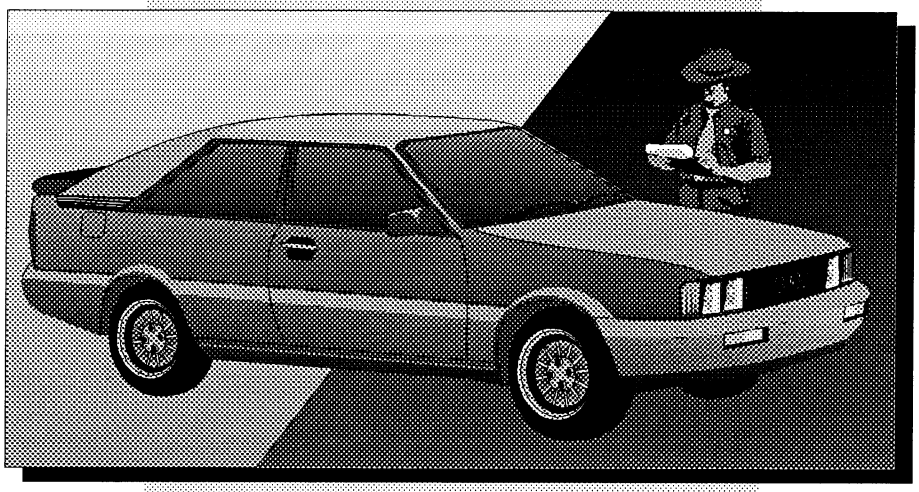
FINAL REPORT

EXTERNAL VIEWING OF VEHICLE CONTENTS UNDER VARYING WINDOW TINTING AND ILLUMINATION CONDITIONS



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Abstract

The purpose of this study was to determine the degree to which motor vehicle window tint films impede a police officer's ability to see clearly into a stopped vehicle. Three hundred and twenty subjects were asked to view the contents and occupants of one of four experimental cars. One car had no aftermarket tint film and three had varying degrees of tinted windows. Although similar experiments have been conducted in the past, all yielded equivocal results because of methodological flaws. This experiment attempted to correct some of those problems and to simulate standard procedures used in traffic stops by the Virginia State Police.

In general, this study found that the ability of subjects to detect occupants and objects in vehicles was substantially diminished as the level of window tinting increased. However, the detrimental effects of window tinting on viewing occupants and objects within a vehicle at night were substantially reduced when headlights and a spotlight were shone at the stopped vehicle, as would be the case in a traffic stop.

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

The purpose of this study was to determine the degree to which motor vehicle window tint films impede a police officer's ability to see clearly into a stopped vehicle. Three hundred and twenty subjects were asked to view the contents and occupants of one of four experimental cars. One car had no aftermarket tint film and three had varying degrees of tinted windows. Although similar experiments have been conducted in the past, all yielded equivocal results because of methodological flaws. This experiment attempted to correct some of those problems and to simulate standard procedures used in traffic stops by the Virginia State Police.

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INTRODUCTION

The issues of whether motor vehicle window tinting should be allowed or how much tinting should be allowed have been the subject of fractious debate in state legislatures. Federal regulations govern all matters concerning motor vehicle window glass for new vehicles. Except for motor vehicle glass that is installed behind the driver in trucks, buses, and multi-purpose vehicles, the glass on all motor vehicles must allow at least 70% of the light to pass through. Currently, no federal standards apply to aftermarket-applied window tint films.

There is a demand for tinted window films. The window film industry argues that window tinting creates lower interior vehicle temperatures, minimizes sun-related damage to upholstery and dashboards, provides protection for persons harmed by, or sensitive to, sunlight, and adds some measure of privacy to the vehicle. Tinting may also enhance the aesthetic appeal of a vehicle, especially when color-coordinated with the vehicle's exterior paint.

The enforcement and traffic safety communities, on the other hand, take strong exception to the use of what they consider excessively dark window films. Some believe window tinting may increase the incidence of traffic crashes. Also, police officers consider dark window films to be a threat to their safety. There is a desire to afford police officers the opportunity to see contraband or potentially threatening actions that might be obscured by darkly tinted glass. However, empirical evidence to substantiate these beliefs is lacking.

During the 1993 session of the Virginia General Assembly, the level of aftermarket window tinting allowed on motor vehicle glass was lowered. A concern that window tinting may adversely affect traffic safety led to the simultaneous adoption of Senate Joint Resolution No. 293, which authorized a state-of-the-art study of this issue. The report written in response to this resolution summarized the various legal issues related to aftermarket tinting, presented a survey of tinting laws in the 50 states, and summarized the available literature on the effects of window tinting on vehicle interior temperature, medical conditions for which the use of tinting may be advisable, optical theory and empirical evidence concerning the effect of window tinting on vision, and the effect of tinting on police officer safety (Proffitt, Jernigan, Lynn, & Parks, 1994). That report concluded that window tinting reduces the ability to detect targets that would be difficult to see through clear glass, and that this could be a safety liability, especially when ambient light is low. This could increase safety risks in at least three distinct contexts. First, the driver of an automobile may encounter situations in which visibility is impeded when looking through windows that have been tinted. Second, visual communication between drivers and pedestrians, cyclists, or other drivers may be hindered. Finally, window tinting may present an additional

hazard to police officers who must approach a stopped car on foot. In this last situation, tinting may impede an officer's ability to detect weapons, contraband, or threatening acts by the driver or passengers. The report recommended that additional empirical studies be conducted to determine the extent of window tinting's influence on safety in each of these situations. Moreover, it recommended that the latter situation involving police officer safety be studied first.

LITERATURE REVIEW

Optical and Visual Considerations

Window tinting reduces the amount of light emanating from the interior of a vehicle while increasing the proportion of light reflected off of its surface from the outside. Both of these effects reduce interior visibility. Moreover, these effects combine in the ratio of reflected to transmitted light to reduce visibility further.

The reduction in light emanating from the interior of a vehicle is affected *twice* by the transmittance values of its windows. Transmittance refers to the proportion of light incident upon the window glass that passes through into the air on the other side. Thus, if a window has a transmittance value of 50%, then the light passing through and illuminating the vehicle's interior is reduced by 50%, and that reflected back out of the window is again reduced by 50%. In other words, *the light available to someone looking into a vehicle is reduced to the square of the transmittance value of its windows.* (This generalization is approximate and entails a number of simplifying assumptions.)

Consider the case of a police officer attempting to examine the contents of an automobile's back seat through rear side windows with 35% light transmittance. The light illuminating the back seat area is reduced to 35% as it passes into the car and to 35% again as it passes out. Thus, the available luminance is 12.25% of what it would have been without any reduction in transmittance ($.35^2 = 0.1225$). If the rear side windows had 70% transmittance, then luminance would be reduced to 49% ($0.70^2 = 0.49$), which is 4 times greater than the amount of light available with 35% transmittance. In this case, a two-fold difference in window transmittance results in a four-fold difference in effective luminance (4 x 12.25% = 49%).

