaminants when the surface is wet—particularly if surface tension is minimized. However, because of their low mounting height headlamp lenses are also subject to higher levels of contaminants (oil, dirt, bugs, etc.) than windshields, and typically do not have the benefit of cleaning mechanisms like wipers. The principal research question was: Is there a reduction in surface contaminants on a headlamp lens due to hydrophobic treatment that can be described in terms of changes in light output? It was presumed that the water-repelling nature of a glass surface after hydrophobic treatment would aid in minimizing the adhesion, and promote the removal, of contaminants from the lens surface. As a result, it was hypothesized that exposure to naturally occurring contaminants should have less of an effect on light output for the hydrophobically treated headlamps.

METHOD

Apparatus

Two vehicles of the same make and model were used in this study. While the vehicles differed by one manufacturing year, there were no differences in body styling or placement of the headlamps. The vehicles were midsized, four-door passenger cars. Each was equipped with original clear glass headlamp lenses. The lenses were relatively free of wear and were not chipped or cracked. The headlamps were dual-reflector lamps with HB4s replaceable bulbs and faceted reflectors. Each vehicle's lamps were properly aimed at the beginning of the study. The tungsten-halogen lamps were located 600 mm center-to-ground and had a center-to-center separation of 1160 mm.

Experimental Design

The experimental design consisted of four independent variables, each with two levels. The independent variables were hydrophobic treatment (treated versus untreated), precipitation (light rain and wet roadways versus no precipitation and dry roadways), headlamp illumination (headlamp on versus headlamp off), and headlamp location on the vehicle (driver side versus passenger side). This design resulted in 16 treatment conditions that could be examined using two vehicles, each with two headlamps, on four separate occasions of exposure to naturalistic contaminants–twice with active precipitation and twice with no precipitation. The dependent measure was light output measured at eight locations in each of the individual headlamp beam patterns. Four locations were above horizontal (glare points), and four were below horizontal (seeing points). Dirt is expected to increase the light output above the horizontal, because with small nominal light output values there, the increase due to light scatter is likely to dominate the decrease due to light absorption (Sivak, Flannagan, Traube, Kojima, and Aoki, 1996). Conversely, dirt is expected to decrease light output below the horizontal. Differences in light output associated with the 16 treatment conditions were determined by comparing measurements produced by an exposed (dirty) headlamp with measurements of the same lamp after it had been cleaned. In other words, each headlamp served as its own control.

Procedure

Environmental Exposure. The two vehicles were driven simultaneously, on four separate occasions, over a 155-km route in southeastern Michigan. This route was comprised of 75 km of interstate and state highway, and 80 km of arterial and collector roads. Paved surfaces on the route accounted for 140 km, while 15 km were dirt road. The route was traversed on four separate occasions to expose the lenses to the combinations of two levels of precipitation (raining versus dry) and two levels of headlamp illumination (on versus off). Headlamp illumination was included as a variable because it was thought that warming of the lens from an illuminated headlamp might promote drying of water, and that possibly more rapid drying could result in greater adhesion of contaminants. Vehicles were stored indoors immediately after the completion of each route, and until measurements of light output could be made. Exposure occurred during the fall months. The levels of precipitation under the rain condition were light, approximately 0.1 cm per hour.

Hydrophobic Treatment. On each traversal of the route, two of the four headlamps were treated with a commercially available product designed to produce a hydrophobic effect on glass surfaces. The location of the treated headlamps was balanced between the driver and passenger sides of the vehicle as well as between the two vehicles. In other words, on a given route one vehicle would have the passenger-side headlamp treated and the driver-side headlamp untreated, while the second vehicle would have an untreated passenger side headlamp and a treated driver-side headlamp. Balancing of the headlamp position in the treatment process was performed to control for the possibility of more contaminants on the passenger side of a vehicle (the side closer to the curb/gutter), which was an effect reported by Sivak et al. (1996).

