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16. Abstract
This study consisted of a survey and a field experiment to evaluate the potential benefits of hydrophilic treatments for motor vehicle glazing. The survey examined the subjective assessments of 15 drivers whose vehicles had a portion of the rear window and one of the side windows treated with a hydrophilic coating. The field experiment evaluated the effects of hydrophilic and hydrophobic treatments, relative to an untreated condition, on driver visual acuity under simulated wind and rain conditions, both during the day and during the night. Additional independent variables included whether headwind was present, rain rate, and age.

The results of the survey show that drivers did not report a benefit of hydrophilic treated areas compared to untreated areas of the side or rear windows. Consistent with the survey results, the field experiment showed that hydrophilic treatment did not improve visual performance. However, significant improvements in visual performance were associated with hydrophobic treatment of the rear window.

The findings from the field experiment support previous research that showed significant improvements in visual acuity associated with hydrophobic treatment of the windshield. On the other hand, the present study found no subjective or objective benefits of applying hydrophilic treatments to rear or side windows.

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CONTENTS

INTRODUCTION

What are Hydrophilic and Hydrophobic Coatings?

For the purpose of automotive glazing applications, hydrophilic and hydrophobic treatments are transparent chemical coatings that bind with, and change the surface chemistry of, laminated or tempered glazing in order to modify the level of contact between the glazing surface and water that comes into contact with that surface. Hydrophilic treatments attempt to maximize, or evenly distribute, water's contact with a treated surface (Figure 1a). Hydrophilic treatments for automotive glazing applications are relatively new, and there are very few that are commercially available. However, hydrophilic coatings have been used for some time on architectural glazing as well as on medical and laboratory equipment.

Hydrophobic treatments, on the other hand, attempt to minimize water's contact with a treated surface. Acting like water repellents, hydrophobics cause rain and other accumulated moisture to bead (Figure 1b). Aided by airflow resulting from wind and the aerodynamics of a vehicle in motion, beads of water are readily shed from a hydrophobically treated surface. Numerous hydrophobic treatments for automotive glazing are commercially available, including products consumers may apply themselves and others that must be applied by trained personnel.

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), 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).

Sayer et al. (1997) reported that the application of hydrophobic treatment to the windshield of an automobile, under simulated rainy driving conditions, 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 rather large (approximately 34% in terms of the minimum visual angle resolved). By way of comparison, visual acuity improved in a treated nighttime condition to a level that was not significantly different from performance in an untreated daytime condition. The experimental conditions in the Sayer et al. (1997) 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 on distance estimation under conditions of simulated rain and wind when applied to the driver-side window and driver-side exterior rearview mirror. The authors reported that there was no significant effect of hydrophobic treatment of the driver-side windows or mirrors, but that one marginally non-significant 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.

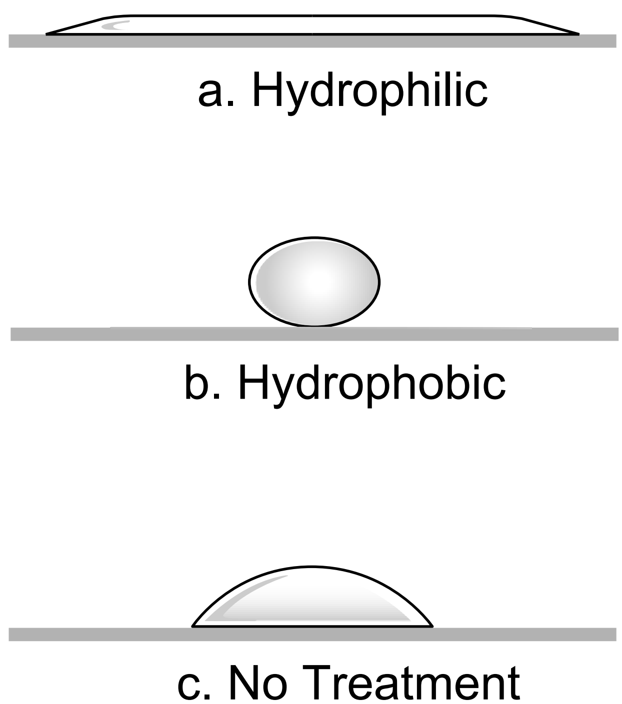

Figure 1. A schematic representation (cross section) of the contact between water and glass surfaces with or without treatment.

The Objectives of the Present Study

The present study investigates the potential benefits of using hydrophilic and hydrophobic treatments on the rear and side windows of a passenger car. 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.