Window tinting films reduce transmittance in part by increasing reflectance. Reflection refers to the proportion of light incident upon the glass that bounces off of its surface. When one looks through glass, the luminance presented to the eye has two sources. One is the light transmitted through the window from the other side, and the other is the light reflected off the window from exterior sources. *The reflected light masks the transmitted light in proportion to the ratio of reflected to transmitted light.* An intuitive example follows. Imagine sitting in a living room that is illuminated by a table lamp. In this situation, one can look out of a window during the daytime and see what is going on outside without any difficulty. At nighttime, however, the window appears to be a mirror and all that can be seen when one looks out are reflections from the inside. The amount of interior light reflected off of the window is the same at both times of

day. The increased visibility of reflections at night is due to the increased ratio of reflected to transmitted light. During the day, the amount of light transmitted from the outside is much greater than that reflected from the inside, whereas at night, the amount of reflected light is far greater than the amount transmitted.

Since window tinting both reduces the light emanating from a vehicle's interior and increases the reflectance value of its window surfaces, the ratio of reflected to emanating light increases. In addition to the reduction in target luminance that is produced by tinting films, the ratio of transmitted to reflected luminance also affects the ability to see into a vehicle. In some cases, the luminance transmitted from a target within an automobile may be more than sufficient to allow for detection; however, if the ratio of reflected to transmitted light is too great, then the target will be masked by the reflection. The occurrence of masking reflections is situationally specific, depending on the orientation of bright luminance sources and the orientation of the observer to the window being observed.

Studies of the Effect of Aftermarket Tinting on Traffic Enforcement

The effect of window tinting on a police officer's ability to see into vehicles during traffic stops has been studied by both police agencies and the window tint industry, with vastly different results. The two studies sponsored or conducted by police agencies have found that window tinting greatly reduces the ability of officers to identify objects inside vehicles with experimentally tinted windows. The single study sponsored by the tint film industry found no detrimental effect for window tinting, even for tint films having transmittance values as low as 20%. These conflicting results are likely due to differences in the experimental designs used in these studies.

The IIT Research Institute (1990) conducted a study for film manufacturers designed to determine whether the presence of window tinting films affected an observer's ability to detect various articles of contraband, weapons, and vehicle occupant movements. Subjects were asked to look into vehicles with various levels of aftermarket tinting and report what they saw. The tinting films ranged from 50% to 20% transmittance and were applied to rear and rear side windows with 70% transmittance original factory glass. Testing occurred during daytime, dusk, and nighttime conditions. The results showed no effect for the presence of any of the tinting films. The most obvious problem with the study was that the obtained recognition rates for all of the tinting conditions were rarely below 95%, and on the few occasions when they were below 90%, variability was very high. In other words, the task of identifying the objects and events within the cars was so easy in all conditions that tinting had no effect. The IIT report did not mention what the viewing distances were or how much time the observers had to make their judgments. It may be that the IIT study is valid and that identifying the contents of a car through tinted windows under varying conditions of ambient illumination is such an easy task that tinting does not interfere with performance. On the other hand, it may be that the viewing distance or inspection times were not within the range afforded to police officers in typical situations. Of this study, Boyd (1991) wrote: "Some of the findings seem to violate principles of visual detection. For example, the ambient light level had no effect on target recognition; window transmittance had

no effect on target recognition and the lowest recognition scores obtained under nighttime conditions were with the 70 percent transmittance glazing" (p. 24).

Two studies were conducted by police agencies, one in Virginia and one in New York. The Virginia State Police (1988) had officers look into vehicles tinted to various levels to determine if the tinting had an effect on their accuracy under various lighting conditions. Four cars were used: (1) no aftermarket tinting, (2) 35% tint film on the rear side and rear windows, (3) 35% film on all windows except the windshield, and (4) 20% film applied to all windows except the windshield. The percentage of officers failing to identify 50% or more of the objects in the vehicle increased as the tint level increased. The problem with this study's design is that all officers made inspections of all four cars in the same order, from most tinting to least. This testing order was probably motivated by the desire not to give the officers too much experience with the items that would be present. An item seen in the untinted car would subsequently be easier to identify in the reduced viewing conditions of the heavily tinted car. However, the converse is also true. Objects viewed initially through heavy tinting and then through less tinted windows would become easier to identify as the officer became familiar with them. Thus, the lowest identification rate for the heavily tinted vehicles could have been due to the fact that these objects were viewed first, before the officers became familiar with the items.

A similar study was conducted by the New York Department of State Police and Motor Vehicles (1992). This study confirmed the increasing decrement in performance associated with more heavily tinted windows found by the Virginia State Police, but unfortunately, also incorporated the design flaws of the Virginia study. Officers tried to identify objects in vehicles, beginning with the most heavily tinted vehicles and progressing to those with lower levels of tinting. Again, the improved perfomance found when viewing less tinted vehicles is likely due to the officers' increasing familiarity with the test objects.

Finally, a demonstration performed by the Maine Department of State Police involved legislators approaching vehicles with various levels of tinting (reported in Boyd, 1991). In the back seat of the vehicle was a man with a drawn gun. When approaching a vehicle with 35% tint film applied to the rear and rear side windows, none of the legislators noticed the gun. However, when the demonstration was repeated using a vehicle with 50% tinting, all of the observers noticed the gun. Of course, this demonstration suffers from the same design flaws as the Virginia and New York studies. By the second trial, the legislators were aware that the man was holding a weapon, and thus were more likely to be able to see it.

PURPOSE, SCOPE, AND LIMITATIONS

The purpose of this study was to determine to what degree tinted window films impede an officers' ability to see clearly into a stopped vehicle. Although similar experiments have been conducted, all yielded equivocal results because of serious methodological flaws. This experiment is an attempt to correct these methodological problems. Every attempt was made to make the procedure for approaching vehicles used in the experiment as similar to standard police procedure as possible. The experiment was limited to testing police procedures used in Virginia.

Although the experiment was designed to control for differences other than transmittance, the generality of the results is somewhat limited. First, only three levels of tinting were tested. Second, ambient illuminance differed somewhat on different testing days and nights. More importantly, light reflectance, which could not be measured and therefore controlled in this experiment, affects the ability to see clearly into a vehicle. Reflectance is so situationally specific that it is impossible to make broad conclusions that apply to all conditions. For this reason, in the current experiment assessments were made at five different testing locations in order to minimize effects that might be specific to a particular location or the vehicles's orientation relative to a reflection source such as the sun.