Measurements of Light Output. Measurements of light output from headlamps were made to test for possible effects of surface contaminants on the lenses. Measurements were taken separately for the passenger-side and driver-side headlamps. During the measurement procedure the headlamps were independently supplied with regulated power set to 12.8 volts. Illuminance measurements were taken at a distance of 10 m from the lens surface using a headlamp aiming board that permitted the mounting of a Minolta T1 illuminance meter. For each of the 16 treatment conditions, the light output of a headlamp was measured at eight test points in the beam pattern (Figure 2), once when the lens was dirty and again after the lens was cleaned. The final value of illuminance at any one test point was an average of three measurements at that point. Test point locations are referenced from H-V, the point directly in front of the lamp.

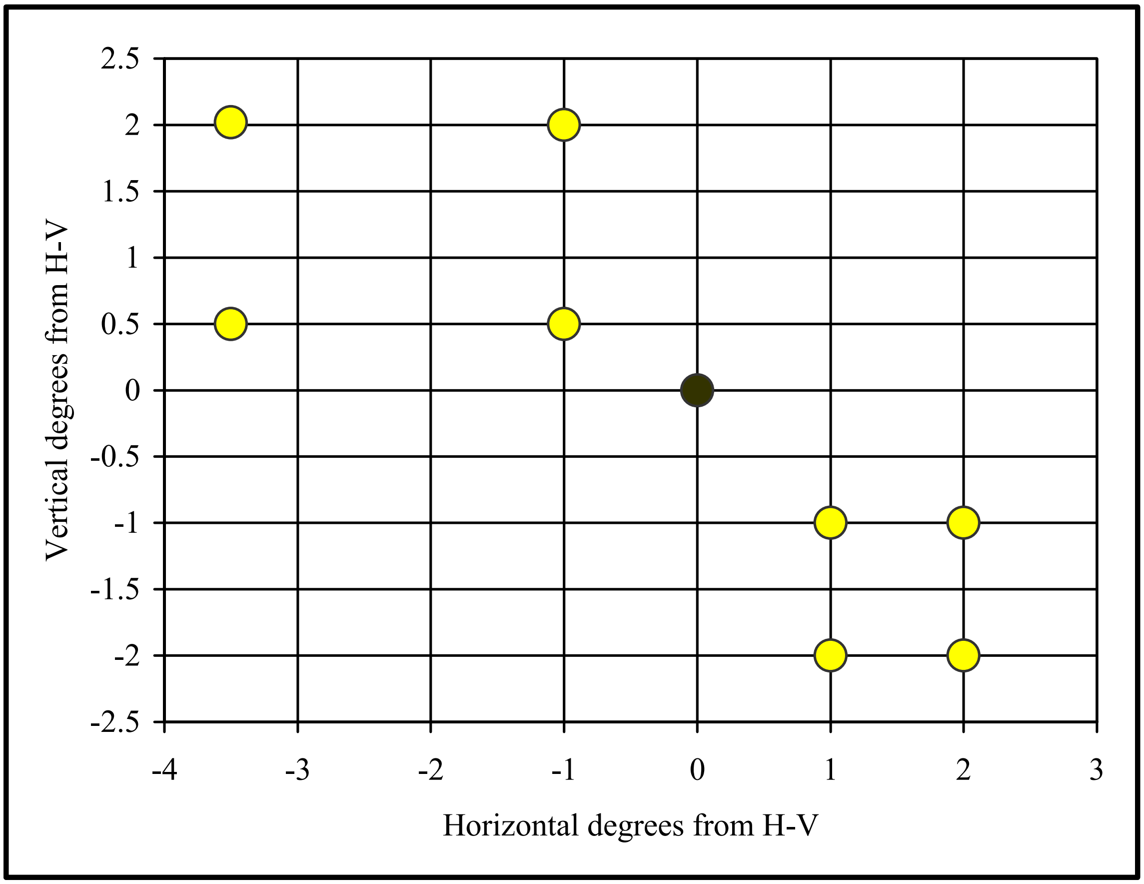

Figure 2. Graphical representation of measurement test points in a headlamp beam pattern.