The present study consists of two parts. Because there was no known literature regarding the use of hydrophilic treatments for automotive glazing, the first segment presents an exploratory survey of driver impressions of the efficacy of hydrophilic treatments. The second part is an experiment that examines the effects of hydrophilic and hydrophobic treatments on driver visual acuity. Visual acuity serves as a general measure of visual performance. While the magnitude of the effects under real driving/raining conditions may differ from those obtained under the simulated conditions, the direction of the effects is expected to be the same. The following independent variables were examined:

- glazing treatment (hydrophilic or hydrophobic treatment versus untreated)
- time of day (daytime versus nighttime)
- wind (presence or absence of headwind)
- participant age (younger versus older)

Like the previous studies by Sayer et al. (1997 and 1999), the present study was performed under conditions of simulated rain and airflow. This experiment did not address the durability or longevity of hydrophilic or hydrophobic products. The conditions of the experiment were such that the hydrophilic and the hydrophobic treatments were always newly applied (and therefore could be expected to be near peak performance). In practice, the effects of hydrophilic and hydrophobic treatments on driver visual performance will change with time and wear, unless the coatings are reapplied or product durability is very long.

SUBJECTIVE IMPRESSIONS OF THE EFFECTIVENESS OF HYDROPHILIC TREATMENTS

Prior to conducting a controlled experiment on the effects of hydrophilic coatings, a survey was conducted in order to better understand what factors might influence the efficacy of hydrophilic treatments.

Participant Recruitment

Fifteen licensed drivers participated in this survey. All were staff members of the University of Michigan Transportation Research Institute (UMTRI). A request for participants, that was distributed to UMTRI staff via electronic mail, briefly described how we would treat certain portions of their vehicle's glazing.

Treatments

All glazing surfaces, interior and exterior, on the participants' 15 vehicles were cleaned with a surfactant-free solution composed largely of isopropyl alcohol. Each of the vehicles had one side window treated with a hydrophilic treatment, either the driver side or the passenger side, and one-half of the rear window treated with a hydrophilic solution, either the driver side or the passenger side. The treatment conditions were approximately balanced across vehicles. The untreated surfaces were simply cleaned. A listing of the vehicles and surfaces treated are shown in Table 1.

The treatment was a proprietary hydrophilic formulation under development. The treatment produced a hydrophilic surface that was similar to surface conditions produced by polishing with high-grade cerium oxide (CeO_2). However, the hydrophilic formulation maintained a hydrophilic surface for at least three weeks under normal conditions of exposure (including multiple car washes).

Table 1. List of the vehicles and surfaces treated.

	VEHICLE TYPE			SURFACE	
	Year	***Make***	***Model***	***Rear Window***	***Side Window***
1	91	TOYOTA	TERCEL	Driver Side	Driver Side
2	88	TOYOTA	COROLLA	Driver Side	Driver Side
3	99	MERCEDES-BENZ	SLK230	Driver Side	Driver Side
4	00	SUBARU	FORESTER	Driver Side	Passenger Side
5	97	FORD	EXPLORER	Driver Side	Passenger Side
6	89	OLDSMOBILE	CUTLASS	Driver Side	Passenger Side
7	99	TOYOTA	COROLLA	Passenger Side	Driver Side
8	98	SATURN	WAGON	Passenger Side	Driver Side
9	97	FORD	F250	Passenger Side	Driver Side
10	00	FORD	RANGER	Passenger Side	Passenger Side
11	00	CHEVROLET	1500	Passenger Side	Passenger Side
12	96	CHEVROLET	CAVALIER	Passenger Side	Passenger Side
13	89	OLDSMOBILE	CUTLASS CIERA	Passenger Side	Driver Side
14	99	HONDA	ACCORD	Driver Side	Passenger Side
15	99	VOLVO	S70 AWD	Passenger Side	Driver Side

Procedure

Participants were told which specific areas of glass on their vehicles had been treated, but were not told the nature of the treatment—or what they might expect from the treatment. However, participants were asked to pay particular attention to the surfaces when driving in the rain. Figure 2 shows the written information given to each participant at the beginning of his or her participation.

Thank you again for your willingness to participate in our informal survey of automotive glass treatments. Please recall that the treatments in question may improve visibility when driving in the rain. However, there is also the possibility that under some conditions visibility could be somewhat worse than no treatment at all. So while we'd like you to make a point of evaluating the treated surfaces when driving in the rain, we are also interested in what you think about the treated surfaces under other conditions (when dirty, morning dew, at night, etc.).

We have cleaned all of the glass surfaces on your vehicle (interior and exterior). Some of the exterior surfaces have subsequently been treated with one or more products. We have identified the specific surfaces that were treated on your vehicle in the list below. In addition, we have placed some small red dots on these surfaces so that you might initially get used to which surfaces are treated, but feel free at any time to remove these markers. After a couple weeks' opportunity to drive with the treated glass we will ask you to describe what, if any, differences you may have observed. This will be done with a brief questionnaire and through informal discussion. After everyone has completed participation we will hold a lunchtime debriefing regarding what we treated the glass with, and what types of responses we were expecting to hear back from you.