METHOD

Subjects

One hundred and twenty male and 120 female volunteers, mostly undergraduate students who were passing by the testing locations on the grounds of the University of Virginia, participated in this study. Others were students enrolled in an introductory psychology course who participated to fulfill a course requirement. All subjects were asked if they needed glasses to drive. If they stated that their driver's license stipulated that they must wear glasses, they were asked to wear their glasses during the testing. If they did not have their glasses with them, they were excluded from the study.

Materials and Apparatus

The four test vehicles were 1987 Dodge Aries K four-door sedans. All had identical blue exterior paint, dark blue interiors, and black dashboards. The only difference among the vehicles was the degree of window tinting applied to the side and rear windows. Table 1 shows the tinting specifications for the four test vehicles as ordered and as described by the tinting company that applied the films. Also shown in Table 1 are the transmittance values achieved. These levels of tinting differ from the levels prescribed to some degree. Because tint film is applied over factory glass tinted to differing transmittance levels, the resulting level of light transmittance is multiplicative. For instance, a 50% aftermarket film applied over an 82% factory tinted window theoretically results in a total transmittance of 41% (.50 x .82 = .41). When tint shops apply the same aftermarket film to factory glass with differing levels of tinting, different results are achieved. Also, there is some variability between window tint film dye lots. In this case, the prescribed and assessed transmittance values are reasonably close, with the achieved transmittance slightly higher than prescribed, except for Vehicle 3, in which the measured value of the rear window was quite a bit lower than ordered. Vehicle 0 had no aftermarket tint film applied, Vehicle 2 represented the maximum reduction in transmittance allowed by Virginia law, and Vehicle 1 had transmittance values chosen as representing intermediate levels. The prescribed

levels of tinting for Vehicle 3 represent the maximum reduction of transmittance allowed by any state in the country, that being Florida.

Table 1: Tinting Specification for Test Vehicles

Transmittance					
Target [a]				Actual	
Vehicle	Windshield	Front Side	Rear	Front Side	Rear
0	No Tint	No Tint	No Tint	88%	88%
1	No Tint	50%	50%	53%	53%
2	No Tint	50%	35%	53%	38%
3	No Tint	35%	20%	40%	13%

[a] Target transmittance is the intended transmittance after applying tint film over a factory tinted window.

The objects placed inside the vehicle were arranged in the same way for each testing episode. Three mannequins were seated upright in the vehicle: one in the driver's seat, one in the front passenger's seat and one in the back right passenger's seat. The mannequin in the driver's seat held a pair of scissors in the left hand. Its hands were arranged such that the right hand was placed by its right side and was covered slightly by the right pants leg. The left hand, holding the scissors, was positioned at the bottom part of the steering wheel. Five common objects of various colors and sizes were arranged on the back left seat and back left floor: a black flashlight, a yellow highlighter pen, and a red soda can were placed on the seat, and a pink spiral notebook and a white tennis shoe were placed on the floor. A stopwatch was used for all timing.

Schedule

All tests took place from October through December, 1993 and in April, 1994. Tests using auxiliary lighting were conducted in April, 1994 while tests done at midday, dusk, and at night without auxiliary lighting were conducted during the previous winter. Since the winter tests were conducted prior to daylight savings time and the spring tests were conducted during daylight savings time, the times for night testing differ slightly to ensure complete darkness. Initial testing with four vehicles occurred at three different times of day (midday, 2:00 - 3:30 pm; dusk, 5:00 - 5:45 pm; night, 6:00 - 7:30 pm EST) and at five different locations on the grounds of the University of Virginia. For the day, dusk, and night conditions, there were 60 separate testing episodes (4 vehicles x 3 times of day x 5 locations). For each episode, four participants were obtained, two males and two females, yielding 240 subjects total. Each observer saw only one car and the identification rate was assessed by examining the performance of different groups of

subjects. For the night conditions in which auxiliary lighting was used, there were eight testing episodes (4 vehicles x 2 locations) between the hours of 8:00 pm and 10:00 pm. At each episode, 10 participants were obtained, yielding 80 subjects.

Procedure

The first step in developing the methodology for these studies was to consult with First Sergeant A. Joseph Anderson of the Virginia State Police. He provided an account of standard procedures for approaching stopped cars and demonstrated the procedures. The procedure is as follows:

(1) The officer parks his or her car approximately 20 feet behind the automobile that has been stopped. At night, the officer positions the vehicle so that its low beam headlights point slightly more toward the driver's side of the vehicle (Figure 1).

(2) Upon exiting the police car, the officer seeks to determine how many occupants are in the stopped car before approaching.

(3) The officer then walks toward the car and stops at its trunk to determine whether it is latched.

(4) The officer then walks cautiously along the side of the car at a distance of about 20 inches and stops just behind the driver's door. During this approach, he or she focuses primarily on the driver, but also scans the back seat area, especially if there are passengers seated there. At night, the officer places his spotlight on his left shoulder and aims the beam with his left hand toward the vehicle's window. (Left-handed officers rest the spotlight on their right shoulders.)

(5) Finally, upon reaching the driver's door, the officer looks to see if the driver is holding anything that might be used as a weapon. At night, the spotlight is used.

This procedure was observed a number of times, and the various components of the approach were timed.

In accordance with police priorities, the detectability of two sorts of targets was assessed. First, experimental observers were required to determine the number of occupants (mannequins) seated in each experimental car from a distance of 20 feet. Second, the observers were asked to identify objects within the car from a distance of about 20 inches. With respect to this second task, observers were asked to perform two time-limited tasks. The first was to report on the position of the hands of the mannequin in the driver's seat and identify a potential weapon that was placed in the mannequin's hand. The second was to identify a set of objects located in the rear seating area. Inspection times were limited to slightly longer durations than those demonstrated by First Sergeant Anderson.

