Colonel W. S. (Steve) Flaherty
Superintendent
(804) 674-2000

COMMONWEALTH OF VIRGINIA

Lt. Colonel Robert B. Northern
Deputy Superintendent

DEPARTMENT OF STATE POLICE

P. O. Box 27472, Richmond, VA 23261-7472

December 15, 2012

TO: The Honorable Stephen D. Newman
Chairman of the Senate Committee on Transportation

Pursuant to correspondence dated March 4, 2011, from Ms. Susan Clarke Schaar, Clerk of the Senate, the subject matter contained in House Bill 1728 was referred by the Senate Committee on Transportation to the Department of State Police for study.

In fulfillment of that request, the Department formed a Window Tint Committee to study the issue. The committee was comprised of representatives from law enforcement agencies, the Department of Motor Vehicles, the Virginia Center for Transportation and Innovation Research and the window tint industry. The committee was able to secure funding for the project through the Department of Motor Vehicles. Research was conducted by the Virginia Center for Transportation Innovation and Research. The goal of this study was to determine the degree to which after-market motor vehicle window tint films influence individuals' abilities to see clearly into a stopped vehicle. Specifically, visibility was compared when the front-side window transmittance was 50 percent (current legal standard) compared to 35 percent (proposed new standard) in daylight, dusk, and nighttime conditions.

Based on research findings, the following recommendations were developed by the Virginia Center for Transportation and Innovation Research:

1. Deciding whether to reduce transmittance levels to 35 percent for front-side window, should take into account that doing so would diminish police officers' ability to detect a driver's hand positions and confidence in that judgment.

2. At night, detection performance for both transmittance levels tested is improved when auxiliary lighting and handheld lighting are employed.

The committee has reviewed the report and is in agreement with these recommendations. The complete report, along with an executive summary, is enclosed for your review.

Respectfully,

W. S. Flaherty

Superintendent

Enclosure

SAFETY AND VISIBILITY ISSUES ASSOCIATED WITH MOTOR VEHICLE WINDOW TRANSMITTANCE AND AFTERMARKET WINDOW TINTING

Dennis R. Proffitt, Ph.D.
Commonwealth Professor of Psychology

Tom Banton
Research Scientist

Elyssa Twedt
Rebecca Weast
E. Blair Gross
Jonathan R. Zadra
Graduate Research Assistants
University of Virginia

Catherine McGhee
Associate Director for Safety, Operations, and Traffic Engineering
The Virginia Center for Transportation Innovation and Research

The Virginia Center for Transportation Innovation and Research is a cooperative organization sponsored jointly by the Virginia Department of Transportation and the University of Virginia.

Charlottesville, Virginia

VCTIR RC00042
October 16, 2012

ABSTRACT

The goal of this study was to determine the degree to which after-market motor vehicle window tint films influence individuals' abilities to see clearly into a stopped vehicle. Three hundred participants viewed the contents and occupants of vehicles from the viewpoint of a police officer making a routine traffic stop. They viewed one of two vehicles in which the front-side windows were tinted to either 50% (current legal standard) or 35% (proposed new standard) transmittance. Viewing was conducted under daylight, dusk, and eight different nighttime conditions typical of those used by officers during a routine traffic stop. This study found that only under certain circumstances, the ability of participants to detect occupants and objects inside a vehicle declined when the level of window tinting increased. In particular, reduced light transmittance negatively affected detection of the driver's hand positions across all viewing conditions, and reduced object detection during midday viewing. Regardless of tinting level, using take down lights, a spotlight, and a handheld flashlight at night improved performance.

INTRODUCTION

The questions of whether motor vehicle window tinting should be allowed or how much tinting should be allowed have been the subject of 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 front side window tint on all motor vehicles in Virginia must allow at least 50% of the light to pass through. For rear side windows and rear windows, the light transmittance cannot be lower than 35%. Currently, policies on aftermarket-applied window tint films vary by state.

There is a demand for tinted window films. The window film industry proposes 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, object to what they consider excessively dark window films. Some believe window tinting may increase the incidence of traffic crashes. Also, police officers have suggested that dark window films may be a threat to their safety. Police officers are concerned that darkly tinted glass may interfere with their ability to see contraband or potentially threatening actions.

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.

The Virginia Center for Transportation Innovation and Research authorized a study to further investigate this potential hazard to police officers approaching a stopped car on foot. Three hundred and twenty participants were asked to view the contents and occupants of one of four experimental cars, following procedures used by the Virginia State Police for traffic stops. One car had no tint film, and three had increasing degrees of tinting. The study found that the ability of participants to detect occupants and objects in vehicles was substantially diminished as the level of window tinting increased. However, these differences were far smaller during nighttime viewing conditions when headlights and a spotlight were shone at the stopped vehicle, as would be the normal procedure for a nighttime traffic stop (Proffitt, Joseph, Bhalla, Durgin, Bertamini, Lynn, & Jernigan, 1995).

The issue of legal limits on window tinting has again come under debate in Virginia. In the 2011 session of the Virginia General Assembly, Bill HB 1728 was introduced to allow increased levels of aftermarket window tinting on front driver and passenger side windows. The current study was authorized to investigate whether there was a potential increase in hazard to police officers approaching a stopped car on foot for the new proposed tinting limit, relative to the currently legal tinting limits. Following procedures similar to the 1995 study, the current study asked participants to view the contents and occupants of one of two cars with either the current standard (50% transmittance) or new proposed tinting level (35% transmittance). The testing occurred during daylight, dusk, and nighttime conditions, and used various combinations of artificial illumination (spotlight and take-down lights) from a police cruiser or in the form of a handheld flashlight carried by the participant.

LITERATURE REVIEW

Optical and Visual Considerations

Window tinting decreases the amount of light emitted from a vehicle's interior, and simultaneously increases the quantity of light reflected off the outside surface, both of which lower visibility. Furthermore, both effects combine to produce a ratio of reflected to transmitted light, which further reduces visibility.

The light emitted from a vehicle's interior is affected *twice* by the amount of window tint. Window tint is expressed as a transmittance value, which refers to the proportion of light that, after striking a glass, passes through the glass to the other side. A transmittance value of 50% indicates that the light passing into a vehicle is reduced by half. Importantly, when standing beside a vehicle, the transmittance value reduces the light passing into the vehicle, and reduces it again when it is reflected off the interior and passed back out. Therefore, *the light available (luminance) when looking into a vehicle is decreased to approximately the square of the transmittance value.*

To illustrate, suppose a police officer is examining the contents of the back seat of a vehicle, with the rear side windows tinted at 35% light transmittance. The light is reduced to 35% as it passes into the vehicle and illuminates the back seat, and reduced another 35% as it passes back out. As a result, the luminance available to the police officer is 12.25% of what it would have been with no window tinting ($0.35^2 = 0.1225$). If the transmittance value of the window tint was 70%, the reduction in luminance would be 49% ($0.70^2 = 0.49$), which is 4 times more light than a window tint with 35% transmittance. In other words, **a two-fold increase in the transmittance value of the window tint results in a four-fold reduction in luminance provided to an outside observer such as a police officer** (4 x 12.15% = 49%).