<u>Treated Surfaces</u>

Rear Window:	**[Driver Side]**	Passenger Side
Side Windows:	Driver Side	**[Passenger Side]**

Figure 2. Written information provided to each participant.

Results

Approximately 18 days after treatment, with participants having driven their vehicles as they would normally, each participant was asked to complete a questionnaire evaluating the effect of the treatment. The questionnaire is reproduced in Figure 3.

Table 2 presents the responses to the questionnaire. All participants reported that they had an opportunity to examine the treated surfaces when it was raining. However, the amount of time that participants reported driving in the rain—and therefore having an opportunity to evaluate the treated surfaces—varied widely, as did the number of times a vehicle was washed. All 15 participants reported having driven their vehicles on a regular basis.

There was a slight tendency to favor the hydrophilic treatment conditions, with mean ratings of 5.5 for the hydrophilic versus 4.9 for the untreated condition of the rear window, and mean ratings of 5.3 for the hydrophilic versus 5.0 for the untreated condition of the side window. In both instances, ratings were based on a 9-point scale. However, sign tests performed on these ratings indicated no statistically significant difference between the treated and untreated surfaces for either the rear window or the side windows.

1. Did you have the opportunity to examine the treated surfaces <u>when it was raining</u>?

Yes No

If yes, approximately how many minutes did you drive the treated car when it rained? _____

2. Approximately how many days a week do you drive this vehicle? ____

3. Have you washed your vehicle since the treatment was applied? If yes, approximately how many times ____

4. Please rate on a scale from 1 to 9 (where 1 is very negative, 5 is neutral, and 9 is very positive) your overall impression for each of the surfaces listed below. Under what conditions, if any, were you able to detect a difference in the surfaces (rain, snow, fog, etc.)? Also, what type of an effect (briefly describe what you saw).

Rear Window

Driver Side:

1	2	3	4	5	6	7	8	9	Condition and Effect
Very Negative				Neutral				Very Positive	

Passenger Side:

1	2	3	4	5	6	7	8	9	Condition and Effect
Very Negative				Neutral				Very Positive	

Side Windows

Driver Side:

1	2	3	4	5	6	7	8	9	Condition and Effect
Very Negative				Neutral				Very Positive	

Passenger Side:

1	2	3	4	5	6	7	8	9	Condition and Effect
Very Negative				Neutral				Very Positive	

Figure 3. Questionnaire evaluating the effect of hydrophilic treatment.

Table 2. Questionnaire results from the hydrophilic treatment survey (values in shaded cells represent ratings of the hydrophilic treated surfaces). The abbreviations DS and PS represent Driver Side and Passenger Side, respectively.

	VEHICLE		***REAR WINDOW***	***RATING***		***SIDE WINDOW***	***RATING***		***MINUTES***	***DAYS***	***TIMES***
	Year	***Make***	***TREATMENT***	***DS***	***PS***	***TREATMENT***	***DS***	***PS***	***DRIVEN***	***DRIVEN***	***WASHED***
1	91	TOYOTA	Driver Side	6	5	Driver Side	5	5	30	6	0
2	88	TOYOTA	Driver Side	5	5	Driver Side	5	5	60	7	0
3	99	MERCEDES-BENZ	Driver Side	5	5	Driver Side	7	5	120	6	0
4	00	SUBARU	Driver Side	5	5	Passenger Side	5	5	60	6	1
5	97	FORD	Driver Side	5	5	Passenger Side	5	5	180	6	2
6	89	OLDSMOBILE	Driver Side	5	5	Passenger Side	5	5	200	7	1
7	99	TOYOTA	Passenger Side	5	5	Driver Side	5	5	5	7	0
8	98	SATURN	Passenger Side	5	5	Driver Side	3	5	10	7	0
9	97	FORD	Passenger Side	5	5	Driver Side	5	5	60	7	0
10	00	FORD	Passenger Side	5	5	Passenger Side	5	5	150	7	1
11	00	CHEVROLET	Passenger Side	5	5	Passenger Side	5	7	180	7	1
12	96	CHEVROLET	Passenger Side	5	5	Passenger Side	5	5	5	7	2
13	89	OLDSMOBILE	Passenger Side	5	7	Driver Side	8	5	60	7	0
14	99	HONDA	Driver Side	8	3	Passenger Side	5	5	120	7	2
15	99	VOLVO	Passenger Side	5	7	Driver Side	5	5	120	7	3
		Treated (sum and mean)		83	5.53		80	5.33	Means		
		Untreated (sum and mean)		73	4.87		75	5.00	90.67	6.73	0.87

EFFECTS OF HYDROPHILIC AND HYDROPHOBIC TREATMENTS ON VISUAL ACUITY

Although the survey showed no significant effects of the hydrophilic treatment on driver subjective impressions, there was a tendency in the positive direction. Consequently, a field experiment was designed to evaluate the effects of hydrophilic treatment of the rear window on visual acuity. For comparison, a condition that involved applying a hydrophobic treatment to the rear window was also included.