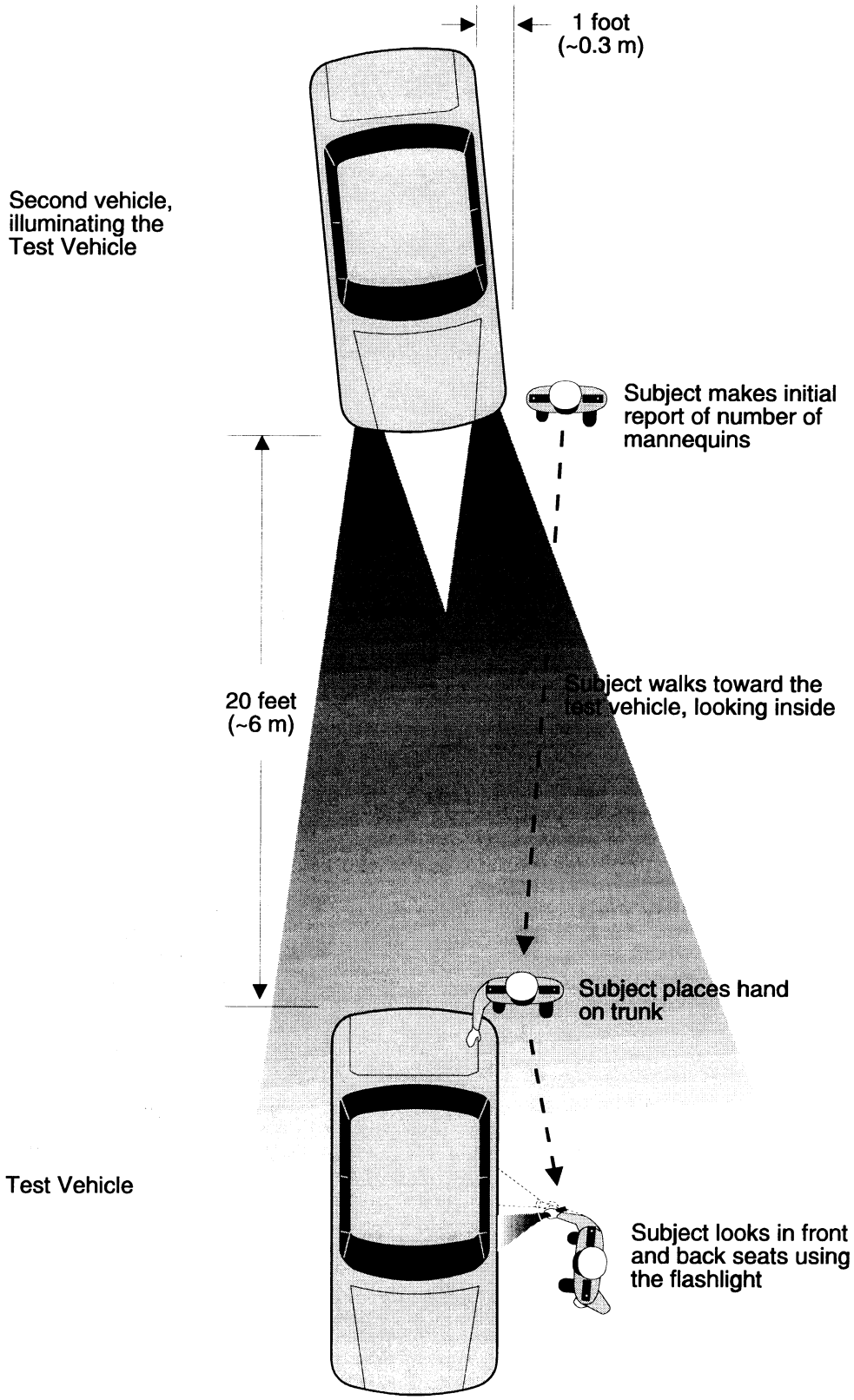

Figure 1. Position of test and illuminating vehicles: auxiliary lighting phase.

An experimenter approached passers-by in the vicinity of the testing location, ensuring that potential participants were not able to see the experimental setup in advance. After the subjects verbally consented to participate in the study, the experimenter first demonstrated the procedure on a nearby vehicle that was not the test vehicle. The purpose of the demonstration was to familiarize the subject with the experimental task and to provide some background on the study. During this demonstration phase, the experimenter explained the procedures that police officers use when stopping a vehicle, incorporating what the experiment would entail. For example, the experimenter explained that initially a police officer makes a quick assessment about the number of vehicle occupants from a distance of 20 feet behind the vehicle. The experimenter then explained that the subject would also be viewing the vehicle from a distance of 20 feet but that as part of the experiment, the subject would have only a short time to view the vehicle, and then would be asked to turn away from the vehicle. The tasks were described in general terms in order to not reveal the contents of the experimental vehicle until testing occurred. When testing occurred at night and auxiliary lighting was used, the experimenter also instructed the subject in the use of the police spotlight, and allowed the subject to practice. The demonstration phase took approximately 5 minutes to complete.

Once subjects understood the procedure, they were escorted to the test vehicle and asked not to look in the direction of the test vehicle when approaching. A second experimenter conducted the actual experiment, and a third experimenter recorded the subjects' responses on a data sheet. Subjects were positioned 20 feet behind the test vehicle on the driver's side with their back to the vehicle. Subjects were told to report the number of mannequins seated upright in the vehicle from that distance. When the experimenter gave the signal, they turned around and looked inside the vehicle for 4 seconds. After 4 seconds, the experimenter told the subjects to turn away from the vehicle. The experimenter then asked them to rate on a scale of 1 to 10 how certain they were about the number of mannequins just reported, where 1 meant "not sure at all" and 10 meant "very certain."

Subjects were then instructed to walk slowly toward the vehicle, looking inside as they approached. Subjects who were initially incorrect in reporting the number of mannequins or were not certain about their response (a confidence rating of 7 or below) were told to walk toward the vehicle but to stop if (1) they became more confident about the number of mannequins, or (2) they changed their mind about the number of mannequins. Subjects who had correctly reported the number of mannequins and were very confident in their judgment were told to stop only if they changed their mind about the number of mannequins. If a subject stopped while approaching the vehicle, the new response was recorded and the distance from the back left fender to where the subject stood was recorded. If the subject was correct and certain at 20 feet, then that distance was recorded. If the subject only became certain at the back fender of the vehicle, the distance was recorded as 0 feet. The subject then completed the path to the left back corner of the vehicle, placed his or her hand on the trunk, and turned toward the experimenter for further instructions. Subjects who did not stop when approaching the vehicle simply walked up to the back left corner of the vehicle, placed their hand on the trunk, then turned toward the experimenter for further instructions.

During the final part of the experiment, subjects were told that they would be walking toward the driver's door with their back to the vehicle, and should not look inside until instructed

to do so. The experimenter guided subjects to a spot between the front and back doors of the driver's side of the vehicle, positioning them approximately 1 to 1-1/2 feet from the vehicle, with their back to the vehicle. When testing occurred at night with auxiliary lighting, the subject was then given the police spotlight to use during the remaining tasks. For the first task, the experimenter told subjects to turn around and look into the front seat of the vehicle for 2 seconds and reminded subjects not to lean toward the vehicle. They were, however, allowed to bend at the knee or stand on tiptoe and to move from side to side. The task was to report where the driver's hands were positioned and, if the driver was holding something, what that object was. After 2 seconds, the experimenter asked subjects to turn away from the vehicle and the third experimenter recorded their responses. For the second task, the experimenter told subjects to look into the back seating area for 3 seconds. The task was to report the objects that were on the back seat and the back floor without leaning toward the vehicle as in the previous task. Subjects had the option of naming the objects immediately or using the 3 seconds simply for observation and then reporting the objects after the 3 seconds were up. If a subject began naming the objects during the 3 seconds, he or she was allowed to continue naming them after turning away from the vehicle. Responses were considered correct only if an appropriate name for the object was provided.