Window tinting reduces the amount of transmitted light by increasing the reflectance on the outside of the glass. Reflection is defined by the ratio between the light striking the glass and the amount that bounces off its surface. Therefore, when viewing vehicle contents through tinted windows, the luminance that reaches the eye has two sources – the light transmitted from inside the vehicle *and* the light reflected off the window. The degree to which the reflected light masks the transmitted light depends upon the ratio between reflected to transmitted light. This phenomenon is commonly experienced. Imagine sitting in room that is illuminated with a lamp. During the day, there is no difficulty in looking through the window to view the outside. However, at night, what is seen is the reflections from the inside room, as if the window were a mirror. The amount of light reflected off the window is the same during both the day and night; the change is in the ratio of reflected to transmitted light. During the day, the amount of light transmitted from the outside is much greater than the reflection, so one sees the outside world. At night, the amount of reflected light is greater and one will see a reflection.

In sum, window tinting simultaneously reduces the amount of light emitted by the vehicle interior and increases the reflectance value of the window surfaces, thereby increasing the ratio of reflected to transmitted light. This introduces an added layer of complexity, where sometimes the luminance from an object inside a vehicle will be sufficient for detection, but in other times the ratio of reflected to transmitted light will cause a reflection that obscure targets inside the vehicle. Whether or not reflections occur will vary 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

A review of the literature found two earlier studies (Proffitt et. al, 1994; Proffitt et. al, 1995) that summarized the literature regarding the effect of window tint on the ability to identify vehicle occupants and contents. Since then, however, the previously cited original reports cannot be accessed, and no subsequent studies regarding the topic were found. Therefore, we summarize the previous literature review, below.

Both the window tint industry and police agencies have published studies regarding the effect of window tinting on identifying objects inside vehicles. The only study conducted by the window tint industry found no effect of window tinting, even for tinting with extremely low transmittance values of 20% (ITT Research Institute, 1990; as cited by Proffitt et. al, 1994). Two early studies conducted in association with police agencies found that an increase in window tinting reduces a police officer's ability to identify vehicle contents (NY State Police, 1992; VA State Police, 1988; as cited by Proffitt et. al, 1994). This large discrepancy in results can be attributed to differences in methodology. However, a later study addressing these methodological issues also concluded that window tinting impairs the ability to identify passengers and objects in vehicles (Proffitt et al., 1995).

In 1990, the IIT Research Institute conducted a study to investigate whether the ability to identify weapons, contraband, and occupant movements in vehicles was diminished in the presence of window tint film during three lighting conditions: daytime, nighttime, and dusk. Participants were instructed to look into vehicle windows and reported what they saw. The window tint films, ranging from 50%-20% transmittance, were applied to the rear and rear side factory windows, which already had 70% transmittance. The results indicated no effect of window tinting. However, the recognition rates for all conditions were mostly above 95% and for conditions where it was below 90%, the variability was very high. Additionally, there was no mention in the report of any details regarding viewing distances or the time allotted participants for the task. The two main concerns are, then, that the task of identifying objects and events in the vehicle were so easy that the window tint had no effect, and that the viewing conditions might not have matched the conditions and procedures utilized by police officers.

Police agencies in Virginia and New York have conducted studies regarding the effect of window tinting on police officer's ability to accurately assess objects in a vehicle. The Virginia State Police (1988) had police officers look into vehicles under various lighting conditions, and used 4 levels of window tinting: no aftermarket tinting, 35% tint on rear side and rear windows, 35% tint on all windows except the windshield, and 20% tint on all windows except the windshield. The number of polices officers that failed to detect half of the objects increased as the window tint increased. Importantly, the police officers always inspected the cars from most tinted to least tinted. It is entirely possible that the low identification rate for the most heavily tinted car was due to the fact that the officers were familiar with the objects in the lighter tinted car, making them easier to identify. The New York Department of State Police and Motor Vehicles conducted a similar study (1992; as cited by Proffitt et. al, 1994), and found similar results to the Virginia study but, regrettably, they also employed the same methodology.

A study conducted in conjunction with the Virginia Transportation Research Council (Proffitt et al., 1994) investigated whether participants could identify vehicle contents in a stopped vehicle with varying lighting and window tint conditions. Researchers made an effort to correct for earlier methodological issues while keeping the procedures as close as possible to actual police protocol for a stopped vehicle. In the study, participants identified both the number of vehicle occupants and the contents of the vehicle. Each participant viewed only one of four window tints (no window tint, 50% transmittance value, 35% transmittance value, 20% transmittance value), during one of four lighting conditions (midday, dusk, night, night with auxiliary lighting). The study confirmed that as the transmittance value of the window tint increased, the participants' ability to detect both vehicle occupants and vehicle contents became significantly impaired. However, the negative impact of window tint was reduced for nighttime conditions when headlights and a spotlight were utilized, as would be the case in a routine traffic stop.

PURPOSE AND SCOPE

The purpose of this study was to determine how clearly individuals can see into a stopped vehicle when the window transmittance is 50% (current legal standard) compared to 35% (proposed new standard) in daylight, dusk, and nighttime conditions. This study extends previous research by assessing how different police vehicle configurations (angled vs. head on) and additional lighting (take down lights, spotlight, and handheld flashlight) affect visibility (see Experimental Design section for complete list of conditions).

This is a field study designed to simulate a typical traffic stop, including the time pressures involved. The experiment was limited to testing police procedures used in Virginia. The results are specific to the set of objects presented, although we selected objects that varied in visibility purposely so that some generalizations about what can be seen through a given tint might be made. Different models of car will have different window sizes, angles, and interior colors, which limit the scope of our results. Finally, atmospheric conditions could not be controlled, so there were differences in ambient illumination and reflected light on different days. However, each condition was run over several different days with varying weather conditions to reduce any unintended effects of weather on performance. Furthermore, this mimics real life situations of unpredictable conditions, so may be an advantage.