RESULTS

The effects of the independent variables (hydrophobic treatment, precipitation, headlamp illumination, and headlamp location) on light output were examined. Each headlamp served as its own baseline, as measurements of light output were compared between when the lamp was "dirty" and once it had been cleaned.

Pre and postcleaning measurements of light output at the eight test points were plotted against one another, and linear regressions were performed. Previous research by Sivak et al. (1996) has shown the relationships between the light output of clean and dirty lamps are reasonably well described by linear modeling. Sivak et al. proposed that the effects of dirt on headlamp light output could be described, at least as a first approximation, by the two parameters of a linear equation: a slope and an intercept. Sivak et al. suggested that dirt reduces the slope (for dirty output regressed on clean output) because of proportional reductions in light output over the entire beam pattern caused by light scatter and absorption, and that dirt increases the intercept because of a nearly uniform distribution of scattered light that is added throughout the beam pattern.

Linear models using data from the present study were consistent with the findings of Sivak et al. Measurements of light output tended to decrease at the seeing points and increase at the glare points with exposure to naturalistic levels of surface contaminants. Therefore, for each condition measurements of light output for the clean and dirty headlamps were plotted against one another and best-fitting linear models were calculated (Figure 3). The slopes and intercepts from the linear models were then used for further analyses to determine whether there were differences in light output that were associated with the independent variables of interest.

Slopes and intercepts were generated for each run. The 16 runs comprise a 2^{5-1} fractional factorial design. However, one factor, vehicle (which of the two vehicles was used), was not expected to affect the light output of the headlamps, since the headlamps on both vehicles were the same type. Thus, when all main effects and interactions with vehicle are ignored, the 16 runs comprise a saturated 2^4 design.

Analysis of saturated designs is discussed in Box, Hunter, and Hunter (1978). Following their procedure, 15 slope effects were calculated, one for each main effect of treatment (treated/untreated), precipitation (dry/wet), headlamp illumination (on/off), and headlamp location (driver/passenger side), and for all possible interactions of these variables. The 15 effects were ranked and graphed against the normal deviate of their rank (Q-Q plot). A line was fit through the central points on this graph, and all large positive or negative values lying noticeably off this line became candidates for significant effects. All other effects were considered to be due to random variation and could therefore be used to estimate error.