After completing the object detection task, subjects were thanked for participating and were briefly told about the purpose and design of the study. The experimenter answered any questions the subjects had.

Performance Measures

Six separate performance measures were taken:

(1) *Mannequin Detection*: detecting the number of mannequins seated upright in the vehicle from a viewing distance of 20 feet behind the vehicle,
(2) *Confidence Ratings*: reporting a level of certainty about the number of mannequins detected in task 1,
(3) *Distance at certainty*: how close to the vehicle the subject needed to be in order to state with confidence that there were three mannequins,
(4) *Detection of driver's hand positions:* reporting the position of the driver's hands when looking into the front side window and standing approximately 1.5 feet from the front window,
(5) *Detection of object in driver's hand:* reporting the object that the driver was holding in the left hand when looking into the front side window and standing approximately 1.5 feet from the front window, and
(6) *Rear seat object detection*: reporting the five common objects that were on the back seat and back floor of the vehicle on the driver's side when looking into the back side window approximately 1.5 feet from the vehicle.

The main independent variables of interest in this study were level of tinting (none, 50%/50%, 50%/35% and 35%/20% transmittance windows) and viewing condition (midday, dusk, night, night with additional lighting). Although testing occurred in different locations, this vari-

able was introduced only to minimize situation-specific effects. Preliminary analyses suggested that there were differences in locations for the different tasks, but these differences were not systematic. That is, one particular testing location did not yield systematically better performance than another location across all of the tasks. Thus, the analyses presented below exclude the location variable.

Each of the six dependent measures was submitted to a 4 (tinting level: 80%, 50%, 35%, 20% transmittance) x 4 (viewing condition: midday, dusk, night, night with lighting) ANOVA. Both factors were manipulated between subjects. Each dependent measure is discussed separately below.

RESULTS AND DISCUSSION

Mannequin Detection

Figure 2 shows the effect of tinting on detecting the number of mannequins seated upright in the vehicle from 20 feet. (Standard errors for all figures appear in Appendix A.) The ANOVA comparing the effect of tinting for all four viewing conditions (midday, dusk, night, and night with auxiliary lighting) revealed a significant main effect of tinting, $F(3, 319) = 15.3$, $p < .01$. As shown in Figure 2, the general trend is a decline in performance as tinting level increased. Dunnett's one-tailed t-test (1955) compared each level of tinting to the control level (Vehicle 0) and revealed that performance with Vehicles 2 and 3 was different from performance with Vehicle 0 but performance with Vehicle 1 was not different from performance with Vehicle 0. The main effect of viewing condition was also significant, $F(3, 319) = 7.2$, $p < .01$. Each of the six performance measures was submitted to a preliminary ANOVA. Dunnett's test compared each of the viewing conditions to the control condition, midday viewing, and revealed that performance was worse at dusk, night and night with additional lighting compared to midday. However, the significant Tinting Level x Viewing Condition interaction, $F(9, 319) = 2.4$, $p < .05$, qualifies this effect further. Figure 2 shows that performance declines as transmittance level decreases from 50%/35% (Vehicle 2) to 35%/20% (Vehicle 3) when viewing occurs at night without lighting and at dusk. However, there is no decrement in performance from 50%/35% to 35%/20% transmittance when viewing occurs at midday and at night with additional lighting. In other words, performance declines when viewing the most heavily tinted car at dusk and at night but performance is not worse with the most tinted car when viewing occurs at midday and at night with auxiliary lighting. Thus, the use of additional lighting at night overcame the effect of heavy tinting. The overall model explained 23% of the variance in responses, $F(15, 319) = 5.9$, $p < .01$.

Confidence Ratings for Mannequin Detection.

The analysis that compared the effect of tinting on the confidence of subjects in their estimates of the number of mannequins for the four viewing conditions revealed a main effect of tinting, $F(3, 319) = 28.7$, $p < .01$, and a main effect of viewing condition, $F(3, 319) = 8.4$, $p < .01$, but no interaction. As shown in Figure 3, confidence decreased as tinting level increased,

and confidence was generally greater at midday and lower at night. Dunnett's test revealed that confidence ratings with the two most heavily tinted vehicles, Vehicle 2 and Vehicle 3, were significantly lower than confidence ratings with Vehicle 0. Ratings with Vehicle 1 were not different from ratings with Vehicle 0. Dunnett's test also revealed that confidence at midday was higher than at dusk, night, or night with lighting. The overall model explained 29% of the variance in responses, $F(15, 319) = 8.3$, $p < .01$.

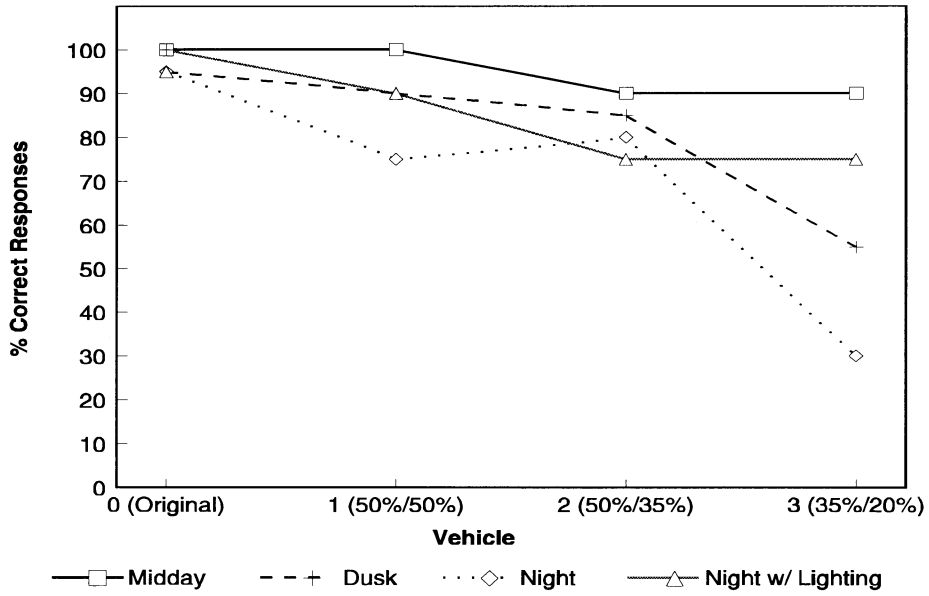

Figure 2. The effect of window tinting and viewing condition on mannequin detection performance.