METHOD

Participants

Three hundred and eight (113 male and 195 female) volunteers participated in the study. Seven participants in the dusk condition were excluded from the data analysis because they completed the experiment prior to dusk and were replaced by seven additional participants. One participant was excluded for not following instructions, and one additional participant was excluded because the incorrect combination of auxiliary lighting was used. Therefore, the final sample included 299 participants. Participants were either recruited from flyers or word of mouth and received $10 for participating, or were students enrolled in an introductory psychology course who participated to fulfill a course requirement. As a result, the participants in this study were mostly undergraduate students (M_{age} = 20.65; range = 17 – 61). Difficulties in recruiting participants caused our sample to have more female than male participants.

Materials & Apparatus

The two test vehicles were (1) a white 2001 Chevy Lumina four door sedan and 2) a red 2001 Chevy Impala four door sedan (Figure 1). The windows for Vehicle 1 were tinted to the current legal standard (50% transmittance) and the windows for Vehicle 2 were tinted to the proposed new standard (35% transmittance). The Chevy Impala had a light interior, while the Chevy Lumina had a darker interior. Both differed in their internal arrangement of seats, dashboard instrumentation, etc. Seat position and height was adjusted to be the same in both cars. Ideally, these vehicles would have been identical so that only the level of window tinting varied, but identical cars were not available. We expect that the lighter interior of the red car would make the objects placed in the car more visible (higher contrast with the light background). Since this is the car with the darker tinted window, the effect should be to lessen the visibility difference between the two cars.

The two police cruisers used in this study were both 2007 Ford Grand Victoria Police Interceptors. One cruiser was used for testing and the second was used to train participants on the experimental procedure.

Table 1 shows the tinting specifications for the two test vehicles as ordered and as described by the tinting company that applied the window tint films. The transmittance values achieved differ slightly from the level of tinting requested. This is because aftermarket tint film is applied over factory glass that is tinted to varying transmittance levels, such that the resulting level of tint is multiplicative and will vary across different tint shops. For this experiment, the level of actual transmittance level was slightly higher than requested but still reasonably close. Furthermore, although the levels of rear side and rear window tint were not supposed to differ between the two vehicles, the actual transmittance levels are higher in the light-tinted vehicle compared to the dark-tinted vehicle. Therefore, if performance is better when viewing the light-tinted vehicle compared to the dark-tinted vehicle when viewing through the rear window, differences may be attributed to the differences in rear window tint between the two vehicles.

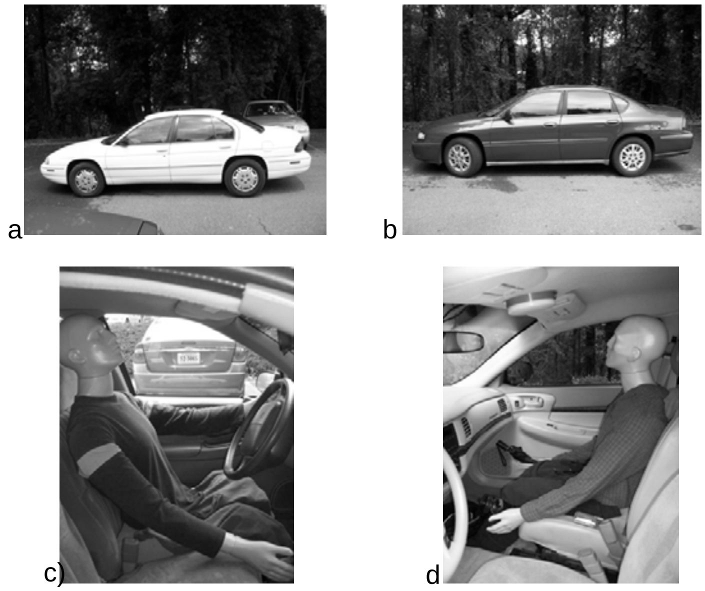

Figure 1. Exterior and Interior views of the light-tinted vehicle (images a and c) and the dark-tinted vehicle (images b and d).

Table 1. Tinting Specifications for Test Vehicles

Transmittance						
	Target*			Actual		
Vehicle	Rear Windshield	Front Side	Rear Side	Rear Windshield	Front Side	Rear Side
Current Standard (light-tinted car)	35%	50%	30%	34%	55%	34%
Proposed Standard (dark-tinted car	35%	30%	30%	30%	31%	30%
* Target transmittance is the intended transmittance after applying the tint film over a factory tinted window						

Objects

The objects placed inside the vehicles were arranged in the same way for each testing episode. Three identical male 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 left passenger's seat.

Seven common objects of various shape, size, and visibility were arranged inside the cars. The objects were: scissors, compact collapsible umbrella, water bottle, cell phone, box cutter, backpack, and sunglasses. A full description of mannequin and object placement can be found in the Experimental Design section.

Experimental Design

Conditions

Window tinting level (50% vs. 35%) and viewing condition (10 levels) were manipulated between-participants for a total of 20 conditions. Viewing condition varied by time of day, use of handheld lighting, and police cruiser configuration, for a total of 10 unique viewing conditions:

1. Midday
2. Dusk
3. Police car parked head on, auxiliary lighting, handheld light used
4. Police car parked head on, auxiliary lighting, no handheld light
5. Police car parked head on, no auxiliary lighting, handheld light used
6. Police car parked head on, no auxiliary lighting, no handheld light
7. Police car angled, auxiliary lighting, handheld light used
8. Police car angled, auxiliary lighting, no handheld light
9. Police car angled, no auxiliary lighting, handheld light used
10. Police car angled, no auxiliary lighting, no handheld light

Auxiliary lighting was defined as employing both the take down lights and spotlight. The spotlight was pointed directly at the driver's side-view mirror in the test vehicle. For all conditions, low-beam headlights were turned on. For all night conditions, standard flashing overhead lights were also turned on.

Testing Schedule

All tests took place from April 2012 through October 2012 in the rear parking lot of the Virginia Center for Transportation Innovation and Research building at the University of Virginia. Daylight testing was done between 10:30 am and 3:30 pm (n=30). Dusk testing was done in the period of time between sunset and civil dusk, which changed slightly on a daily basis (n=30). Night testing was done after civil dusk (n=240). The distribution of testing times in relation to sunset and civil dusk is seen in Figure 2. Data collection required 48 experimental sessions, with 2 to 17 participants per session.

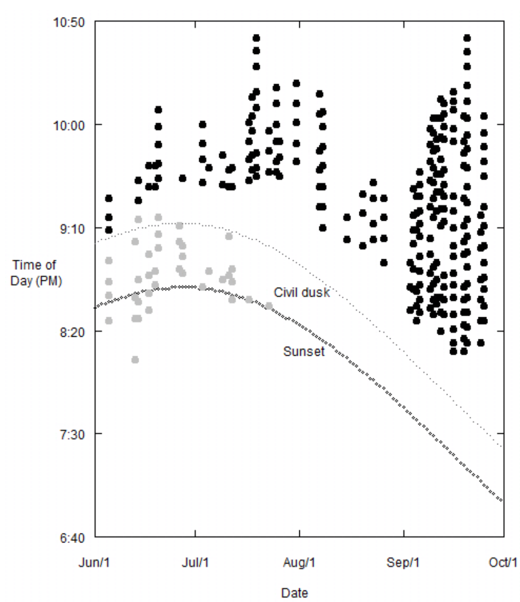

Figure 2. Distribution of testing times for each participant over the duration of the study.