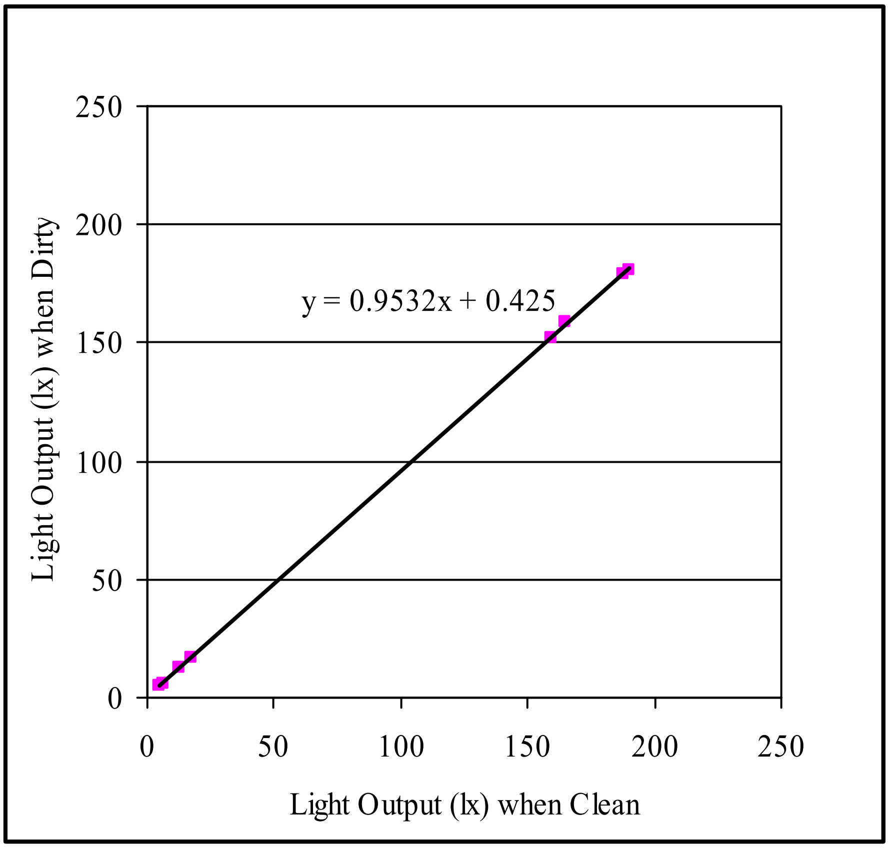

Figure 3. Example plot demonstrating the comparison of light output measurements for the eight test points from clean and dirty headlamps, and the process of calculating a best-fit linear model to produce slope and intercept values.

Figure 4 shows the Q-Q plot of slope effects. The main effect of precipitation was selected as a candidate for significant effect because it had the greatest absolute magnitude. Differences in absolute magnitude of the remaining effects were considerably smaller, and were not considered in the analysis. One problem with this analysis procedure is that as more effects are chosen as candidates for significance, the average size of the remaining effects decreases. Thus, the estimate of error variance is smaller when more effects are selected. This is an inherent problem with this form of analysis and must be taken into account when deciding which effects are considered significant.

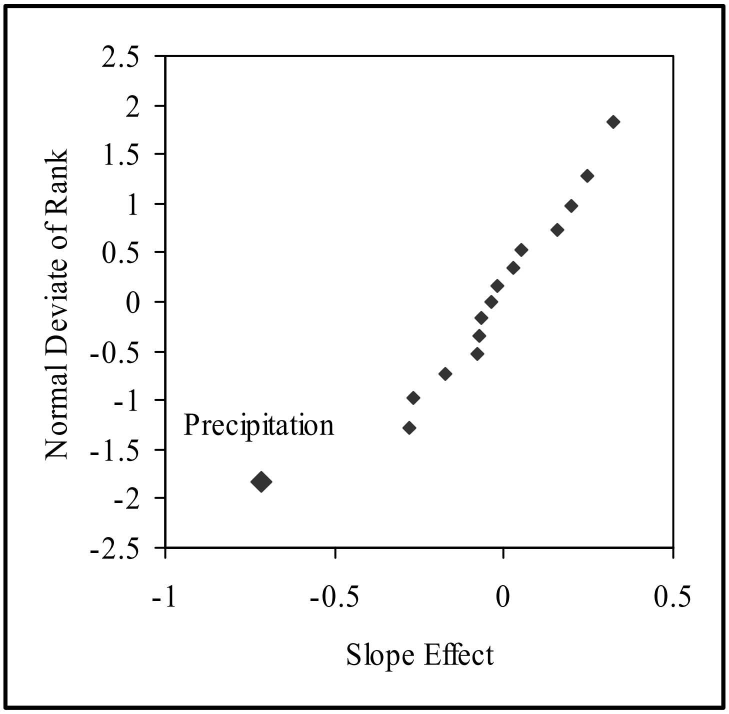

Figure 4. Q-Q plot of slope effects. The enlarged point represents the effect selected for examination.

To begin, slope was regressed on the potential predictor. The t-test for precipitation was statistically significant, $t(14) = -4.07844$, $p < 0.002$. So the null hypothesis that precipitation does not affect slope was rejected. The mean slope of light output in dry weather is 0.990 and the mean slope during wet weather is 0.901.

The same procedure was repeated for the intercepts calculated from each of the 16 tests. The Q-Q plot of intercept effect is shown in Figure 5. The precipitation x headlamp illumination interaction is the only effect to clearly appear off the line. However, the main effects of precipitation and headlamp illumination are the next largest effects, so these were also considered candidates for significant predictors of intercept.