Distance at Certainty

The analysis that compared the effect of tinting for all four viewing conditions revealed a main effect of tinting level, $F(3, 299) = 22.8$, $p < .01$. As shown in Figure 4, the general trend for all four viewing conditions is a decrease in distance as tinting level increases. That is, subjects needed to be closer to the more tinted vehicles to be certain about the number of mannequins. Dunnett's test revealed that, compared to the control vehicle (Vehicle 0), subjects needed to be significantly closer to all of the other vehicles, implying that even levels of tinting as low as 50% can lower confidence about reports of the number of occupants inside a vehicle. The main effect of viewing condition was also significant, $F(3, 299) = 2.9$, $p < .05$. That is, the distance at which subjects became certain about the number of mannequins was generally greater when viewing occurred at midday and lower at night. In fact, Dunnett's test revealed that distance at certainty at night was significantly lower than distance at certainty at midday. However, this distance at dusk or at night with additional lighting was not significantly different from this distance at midday. The fact that the Tinting Level x Viewing Condition interaction was not significant, however, implies that greater tinting lowered confidence in all viewing conditions. The overall model explained 23% of the variance in responses, $F(15, 299) = 5.7$, $p < .01$.

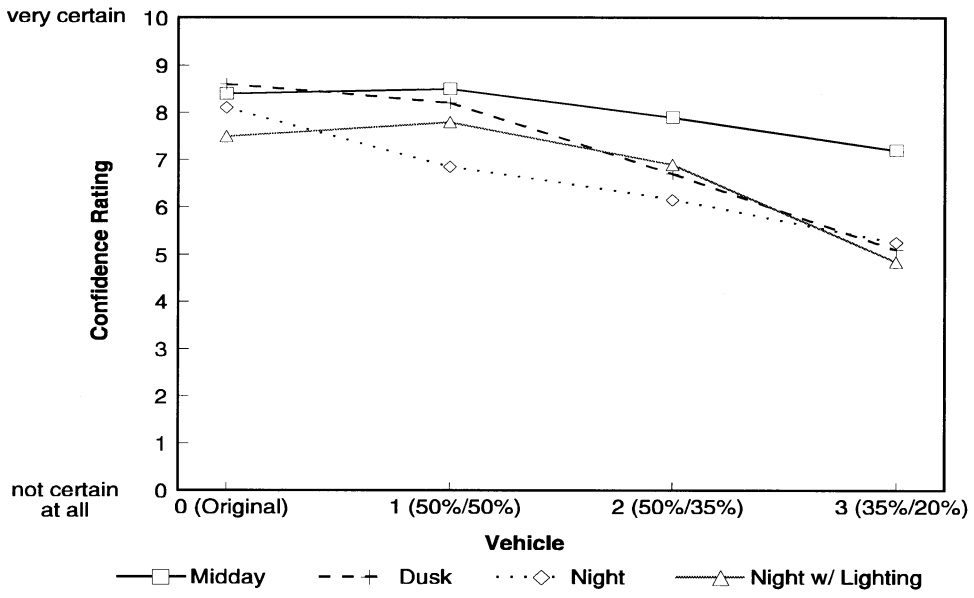

Figure 3. The effect of window tinting and viewing condition on confidence ratings.

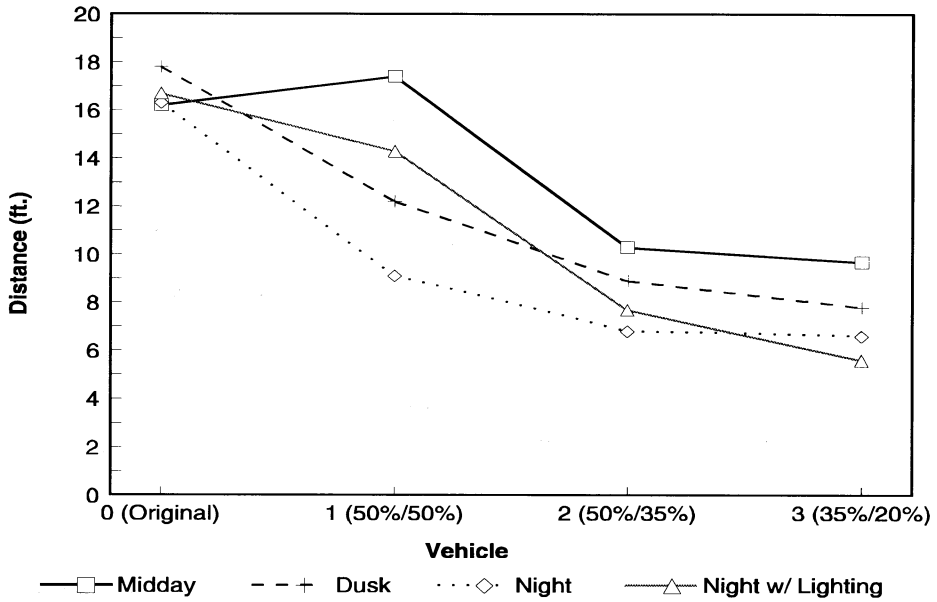

Figure 4. The effect of window tinting and viewing condition on distance at certainty.

Detecting the Position of the Driver's Hands

As Figure 5 shows, subjects were quite good at detecting the position of the driver's hands regardless of tinting level. The ANOVA that assessed the effect of tinting for all four viewing conditions revealed a main effect for viewing condition, $F(3, 319) = 33.0$, $p < .01$, but no main effect for tinting and no interaction. As shown in Figure 5, detecting the position of the driver's hands was much worse at night without lighting compared to the other three viewing conditions. Dunnett's test revealed that only performance at night without additional lighting was worse than performance at midday. The other two viewing conditions yielded similar levels of performance as that achieved at midday. The overall model explained 27% of the variance in responses, $F(15, 319) = 7.4$, $p < .01$.

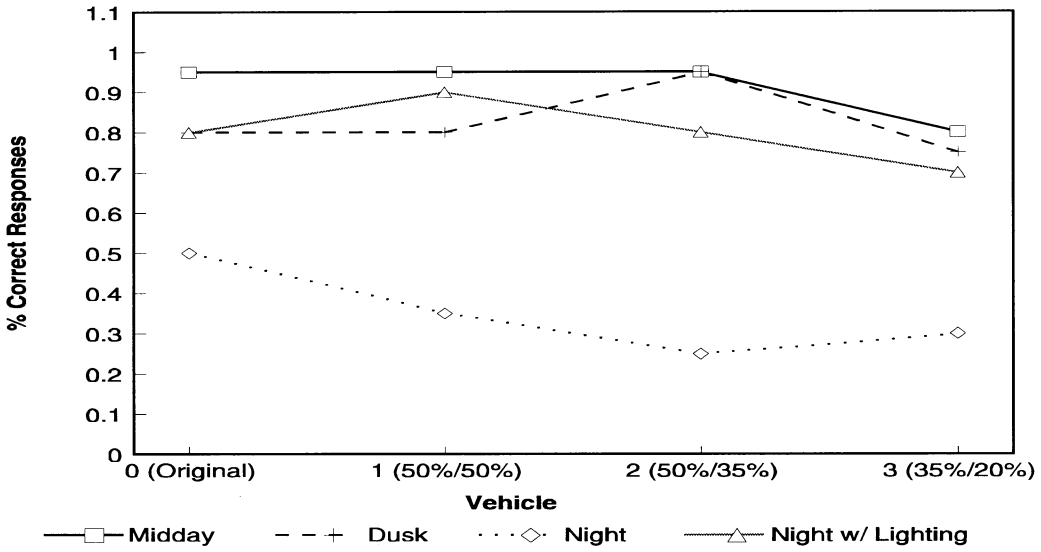

Figure 5. The effect of window tinting and viewing condition on detecting the position of the driver's hands.