Subject Assignment

Participants were scheduled to study time slots based on their availability. Groups of participants who were available at the same time were randomly assigned to one of the twenty experimental conditions until a total of fifteen participants had completed each of the 20 experimental conditions. One extra participant was run in the night, head-on, auxiliary lighting, no handheld used, light-tinted vehicle condition (n = 16).

Experimenter Training

The first step in developing the methodology for these studies was to become familiar with the procedures used during a traffic stop. We consulted with a trooper from the Virginia State Police, who trains officers on this procedure. He provided an account of standard procedure for approaching stopped vehicles and demonstrated the procedure several times. 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 in one of two positions: either parallel to, or at a slight angle with, the stopped car so that its low beam headlights point slightly more toward the driver's side of the stopped vehicle. (Figure 3).

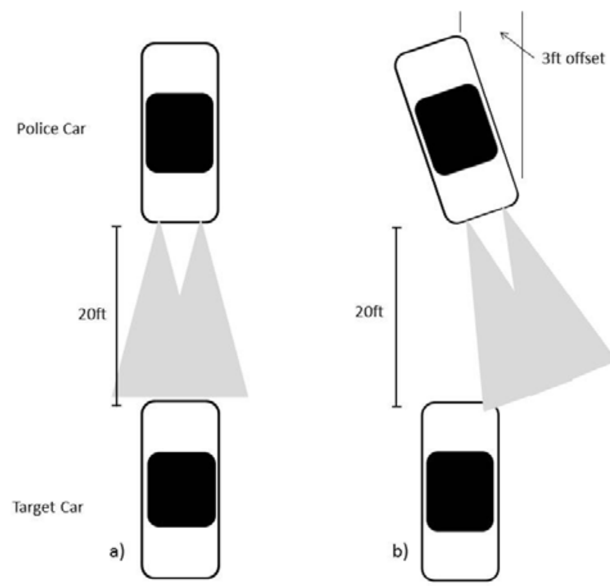

Figure 3: Positioning of police cruiser and test vehicle. a) Experimental set-up in conditions where the police cruiser faced the test vehicle 'head on.' b) Experimental set-up when the police cruiser was positioned at an angle to the test vehicle.

2. Upon exiting the police car, the officer attempts to determine how many occupants are in the stopped car before approaching.
3. The officer walks toward the vehicle and stops at its trunk, viewing passengers and objects through the rear window.
4. The officer then walks cautiously along the driver's side of the car within arm's reach of the car, stopping at the rear side window. He gets close to the window and scans the back

seat area for passengers and potentially dangerous objects. The officer may use a flashlight during nighttime vehicle inspection, which is held overhand in the officer's non-dominant hand.

5. Once clear, the officer moves to the driver's window, and gets as close as necessary to scan the driver and front seat area for potentially dangerous objects.
6. The officer tries to complete this procedure quickly (within about 10-20 seconds).

While the trooper was present, the positions of the test vehicle and police cruiser were marked with paint on the pavement so that the vehicles were positioned in the same locations for each testing session.

Procedure

Experimental setup

During the dusk and dark conditions, the parking lot flood lights were turned off for the duration of the study. One building light and parking lot lights from an adjacent building remained on. These lights could not be turned off and may have affected ambient lighting conditions, but were not directly pointed on the experimental set-up.

One test car and one police cruiser were arranged in one of the two configurations depicted in Figure 3. A third vehicle was used for training and was parked approximately 20 feet behind the police cruiser used for testing.

The lighting condition designated by the study design was set up. Low beam headlights and police cruiser lights 1 and 2 – the colored flashing lights pointing both forward and backward - were turned on for all conditions. In the auxiliary lighting night conditions, the take-down lights were turned on and the spotlight was aimed toward the driver's side-view mirror so that it reflected light maximally. If the use of a handheld light was also specified, one of the rechargeable flashlights in the police cruiser was used. As in a traffic stop, the police car engine was left running during the study.

Three mannequins were placed in the test car: one in the driver's seat, one in the front passenger seat, and one in the seat directly behind the driver (as shown in Figure 4). The left hand of the driver was positioned up on the dashboard next to the steering wheel, and the right hand was positioned down by its side. The hands of the other two mannequins were all positioned down at their sides.

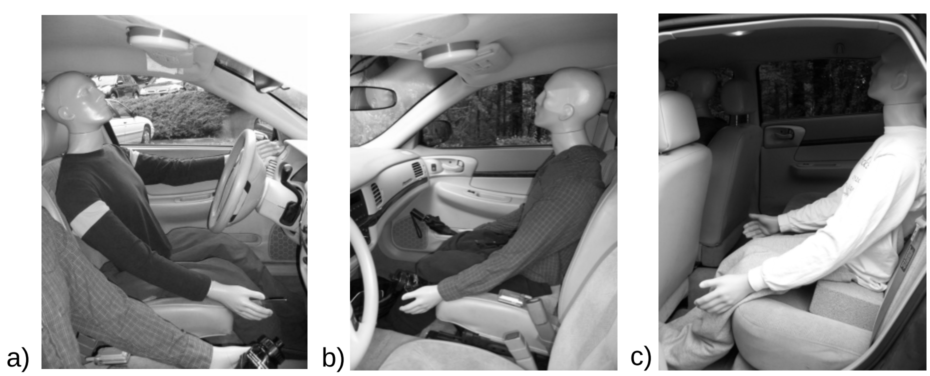

Figure 4. Mannequin positions as seen in the dark-tinted car: (a) driver, (b) front passenger, and (c) rear left-side passenger.

The seven test objects were positioned in the car as shown in Figure 5. With the exception of the sunglasses, which served as a control, the objects were positioned throughout the front seat area so that participants would look for them through the experimental tint on the front driver's side window. The objects were carefully positioned as follows for consistency between sessions:

- **Scissors** – attached to driver's right hand with Velcro; blade as high up as possible and touching thumb.
- **Compact collapsible umbrella** – placed in front passenger door pocket; handle showing and tilted up.
- **Water bottle** – attached to front passenger's left hand.
- **Cell phone** – on seat next to front passenger; position marked with Velcro/tape; antenna facing back of car.
- **Box cutter** – velcroed to front passenger's lap; pants smooth so that knife is level; blade 3 clicks open and pointing away from passenger.
- **Backpack** – placed on floor next to front passenger's feet; top points toward driver.
- **Sunglasses** – centered on back right seat; lenses facing up.