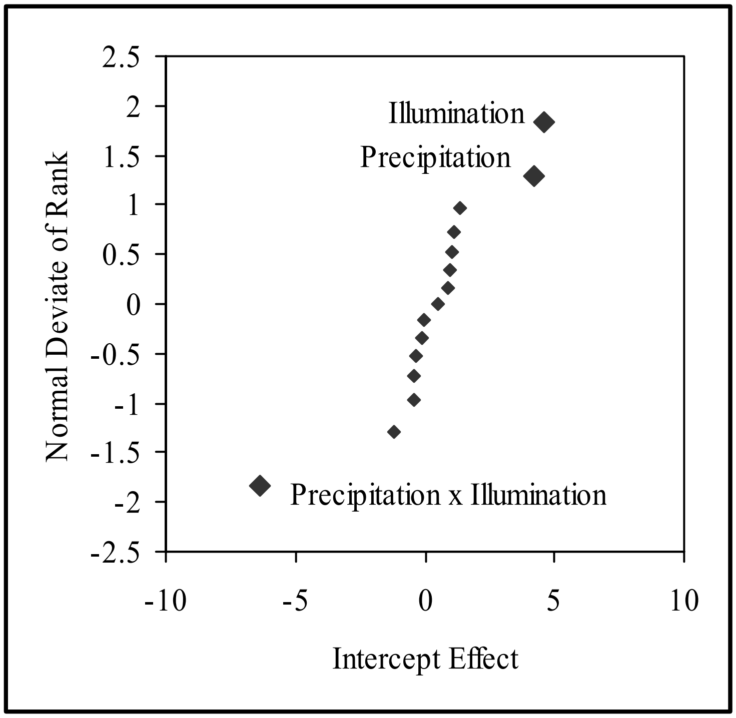

Figure 5. Q-Q plot of intercept effects. The enlarged points represent the effects selected for examination.

Intercept was regressed on the main effects of precipitation and headlamp illumination, as well as the interaction between the two. All three t-tests were statistically significant (precipitation: $t(12) = 5.06$, $p < 0.001$; headlamp illumination: $t(12) = 5.52$, $p < 0.001$; the interaction of precipitation and headlamp illumination: $t(12) = -7.70$, $p < 0.001$). Understanding the effects of precipitation and headlamp illumination on intercept of light output requires understanding the pattern of the interaction. This pattern is shown in Figure 6. The combination of wet weather and having the headlamps illuminated reduces the intercept of light output in a way that is not explained by precipitation or headlamp illumination alone.