Detection of the Object in the Driver's Hand

Subjects were also very good at reporting the object that the driver was holding in the left hand. Figure 6 shows the effect of tinting on performance for the four viewing conditions. Similar to the task of detecting the position of the driver's hands, detecting the object held in the driver's left hand was not affected by level of tinting, but performance was affected by viewing condition, $F(3, 319) = 35.1$, $p < .01$. Dunnett's test revealed that using a spotlight at night yielded performance comparable to that at midday. However, performance at dusk and at night without additional lighting was significantly worse than performance at midday. The overall model explained 27% of the variance in responses, $F(15, 319) = 7.6$, $p < .01$.

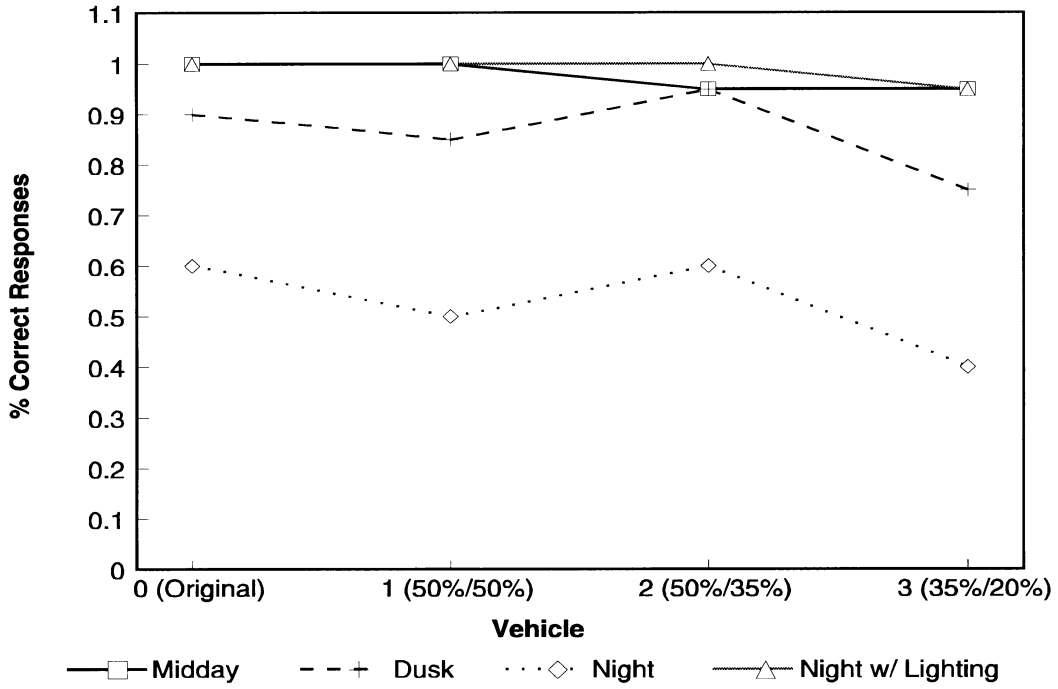

Figure 6. The effect of window tinting and viewing condition on detecting the object in the driver's hand.

Rear Sear Object Detection

Figure 7 shows the effect of tinting on object detection for the four viewing conditions. The main effect for tinting was significant, $F(3, 319) = 56.3$, $p < .01$, indicating that fewer objects were detected with the more heavily tinted vehicles. In fact, Dunnett's test revealed that all levels of tinting elicited worse performance compared to the control level (Vehicle 0). The main effect for viewing condition was also significant, $F(3, 319) = 232.0$, $p < .01$, indicating that the fewest objects were detected at night with no additional lighting and the most objects were detected at night with additional lighting. According to Dunnett's test, fewer objects were detected at dusk and at night compared to midday. However, performance at night with additional lighting was as good as performance at midday. The significant Tinting Level x Viewing Condition interaction, $F(9, 319) = 13.6$, $p < .01$, indicates that tinting only affected performance in some viewing conditions. Specifically, tinting affected object detection performance at midday and at dusk so that fewer objects were detected when windows were more tinted. However, tinting did not affect performance in either night condition. This is because object detection performance was already so poor at night without additional lighting for the untinted vehicle that it could not get any worse. Moreover, the use of a spotlight at night significantly overcame the effects of tinting. The overall model explained 76% of the variance in responses, $F(15, 319) = 65.8$, $p < .01$.

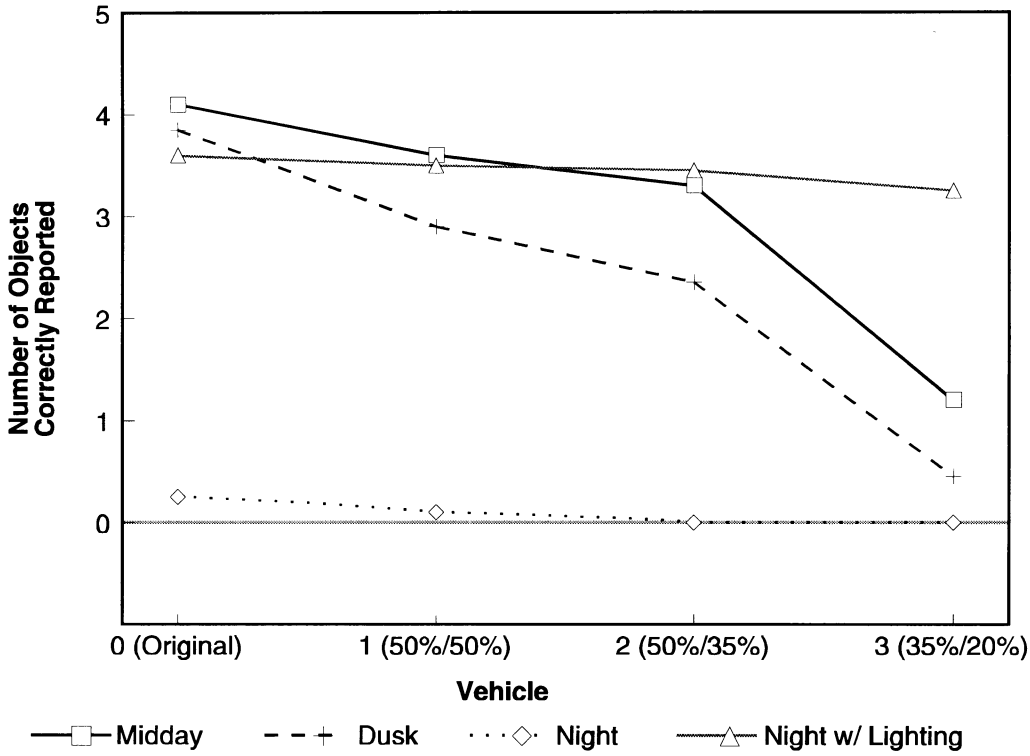

Figure 7. The effect of window tinting and viewing condition on object detection.