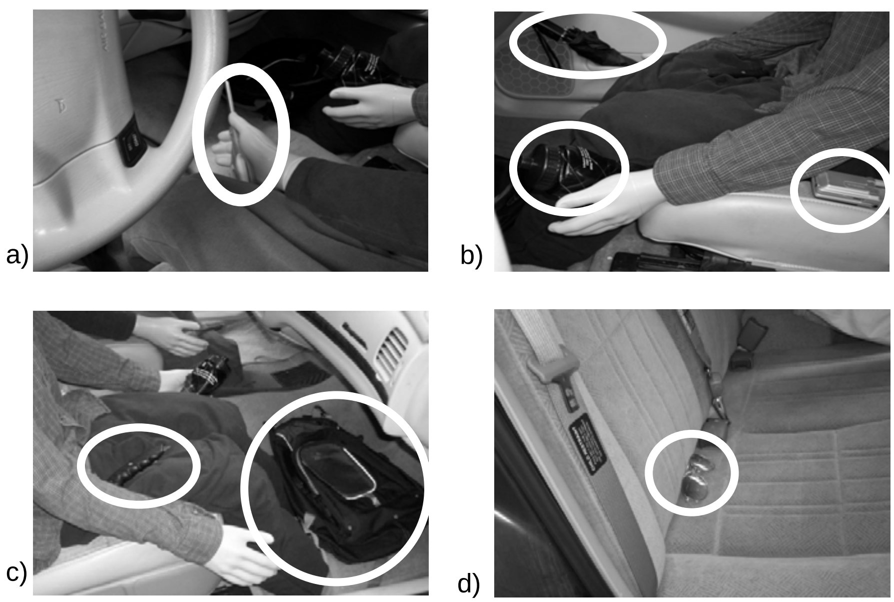

Figure 5. Objects and their placement in the test vehicle, circled for clarity. (a) Scissors in the driver's right hand, (b) a cell phone on the front passenger seat, a water bottle in the front passenger's left hand, a compact collapsible umbrella in the front passenger door pocket, (c) an open box cutter on the front passenger's lap, a backpack by the feet of the front passenger, and (d) a pair of sunglasses next to the backseat passenger.

Consent & Instructions

Prior to consent, the study was described. Potential participants were told that they would assume the role of a police officer making a routine traffic stop. They would be taught the procedure used for making a stop and they would practice it. Then they would perform the procedure on a test car, and would be asked questions about what they saw in the test vehicle.

They would be paid $10 for their assistance. If this was agreeable, they provided written consent to participate. Participants could withdraw from the study at any time without penalty.

Participant Training

Participants stood at the rear of the police cruiser (pretending it was the front) looking toward a second police car (pretending it was an ordinary stopped vehicle) so that participants could not view the test vehicle during training. First, the experimenter demonstrated the procedure as it was described by the state trooper (see Experimenter Training section for details). Next, the participant was asked to demonstrate the procedure, with coaching from the experimenter. If the procedure was done incorrectly, the participant was corrected and asked to repeat the procedure. Training was repeated until the procedure was mastered.

There were no mannequins or dangerous objects in the practice vehicle. It was found during training that emphasis had to be placed on getting close enough to the window to optimize viewing, and in doing the procedure quickly.

Testing

In accordance with police priorities, two tasks were assessed:

1. Determining the number of occupants in the stopped vehicle and;
2. Determining what weapons/dangerous objects and other objects were present in the vehicle or being held by the vehicle's occupants.

These were done during an approach from the front of the police cruiser toward the back of the experimental vehicle.

Occupant assessment.

Participants began the experiment positioned at the left-front bumper of the police cruiser, at a distance of 20 feet from the test vehicle. Participants were given 4 seconds to turn and view the test vehicle from that stationary position. Participants then turned away from the test vehicle and reported the number of seated occupants they saw through the rear window. Participants then rated their confidence in their assessment, using a scale from 0 (completely uncertain) to 10 (completely certain).

Next, participants turned and walked toward the test vehicle, matching the experimenter's slow walking pace. They were instructed to update their occupancy assessment and confidence rating as they approached the car. If their assessment changed, they were to stop and turn away from the vehicle before reporting their updated number of occupants and/or confidence rating. If they stopped, the location at which they stopped was marked, and later measured as their distance from the test vehicle. All participants proceeded toward the test vehicle until they reached the left-rear bumper. At this point, participants turned away from the test vehicle and provided a final occupant assessment and confidence rating.

Object assessment.

Participants were asked to identify objects within the car from a distance of less than one foot. Two time-limited tasks were done: The first was to report the position of the hands of the mannequin in the driver's seat. The second was to identify a set of 7 objects in the vehicle, 2 of which were potentially dangerous (scissors, box cutter). Participants had no prior knowledge of the nature or number of objects that they might see in the car. Inspection time was limited to 10 seconds.

Participants were asked to inspect the inside of the vehicle in the same manner as they were taught during training. They were again reminded how to inspect the vehicle and that they should look for the driver's hand positions, dangerous objects, and other objects during their search. They were also told they would be given 10 seconds to complete the inspection. Participants could call out the objects as they saw them. After the 10 second inspection period, participants were asked if there was anything else they saw that they had not already reported. Then, using the 0-10 confidence scale, they rated their confidence for each object detected and for the driver's hands position.

Debriefing.

Immediately after participation, participants were thanked for participating and were verbally debriefed so that they would understand the goal of the study and how they contributed. They were encouraged to ask questions about their participation.

Performance Measures

Nine separate performance measures were taken:

1) *Mannequin detection at 20 feet*: Detecting the number of mannequins seated upright in the vehicle from a viewing distance of 20 feet behind the vehicle.
2) *Confidence ratings at 20 feet*: Reporting a level of certainty about the number of mannequins detected from a viewing distance of 20 feet.
3) *Mannequin detection at test vehicle*: Detecting the number of mannequins seated upright in the vehicle when standing directly behind the test vehicle.
4) *Confidence ratings at test vehicle*: Reporting a level of certainty about the number of mannequins detected when standing directly behind the test vehicle.
5) *Distance at certainty*: How close to the vehicle the participant needed to be in order to state with confidence that there were three mannequins within the vehicle.
6) *Detection and identification of driver's hand positions:* Reporting the positions of the driver's hands when looking into the front side window and standing within arm's reach of the window.
7) *Confidence ratings for driver's hand positions:* Reporting a level of certainty about the position of the driver's hands.
8) *Detection of objects in test vehicle*: Reporting the identity of 7 objects throughout the vehicle, while looking into either the front or rear side window, standing within arm's reach of the window.
9) *Confidence ratings for objects in test vehicle:* Reporting a level of certainty about correctly identifying objects in the test vehicle.