Participant Recruitment and Screening

Twelve licensed drivers were paid $50 each to participate in this study. The duration of each driver's participation was approximately two hours total (one hour under daytime conditions, and one hour under nighttime conditions). Six participants were in an older age group (62-70 years, mean = 66.7 years) and six were in a younger age group (20-29 years, mean = 23.7 years). Each age group was balanced for gender. All participants were recruited from a list of persons potentially interested in participating in UMTRI studies. Ten of the twelve participants had visual acuity (corrected for those with corrective lenses) of 20/25 or better as determined by an Optec® 2000 vision tester. The remaining two participants, both in the older age group, had visual acuity of 20/40 and 20/50.

Experimental Task

The task in this experiment was to report the orientation of the gap in a Landolt "C" under a variety of simulated weather conditions. The complete instructions were as follows:

> *Thank you for agreeing to participate in this study. During this study you will be seated in three different cars. You will be asked to look at targets located behind you using only the interior rear-view mirror (the center one). The targets are always the letter "C", but vary in orientation and size. You will be asked to state in which direction the opening of the "C" is pointed; up, down, left or right. You will be given three seconds to view the "C" before it is covered. Even if you cannot accurately judge the orientation of the target, you must still guess.*
>
> *Water will be sprayed on the car to simulate rain and the large blower in front of the car will be used to simulate wind. You will be asked to report the orientation of the targets to the experimenters using a hand-held radio. We recognize that this is a difficult task, but we ask you to try as hard as possible to correctly identify the orientation of the targets presented.*
>
> *Make sure the rear defogger is on in all of the cars, and you may adjust only the climate control buttons in the car.*

Apparatus

A series of 12 Landolt "C" targets were presented at a distance of 15 m behind the participants, across an asphalt-paved lot. Given the distance from the rearview mirror to the participant's eyes and the distance from the rearview mirror to the target location, the total sight distance was approximately 16.4 m. The Landolt "C" recognition task is a common measure of visual acuity. Performance on the Landolt "C" task is determined by the smallest gap size in the letter "C" a participant can detect when the gap is presented in one of four possible locations, separated by 90 degrees. The stroke width of the character is kept equal to the gap size and the height of the character is five times the gap size. The range of gap sizes, and the associated subtended visual angles of the targets are presented in Table 3. The target gap size ranged from 4 to 33.5 mm (0.8 to 7.0 minutes of arc).

Table 3. Stimulus gap size and associated subtended visual angle.

Stimulus	Gap Size (mm)	Visual Angle (min)
1	4.0	0.8
2	5.4	1.1
3	6.6	1.4
4	8.1	1.8
5	10.0	2.1
6	11.6	2.5
7	14.3	3.0
8	16.9	3.5
9	20.0	4.2
10	24.6	5.2
11	29.4	6.2
12	33.5	7.0

Participants viewed the targets while seated in the driver's seat of a research vehicle, one of three late-model full-sized sedans. The rake angle of the vehicle's rear window was 65º. The center of the target was 1200 mm above the pavement, and in line with the center of the vehicle. The targets were constructed of retroreflective sheeting affixed to square aluminum plates that were 305 mm on each side. The "C" was white and the background was green; both were made of retroreflective sheeting. The target was illuminated under nighttime conditions.

Procedure

A variation of the staircase method, a psychophysical method used to determine thresholds, was employed. Each session began with three practice trials. Stimuli were presented for three seconds each. Stimuli for which the correct orientation could not be identified during a three-second presentation where scored as incorrect responses. The first trial always began with the largest stimulus (#12 in Table 3). Stimuli were presented in progressively decreasing order of gap size as long as the participant's responses were correct. When a participant incorrectly identified a stimulus orientation the order was reversed (gap size increased) until a correct response was again elicited. The reversal points were used as estimates of the threshold, where the mean of two last correctly identified stimulus orientations in the decreasing and increasing orders was considered the participant's threshold for a given condition.

One experimenter placed the stimuli in a frame, mounted on a tripod. A second experimenter recorded the stimuli presented, whether the participant correctly identified the stimulus orientation (communicating via hand-held radio with the participant), and instructed the first experimenter as to which stimulus to present next in the series.

Experimental Design

A mixed-factor design was used where the between-subjects variable was participant age, and the within-subject variables were rear-window treatment, time of day, wind, and rain rate. Each participant saw all combinations of the within-subject variables. All participants took part in the daytime session before the nighttime session.