SUMMARY AND CONCLUSIONS

In general, higher levels of window tinting made seeing inside a vehicle more difficult. Window tinting impaired performance on four of the six tasks in this study (mannequin detection, certainty in mannequin detection, distance at certainty, and object detection). For all of these tasks, the heaviest tinting level (Vehicle 3, representing the maximum level for any state) significantly impaired performance relative to no tinting. The maximum legal level allowed in Virginia (Vehicle 2) also significantly impaired performance on these four tasks relative to no added tinting. An intermediate level of tinting (Vehicle 1) impaired performance for only two of these four tasks (distance at certainty and object detection) relative to no tinting. The four tasks that were impaired by window tinting all involved looking into the vehicle through the rear window or the rear side windows. The two tasks that were not affected by window tinting (detecting the position of the driver's hands and detecting the object in the driver's hand) involved looking into the vehicle through the front side window, which had the least amount of tinting relative to the other windows for the same vehicle (Table 1). In sum, tinting affected looking into a vehicle through the back windows, but did not affect looking through the front side window. The legal limits of window tinting allowed in Florida and Virginia significantly impaired the ability to see inside those vehicles through the rear windows.

Not surprisingly, poor viewing conditions (night and dusk viewing) impaired subjects' ability to see inside vehicles. All six of the tasks employed in this study were negatively affected by poor viewing conditions. Viewing the vehicle contents at night without the use of headlights and a hand-held spotlight was significantly worse than viewing at midday for all of the tasks. Many of the tasks were also more difficult when viewing occurred at dusk compared to midday (mannequin detection, certainty in mannequin detection, detecting the object in the driver's hand, and object detection). However, only two of the tasks were more difficult when viewing occurred at night with the use of headlights and a hand-held spotlight compared to midday viewing (mannequin detection and confidence in mannequin detection). In other words, the use of additional lighting at night significantly improved performance relative to viewing at night without additional lighting for four of the tasks. In fact, for two of the tasks, the use of additional lighting overcame the effects of heavy window tinting (mannequin detection and object detection).

The experimental results indicate that the detrimental effects of window tinting on viewing people and objects within a stopped vehicle at night are greatly reduced by the use of auxiliary lighting. Performance at night with the use of headlights and a spotlight was not affected by window tinting in terms of the accuracy of any of the judgments about what was inside the vehicle. That is, level of window tinting did not influence mannequin detection, reporting the position of the driver's hands, reporting the object held in the driver's hand, or reporting the objects on the back seat and back floor.

Window tinting levels did affect the subjects' confidence in their judgments about the number of occupants in the vehicles. At the initial 20 foot viewing distance, subjects' confidence in the accuracy of their judgments about the number of mannequins in the vehicles decreased with level of window tinting. Moreover, the distance from the vehicle at which subjects felt confident in this judgment decreased with level of window tinting.

Relative to nighttime viewing without lighting, auxiliary lighting significantly improved the accuracy of performance on all of the assessments of vehicular contents: mannequin detection, detecting the position of the driver's hands, detecting the object in the driver's hand, and object detection. Only confidence and distance at which subjects felt confident were not affected by the use of auxiliary lighting.

The use of the spotlight to detect objects within the vehicles from close range dramatically improved performance. In fact, subjects who used a spotlight at night to detect objects in the back seat and on the back floor detected more objects than subjects in all other viewing conditions, including midday viewing. In addition, nighttime performance with the use of the spotlight was better for the task of detecting the weapon in the driver's hand compared with dusk viewing without a spotlight.

It is tempting to conclude from these last findings that police officers might do well to use a hand-held spotlight during daytime and dusk hours when approaching a stopped vehicle with tinted windows. This conclusion cannot be made, however, without actually performing an empirical study. The effectiveness of the spotlight may vary with the overall level of ambient illumination at different times of day.

In summary, the level of window tinting does not affect viewer's accuracy in detecting persons and objects within a stopped vehicle when viewing occurs at night with the aid of headlights and a hand-held spotlight. It does, however, affect the confidence that one has in the accuracy of judgments made about the number of occupants. When viewing the interior of a vehicle from a distance of one-to-two feet, object detection is better at nighttime with a spotlight than at any other time of day without it. Across all times of day and so long as auxiliary lighting is used, the effect of window tinting on police officer safety is greatest at dusk.

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APPENDIX A

STANDARD ERRORS

Standard Errors for Figures 2-7				
	Night	Night with Lighting	Midday	Dusk
CAR 0				
Mannequin detection	0.05	0.05	0	0
Position of driver's hands	0.09	0.11	0.05	0.09
Object in driver's hands	0	0.11	0	0.07
Confidence rating	0.15	0.1	0.19	0.23
Detecting objects	0.49	0.38	0.22	0.22
Distance at certainty	1.46	1.7	1.76	1.27
CAR 1				
Mannequin detection	0.07	0.1	0	0.07
Position of driver's hands	0.07	0.11	0.05	0.09
Object in driver's hands	0	0.11	0	0.08
Confidence rating	0.14	0.07	0.25	0.31
Detecting objects	0.39	0.47	0.22	0.33
Distance at certainty	1.88	2.1	1.48	2.19
CAR 2				
Mannequin detection	0.1	0.1	0.07	0.08
Position of driver's hands	0.09	0.1	0.05	0.05
Object in driver's hands	0	0.11	0.05	0.07
Confidence rating	0.22	0	0.21	0.33
Detecting objects	0.42	0.59	0.23	0.47
Distance at certainty	1.68	1.7	2.11	1.93
CAR 3				
Mannequin detection	0.1	0.11	0.07	0.11
Position of driver's hands	0.11	0.11	0.09	0.1
Object in driver's hands	0.05	0.11	0.05	0.1
Confidence rating	0.25	0	0.18	0.15
Detecting objects	0.54	0.6	0.44	0.52
Distance at certainty	1.62	1.92	1.94	2.12