RESULTS AND DISCUSSION

The main independent variables of interest in this study were tinting level (50% or 35%) and viewing condition (10 police cruiser and lighting configurations). Each of the detection tasks (mannequins at 20 feet, mannequins at test vehicle, driver's hand positions, and object detection) were submitted to a 2 (tinting level) X 10 (viewing condition) X detection (Yes or No) hierarchical loglinear analysis. This type of analysis shows how the proportion of participants achieving accurate detection varies with tinting level and viewing condition. Each of the confidence measures and the distance at certainty measure were submitted to a 2 (tinting level) X 10 (viewing condition) analysis of variance (ANOVA). Each dependent measure is discussed separately. Because the primary interest of this study is on the visibility into the driver's side window, those dependent measures assessing performance at the test vehicle are discussed first.

Detecting and Identifying the Position of the Driver's Hands

Detection Performance

For detection performance, participants reported whether or not they could see the driver's hands, without considering if they could accurately describe the hand positions. Their response was recorded as either 'Yes Detected' or 'No Detected.' A three-way hierarchical loglinear analysis was used to test the relationship between tinting level, viewing condition, and the proportion of participants who detected the driver's hands. In general, performance for detecting the driver's hands was near perfect, such that 91.60% of all participants detected the driver's hands. The analysis revealed a significant association between tinting level and detection performance, $\chi^2 = 23.43$, $p < .0001$. Detection was better when viewing the light tint vehicle (98.7%) compared to the dark tint vehicle (84.4%). Based on the odds ratio, participants were 13.64 times more likely to detect the driver's hands position if the vehicle was lightly tinted compared to darkly tinted.

$$\text{odds ratio} = \frac{\text{odds}_{\text{detect with light-tint vehicle}}}{\text{odds}_{\text{detect with dark-tint vehicle}}} \qquad \text{Odds}_x = \frac{\text{number detected}}{\text{number not detected}}$$

There was also a significant association between viewing condition and detection performance, $\chi^2 = 18.79$, $p = .03$.Detection performance was best at midday. Performance was also high at night during all conditions when a flashlight was used. Performance was lowest at night when a flashlight was not used. Table 2 shows the proportion of participants who detected the driver's hands across all conditions.

Table 2. Percentage of participants in each condition who detected and who correctly identified the driver's hand positions.

	% Detected Driver's Hands		% Correctly Identified Driver's Hands	
	Light Tint – 50%	Dark Tint – 35%	Light Tint – 50%	Dark Tint – 35%
Midday	100	100	86.7	66.7
Dusk	100	78.6	73.3	57.1

Night, head on, no auxiliary, no handheld lighting	100	73.3	66.7	20
Night, head on, no auxiliary, yes handheld lighting	100	93.3	86.7	66.7
Night, head on, yes auxiliary, no handheld lighting	100	73.3	60	20
Night, head on, yes auxiliary, yes handheld lighting	93.3	100	60	60
Night, angled, no auxiliary, no handheld lighting	100	66.7	64.3	13.3
Night, angled, no auxiliary, yes handheld lighting	93.3	86.7	80	66.7
Night, angled, yes auxiliary, no handheld lighting	100	71.4	60	35.7
Night, angled, yes auxiliary, yes handheld lighting	100	100	66.7	78.6

Correct Identification

Participants were also asked to describe where the driver's hands were positioned and their responses were either coded as 'Correct' or 'Incorrect.' Participants had to correctly identify the position of both hands to be coded as 'Correct.' Whereas a high percentage of participants reported detecting the driver's hands (91%), fewer correctly identified where both hands were positioned (59.5%).

A three-way hierarchical loglinear analysis was used to test the relationship between tinting level, viewing condition, and the proportion of participants who correctly identified the driver's hands positions. The analysis revealed a significant association between tinting level and detection performance, $\chi^2 = 16.55$, $p < .0001$ and between viewing condition and detection performance, $\chi^2 = 29.01$, $p < .001$.

More participants correctly identified the driver's hands positions when viewing the light tint vehicle (70.5%) compared to the dark tint vehicle (48.3%). Based on the odds ratio, participants were 2.57 times more likely to detect the driver's hands position with the light-tint vehicle compared to the dark-tint vehicle. Identification performance was best at midday and at night during all conditions when a flashlight was used. Performance was worst at night when a flashlight was not used. Table 2 shows the proportion of participants who correctly identified the driver's hands across all conditions.

Confidence

Of the participants who detected the driver's hands positions, 10 were missing confidence rating data and were excluded from the analysis. The effects of tinting level and viewing condition on confidence ratings for the driver's hand position were analyzed using a 2 (window tint: 50% vs. 35%) by 10 (viewing condition) ANOVA. On average, participants rated their confidence as quite high ($M = 8.33$, $SD = 1.85$). There was a significant main effect of tinting level, $F\ (1, 261) = 4.08$, $p = .045$. Participants were more confident when viewing the light-tinted vehicle ($M = 8.51$, $SD = 1.66$) compared to the dark-tinted vehicle ($M = 8.10$, $SD = 2.07$). There was no main effect of viewing condition, $F\ (9, 261) = .63$, $p = .77$, nor a significant tinting level x viewing condition interaction, $F\ (9,261) = .22$, $p = .99$.

Detection of Objects in Vehicle

The proportion of correctly identified objects out of a possible 7 was calculated for each participant. A ratio was calculated, rather than using raw count scores, in order to retain 9 participants in the analysis who had 1-2 objects missing from the vehicle during their testing session. Across all viewing conditions, the scissors, glasses, and bottle were detected most frequently and the cellphone and backpack were detected least often.

Only 161 participants detected the presence of any objects in the vehicle and a smaller number of participants (n = 148) were able to correctly identify any objects in the vehicle. Without a flashlight at night, correct identification of objects was nearly zero (i.e., only 6 of 118 participants correctly identified any objects). A generalized linear model was used to assess the relationship between tinting level, viewing condition, and the ratio of correctly identified objects. There was no effect of tinting level on object identification, $\chi^2 = .63$, $p = .43$, but there was a significant association between viewing condition and object identification, $\chi^2 = 377.20$, $p < .0001$. Participants correctly identified the most number of objects during midday ($M = .38$, $SD = .21$). Performance at midday was compared to all other conditions and was found to be significantly better than dusk and all night conditions when a flashlight was not used. Using a flashlight at night led to comparable performance as midday. This main effect is qualified by a significant tinting level X viewing condition interaction, $\chi^2 = 35.68$, $p < .0001$, indicating that level of window tinting affected performance differently across viewing conditions (Figure 6). Specifically, performance improved as tinting level increased at night, when the police vehicle was angled, a flashlight was used, and auxiliary lighting was either on or off. However, performance declined as tinting level increased at midday. For all other conditions, performance did not differ across different window tints.