Rear-window treatment. Three late-model, full-sized sedans that were identical in make, model, and year were used. The rear window of one vehicle was polished using high-grade cerium oxide (CeO_2) in order to produce a hydrophilic surface; one was treated with a commercially available hydrophobic treatment; and the third was simply cleaned with a surfactant-free glass cleaning solution. The rear window of the hydrophilic vehicle was polished with cerium oxide before each session, or every two hours during continuous testing. The rear window of the untreated vehicle was cleaned on several occasions during testing. The hydrophobic treatment was applied several times over the course of testing to ensure a consistent effect.

Time of day. The experiment was conducted under two ambient light conditions, during daylight and at night (without fixed lighting).

Wind. In order to simulate air moving over a vehicle in motion, which normally aids in removing water from a vehicle's surface, a rotary-turbine powered by a four-cylinder automotive engine was used (Figure 4). The wind machine was positioned 5.6 m from the front of the vehicle, or 9.35 m from the center of the rear window. Average wind speed produced by the machine at the front fascia was approximately 101 km/hr. Average wind speeds over the surface of the rear window ranged from 43.5 km/hr at the bottom of the window to 56.3 km/hr at the top. Wind speeds were regularly sampled using a Davis Instruments Model 7908 Anemometer, which was mounted to the rigging adjacent to the vehicle. Air speeds varied slightly as a result of uncontrollable ambient wind conditions.

Rain rate. Rain was simulated using a series of commercially available irrigation sprinkler heads mounted to wooden rigging under which the vehicles were parked (Figure 5). The selection of the sprinkler heads was based on the size of the water droplets and the volume of water produced. Droplet sizes were determined using an empirically validated filter-paper technique (Rinehart, 1997). Droplet sizes ranged from 0.2 to 1.8 mm in diameter, with a mean droplet diameter of 0.53 mm. Two rates of rainfall were simulated, 23 mm/hr and 46 mm/hr. Measurements of rain volume were made using a Davis Instruments Rain Collector II that was calibrated to measure rain volume in increments of 0.2 mm. Rain volumes were sampled for 20-minute periods in five locations under the rigging (center and the four corners); the rain volumes from the five locations were then averaged to determine associated rain rates in mm/hr.

Figure 4. The rotary-turbine wind machine used to simulate air moving over a vehicle in motion.

Figure 5. Rigging supporting the overhead sprinkler system used to simulate rain.

Results

A repeated-measures analysis of variance (ANOVA) was performed where the dependent variable was threshold visual acuity for the Landolt "C" task, and the independent variables were rear-window treatment, time of day, wind, rain rate, and driver age group. The analysis included an adjustment of the degrees of freedom using the Greenhouse-Geisser test (Winer, Brown, and Michels, 1991).

Rear-window treatment. The rear-window treatment condition significantly affected performance on the Landolt "C" visual acuity task, $F(1.2,9.6) = 87.9$, $p < 0.001$ (Figure 6). Participants' visual acuity was significantly better in the hydrophobic treatment condition; mean 2.2 minutes of arc, relative to the hydrophilic or untreated conditions, means 6.9 and 7.2 minutes of arc, respectively. A Newman-Keuls post hoc analysis showed no statistically significant difference between the untreated and the hydrophilic treatment conditions.

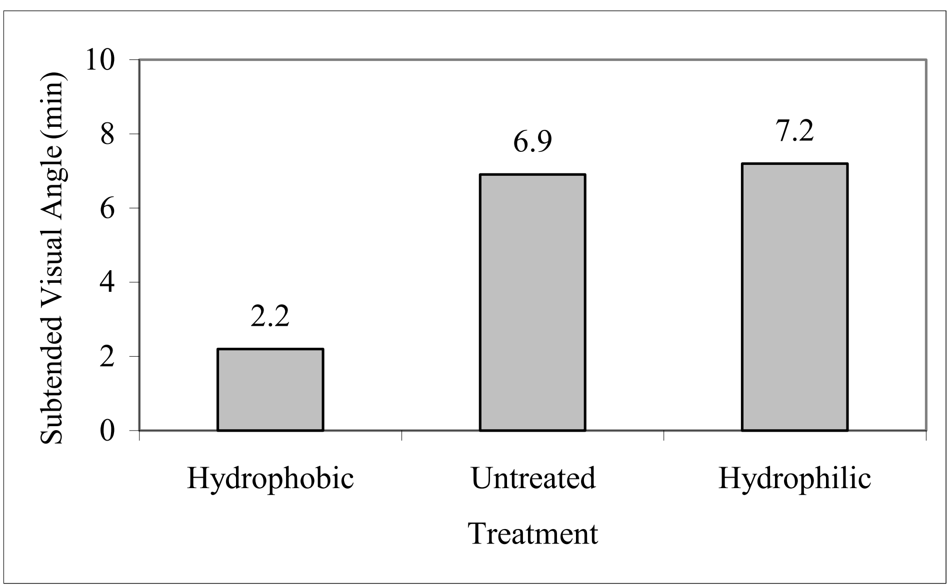

Figure 6. Visual acuity as a function of rear-window treatment condition.