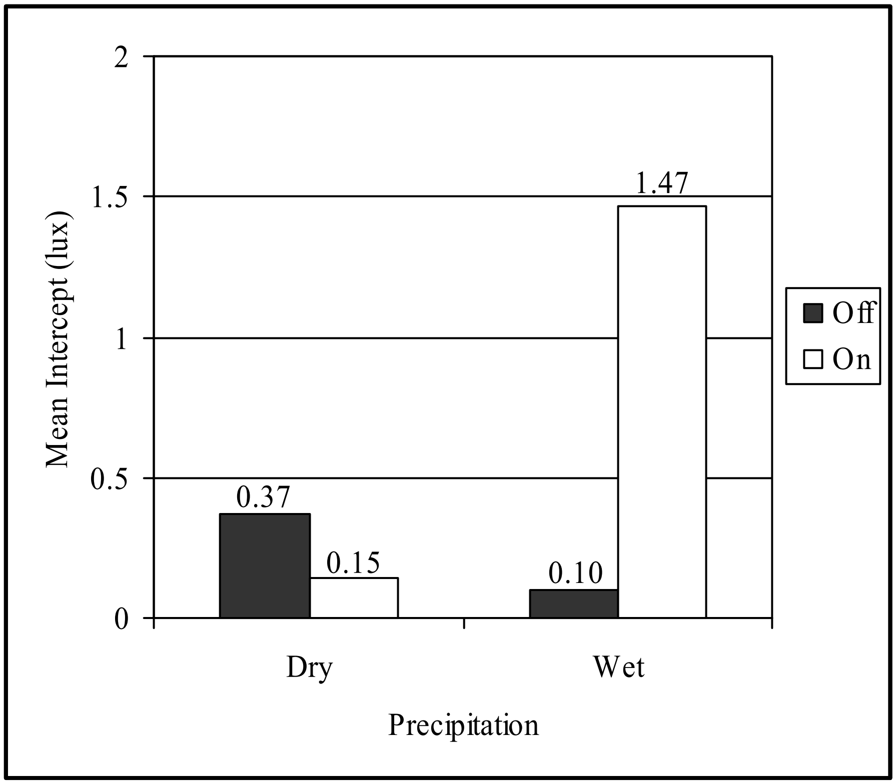

Figure 6. Interaction of precipitation and headlamp illumination (on/off) on intercept of light output.

DISCUSSION AND CONCLUSION

The principal objective of this study was to determine whether hydrophobic treatment of a glass headlamp lens would result in a reduction in surface contamination during naturalistic exposure. Light output of the headlamp was measured to test for the possible effects of surface contaminants on the lens surface. The *a priori* hypothesis was that hydrophobic treatment, with its ability to cause water to bead, would decrease the accumulation of dirt on the lens relative to an untreated lens.

Contrary to the hypothesized effect, the results of this study demonstrate that use of hydrophobic treatments on glass headlamp lenses does not decrease the presence of surface contaminants, at least as determined by measures of light output. Hydrophobic treatment did not significantly reduce the accumulation of dirt under conditions of light rain or provide any observable benefit under dry conditions. However, there was not an observable *dis*benefit attributable to hydrophobic treatment, either. Overall the use of hydrophobic treatments on glass headlamp lenses appears not to influence light output in either the seeing or the glare test point locations examined.

One factor that was found to significantly reduce light output was the presence of precipitation, specifically light rain. Precipitation had a statistically significant effect on the calculated intercepts. Precipitation also had a significant effect on the calculated slopes. Lamp illumination also had a significant effect on intercepts. The interaction of precipitation and lamp illumination also had a statistically significant effect on the intercepts. Neither lamp illumination nor the interaction of precipitation and lamp illumination affected slope. Lastly, the location of the headlamp on the vehicle did not affect either the slope or the intercept.

Although hydrophobic treatment produced no measurable effect, the results of this study are in agreement with those of Sivak et al. (1996) with regard to the effects of dirt. Measurable differences in light output that were associated with surface contaminants (dirt) were found, and the pattern of these differences was consistent between studies. Specifically, dirt resulted in reduced light output in the seeing points and increased light output at the glare points. The one significant new contribution toward an understanding of this effect is the demonstration that headlamp illumination (headlamps on) increases the accumulation of surface contaminants when precipitation is present. This is presumably because of the increased rate at which water and dirt dry on a lens surface when the lens is warmed. Therefore, future studies like that of Sivak et al.

should consider headlamp illumination as a factor in determining the rate of accumulation and effects of dirt on headlamp light output. Similarly one might expect to see a difference in the accumulation of surface contaminants between hotter (e.g., incandescent) and cooler (e.g., HID, LED) sources of illumination, regardless of the exterior lighting application.

Suggestions for Future Research

The results of this study suggest the following topics for future investigations:

- This study did not examine the effects of hydrophobic treatment on lenses under winter conditions. In winter the build-up of contaminants on the lens surface may be greater, because of salt or sand being spread on roadways and because headlamps are illuminated more because of fewer daylight hours relative to summer months.
- This study did not examine whether hydrophobically treated lenses, in comparison with untreated lenses, might be cleaned more readily by naturally occurring precipitation after contaminants had the opportunity to dry on a lens surface. This could be tested in a long term study.
- This study only examined the effects of hydrophobic treatment associated with 155 km of driving. The effects of hydrophobic treatment over longer exposures to naturalistic contaminants should also be considered.

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