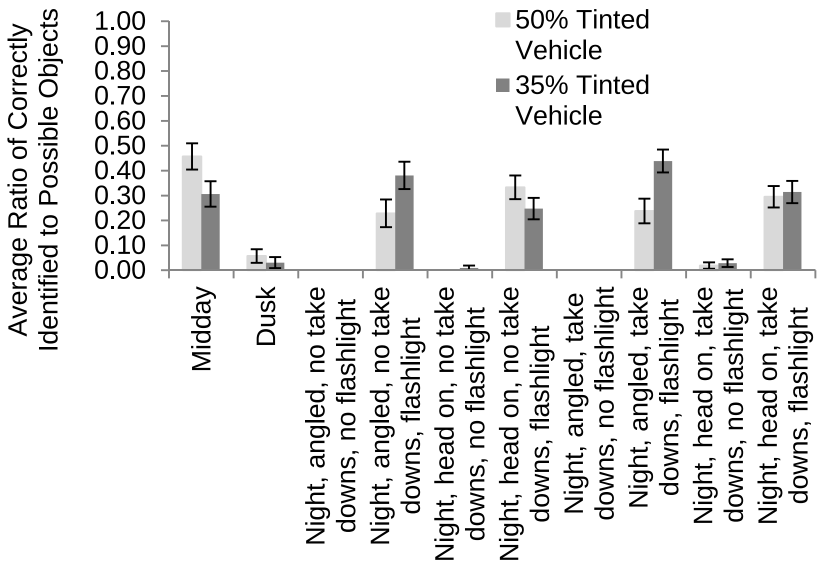

Figure 6. The effect of window tinting and viewing condition on the number of correctly identified objects. Error bars denote +/- 1 standard error from the condition mean.

Confidence Ratings for Objects in Vehicle

The average confidence rating across all 7 objects was calculated for each participant. Because only 161 participants detected the presence of objects within the test vehicle, some viewing conditions had few participants included in the analysis, meaning that interpreting this result with confidence is compromised. On average, participants were very confident when identifying objects ($M = 8.76$, $SD = 1.74$). A 2 (tinting level) by 10 (vehicle condition) ANOVA was run on average confidence rating. Tinting level did not affect confidence ratings, $F\ (1, 160) = 1.69$, $p = .20$, but there was a main effect of viewing condition, $F\ (9, 160) = 4.39$, $p < .0001$. Confidence was lowest at night when the police vehicle was head on, auxiliary lights were off, and flashlight was not used ($M = 3.00$), and confidence was highest at night when the police vehicle was angled, auxiliary lights were off, and a flashlight was used ($M = 9.23$; $SD = 2.01$). However, this main effect is qualified by a significant window tint X viewing condition interaction, $F\ (6, 160) = 3.82$, $p = .001$. To explore the interaction, separate one-sample t-tests were run for each viewing condition. Confidence declined as tinting level increased during midday, but confidence increased as tinting level increased at night when auxiliary lights were on, the flashlight was used, and the police vehicle was positioned head on. Confidence did not differ with window tint across the remaining viewing conditions.

Mannequin Detection

Detection at 20 feet from test vehicle

A three-way hierarchical loglinear analysis was used to test the relationship between tinting level, viewing condition, and the proportion of participants who detected 3 mannequins from a viewing distance of 20 feet. The analysis revealed a significant association between viewing condition and detection performance, $\chi^2 = 173.49$, $p < .0001$. Figure 7 shows that detection was worst at midday, dusk, and at night when the police vehicle was angled with no auxiliary lighting. Performance was best at night with auxiliary lighting (paired with or without handheld lighting). This main effect is qualified by a significant three-way interaction, $\chi^2 = 26.63$, $p = .002$. To break down this effect, separate chi-square tests on the viewing condition and detection variables were performed for the light and dark tint vehicles. For the light tint vehicle, there was a significant association between the viewing condition and whether or not 3 mannequins were detected, $\chi^2 = 82.75$, $p < .0001$; this was also true for the dark tinted vehicle, $\chi^2 = 84.19$, $p < .0001$. Due to variability in transmittance levels when applying after-market window tint, the two test vehicles did have different levels of tinting for the rear window (34% for the light-tinted vehicle and 30% for the dark-tinted vehicle). For some viewing conditions, performance was better with the light tint vehicle, but for other viewing conditions, performance was better with the dark tint vehicle. There does not appear to be a systematic reason for this different pattern of results. Regardless, using auxiliary lighting at night, especially when the police cruiser is pointed head-on towards the test vehicle, improves mannequin detection accuracy at 20 feet. There was no main effect of tinting level on mannequin detection performance.

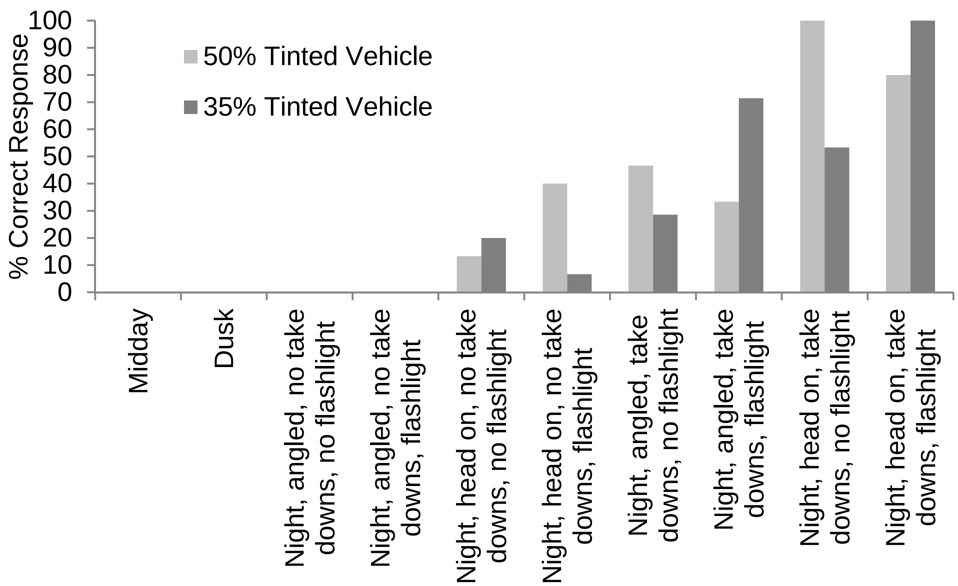

Figure 7. The effect of window tinting and viewing condition on mannequin detection performance from a viewing distance of 20 feet.