Time of day. Time of day significantly affected visual acuity, $F(1,8) = 23.7$, $p = 0.001$ (Figure 7). Participants' visual acuity was significantly better in the daytime condition (mean 4.4 minutes of arc) than in the nighttime condition (mean 6.5 minutes of arc). There was also a statistically significant interaction of rear-window treatment and time of day, $F(1.8,14.6) = 5.2$, $p = 0.02$. Figure 8 shows that the poorest mean visual performance was recorded for the untreated rear window during the nighttime condition. A Newman-Keuls post hoc analysis showed that all mean comparisons were statistically different from each other, except for the comparison of the daytime and nighttime hydrophobic conditions, the comparison of the daytime-untreated and daytime-hydrophilic conditions, and the comparison of the nighttime-untreated and nighttime-hydrophilic conditions.

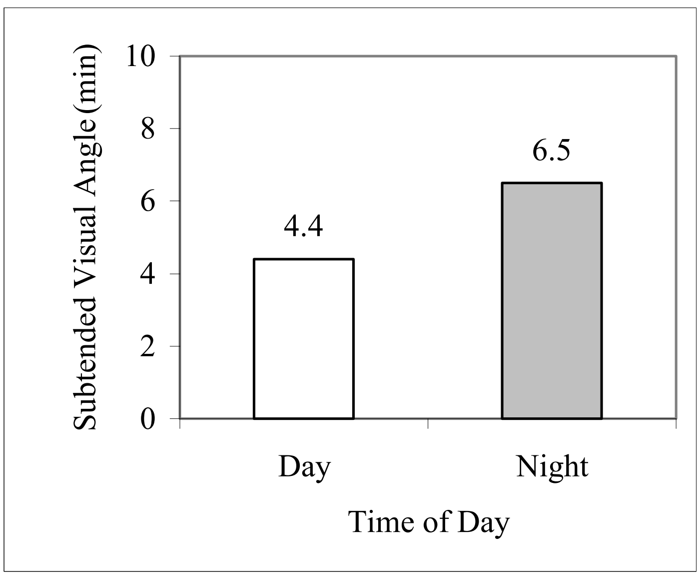

Figure 7. Visual acuity as a function of time of day.

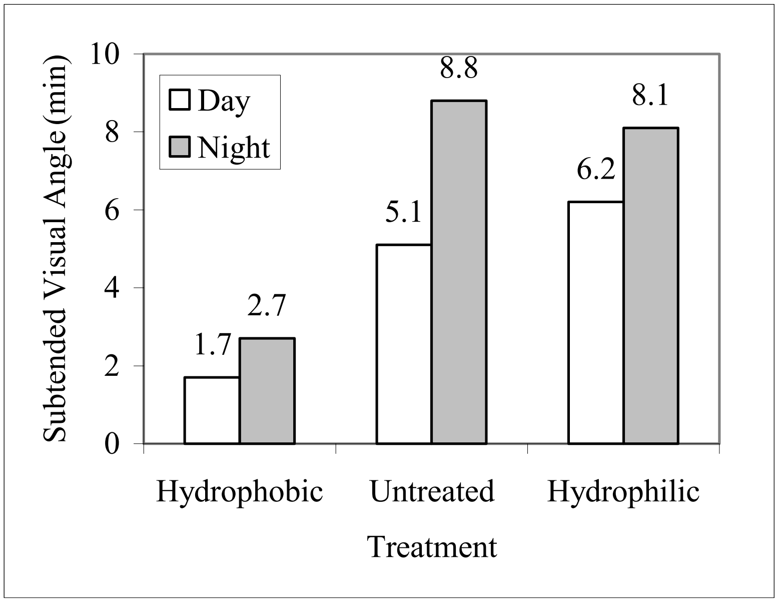

Figure 8. Visual acuity as a function of rear-window treatment and time of day.

*Wind. T*he presence or absence of wind significantly affected visual acuity, $F(1,8) = 31.0$, $p = 0.021$ (Figure 9). Participants' visual acuity was better in the wind condition, mean 5.1 minutes of arc, in comparison with the no-wind condition, mean 5.8 minutes of arc. This difference represents a 12% improvement in visual acuity.

Rain rate. Rain rate significantly affected visual acuity, $F(1,8) = 19.6$, $p = 0.002$ (Figure 10). Participants' visual acuity was better in the low-rain condition (mean 4.7 minutes of arc), in comparison with the heavy-rain condition (mean 6.2 minutes of arc).

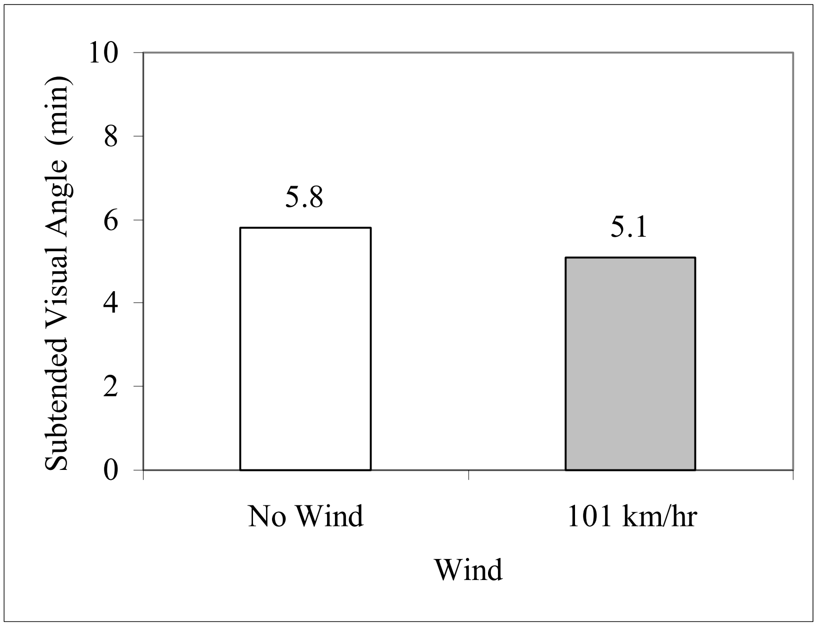

Figure 9. Visual acuity as a function of wind.

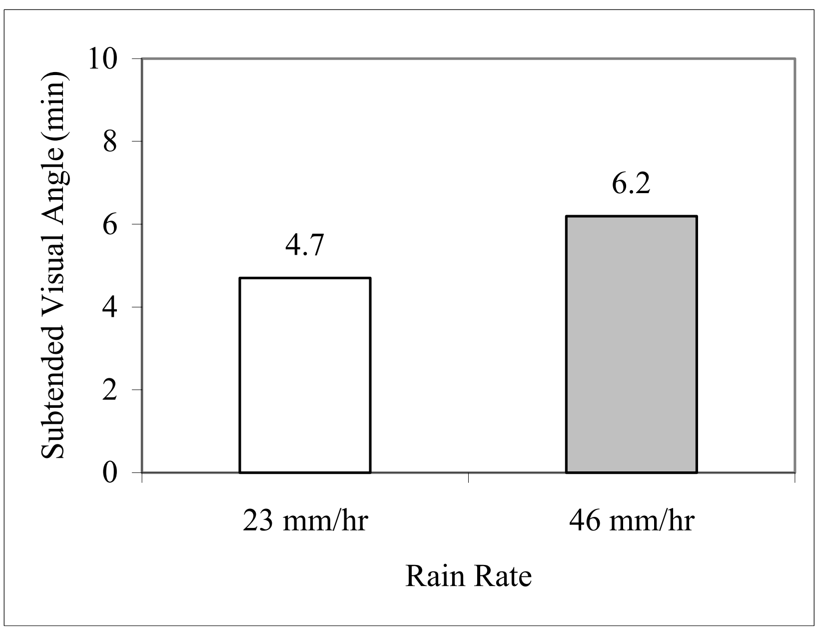

Figure 10. Visual acuity as a function of rain rate.

Participant age. While participant age did not significantly affect performance on the visual acuity task, there was a significant three-way interaction between participant age, rain rate, and time of day, $F(1,8) = 5.6$, $p = 0.05$ (Figure 11). Nighttime visual acuity was worse than daytime acuity in all conditions, and visual acuity of younger participants was always better than that of older participants. The combination of heavy rain and the nighttime condition appeared to be particularly difficult for older participants.

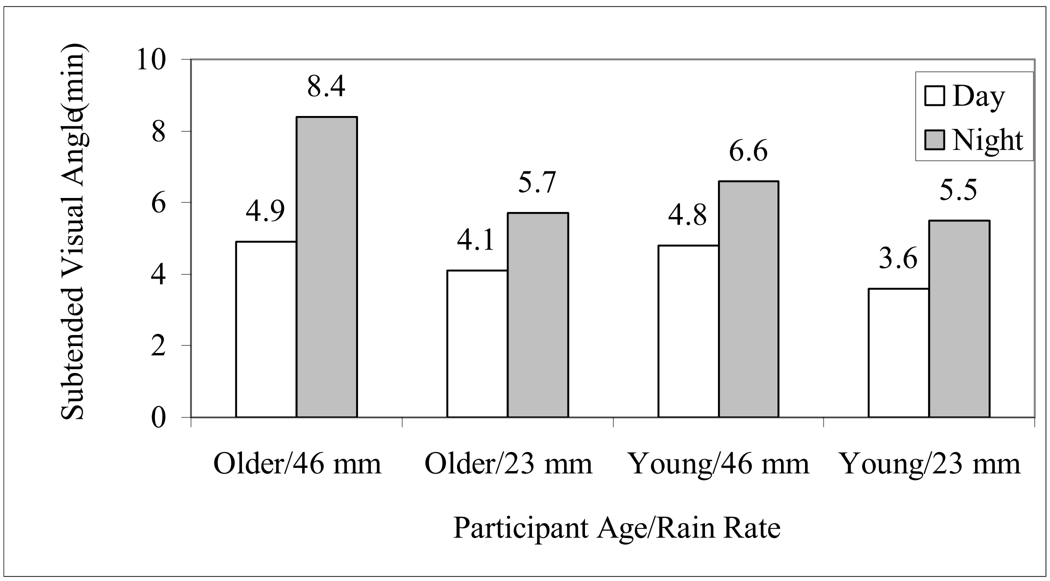

Figure 11. The three-way interaction between participant age, rain rate, and time of day.

DISCUSSION

Subjective Impressions

The hydrophilic-treatment survey was performed using a wide range of vehicles, including a variety of window rake angles and differences in vehicle aerodynamics. Furthermore, the majority of the participants in the survey reported having more than enough time to evaluate the effects of the hydrophilic treatment while driving in the rain. The results of the survey suggest that hydrophilic treatment of a vehicle's rear window and side window do not produce substantial improvements in appearance, at least at a subjective level. Yet, the trend in the data (which was statistically non-significant) slightly supported the hydrophilic treatment. For a more thorough evaluation of possible befits of hydrophilic treatments, we decided to compare objective visual performance with a hydrophilic treatment, a hydrophobic treatment, and no treatment of a rear window.

Visual Acuity

The results of the visual acuity experiment support the survey findings. Specifically, there appears to be no benefit of hydrophilic treatment of the rear window relative to an untreated window. The results do, however, support previous findings related to hydrophobic treatments (Sayer et al., 1997), namely that hydrophobic treatment of vehicle glazing improves performance in a visual acuity task and that hydrophobic treatments are particularly beneficial under nighttime conditions. Additional results of interest include improved visual performance associated with simulated wind, and decreased visual performance associated with increasing levels of rain. Older drivers in particular were negatively affected by the higher rain rate under the nighttime condition.

Future Research Needs

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

a) *Hydrophobic treatment durability*. In the current study, as with previous studies, the hydrophobic coating was always recently applied, and thus was presumably near peak performance. The levels of improved visual performance in this experiment may be reduced in real-world applications where treatments are more likely to be at less than peak performance. The durability of these treatments, and the resulting effects on visual performance, remain to be investigated.

b) *Vehicle styling and aerodynamics*. The objective portion of the current study only compared treatments on a passenger car having a relatively low rake angle of the rear window. It is likely that the aerodynamics of a vehicle and the rake angle of the rear window would influence the level of benefit found for the hydrophobic treatment condition by changing the manner or rate at which water was removed from the glass surface.

c) *Testing under conditions that are even more naturalistic*. While we believe that the simulations of rain and wind in the present experiment were reasonably good, it is not clear how the quantitative results of the present study would transfer to real-world driving conditions. Dirt, road salt, or other substances might influence the effectiveness of hydrophobic coatings. The next logical step in this area of research might include a field operational test in which a large number and variety of vehicles were treated, and the results gathered over a long period, perhaps months, in order to better determine the long-term effects of hydrophobic treatments under more naturalistic conditions.

CONCLUSIONS

The results of this study suggest 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 do support previous findings in favor of hydrophobic treatment of vehicle glazing. Specifically, the present study suggests that hydrophobic treatment of the rear window can provide benefit in the form of improved driver visual performance.

This is the second study to report improved visual performance associated with the hydrophobic treatment of vehicle glazing (compare with Sayer et al., 1997), suggesting that even more effort should be made to examine the visual performance benefits of hydrophobic treatments for vehicles. Two important issues remain: the effects of hydrophobic treatment durability on visual performance, and the effects of vehicle aerodynamics on the hydrophobicity of treated surfaces. These issues should be addressed to more comprehensively assess the real-world benefits of hydrophobic treatments.

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