Detection at back of test vehicle

A separate three-way hierarchical loglinear analysis was used to test the relationship between tinting level, viewing condition, and the proportion of participants who detected 3 mannequins while standing at the back of the test vehicle. The analysis revealed a significant two-way interaction between viewing condition and the proportion of participants who detected 3 mannequins, $\chi^2 = 103.17$, $p < .001$. Tinting level did not affect mannequin detection performance. Figure 8 shows that detection was worst at dusk. Performance was best at night whenever auxiliary lighting was used. This result confirms the finding from detection at 20 feet; that is, using auxiliary lighting at night improves detection performance. Furthermore, mannequin detection improves as participants approach the test vehicle.

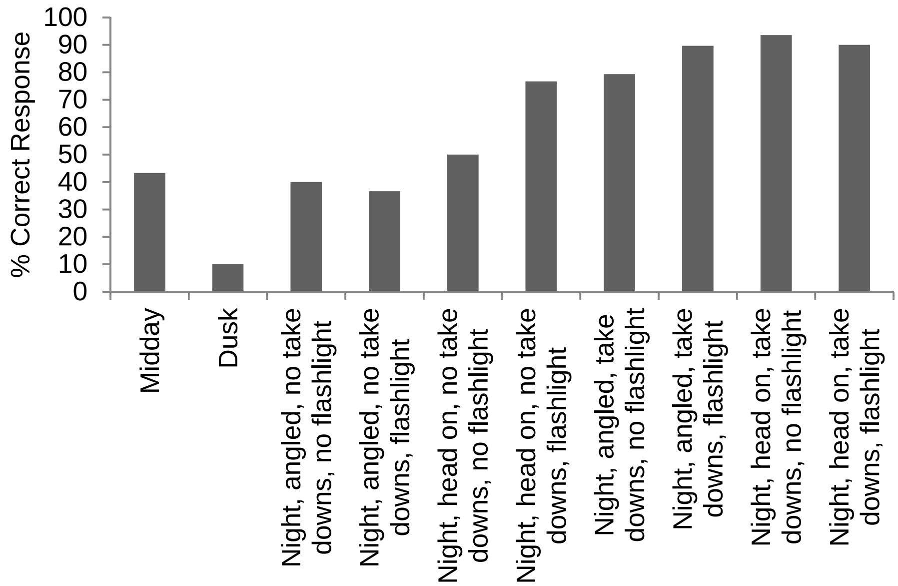

Figure 8. The effect of window tinting and viewing condition on mannequin detection performance when stopped at the back of the test vehicle.

Confidence Ratings for Mannequin Detection

Confidence at 20 feet from test vehicle

The effects of tinting level and viewing condition on confidence ratings for mannequin detection at 20 feet were analyzed using a 2 (tinting level: 50% vs. 35%) by 10 (viewing condition) ANOVA. The analysis revealed a main effect of tinting level, F (1, 299) = 4.88, p = .03, a main effect of viewing condition, F (9, 299) = 22.59, p < .0001, and a significant tinting level X viewing condition interaction, F (9, 299) = 1.97, p = .04. Due to variability in transmittance levels when applying after-market window tint, the two test vehicles did have different levels of tinting for the rear window (34% for the light-tinted vehicle and 30% for the dark-tinted vehicle). In general, confidence decreased as tinting level increased. Furthermore, participants were least confident during dusk and most confident at night when auxiliary lighting was used, corresponding to detection performance. For some viewing conditions, confidence declined as window tint increased and for other conditions confidence was not affected by tinting level (Figure 9). Specifically, confidence decreased with tinting level at midday and at night when no auxiliary lighting was used, the police cruiser was positioned head-on, and the participant used a flashlight.

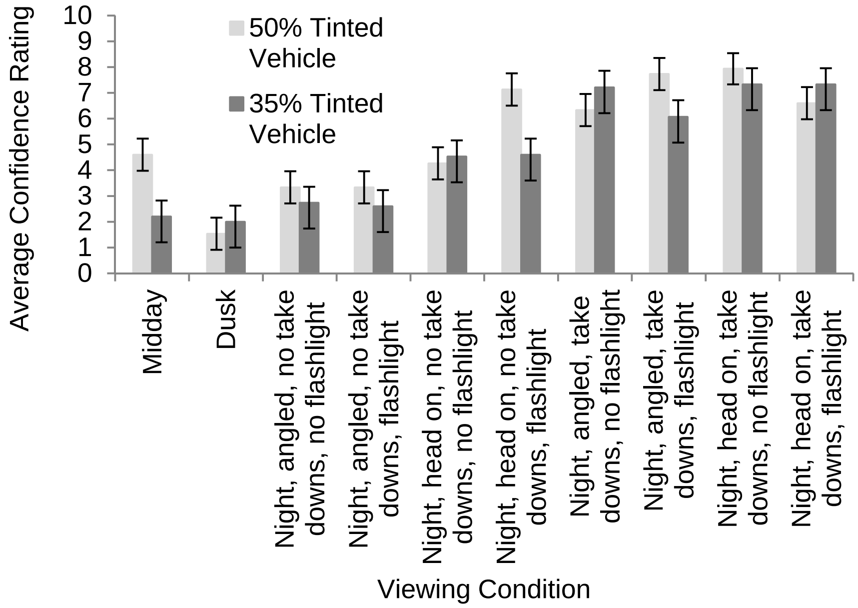

Figure 9. The effect of window tinting and viewing condition on confidence ratings for detecting mannequins from a viewing distance of 20 feet.

Confidence at back of test vehicle

The effects of tinting level and viewing condition on confidence ratings for mannequin detection at the test vehicle were analyzed using a 2 (window tint: 50% vs. 35%) by 10 (viewing condition) ANOVA. The analysis revealed a main effect of viewing condition, F (9, 298) = 7.70, p < .0001 (Figure 10). There was no significant effect of tinting level, F (1, 298) = .15, p = .70 nor a significant vehicle X viewing condition interaction, F (9, 298) = 1.25, p = .27. Participants were least confident during dusk and most confident at night when auxiliary lighting was used. Confidence at dusk was significantly lower than all other conditions except for midday and at night when no take-down lights were used (with the exception of when the police vehicle was positioned head on and a flashlight was used later during the experiment). Once participants are close to the test vehicle, both detection performance and confidence increased for all viewing conditions, relative to viewing at 20 feet.

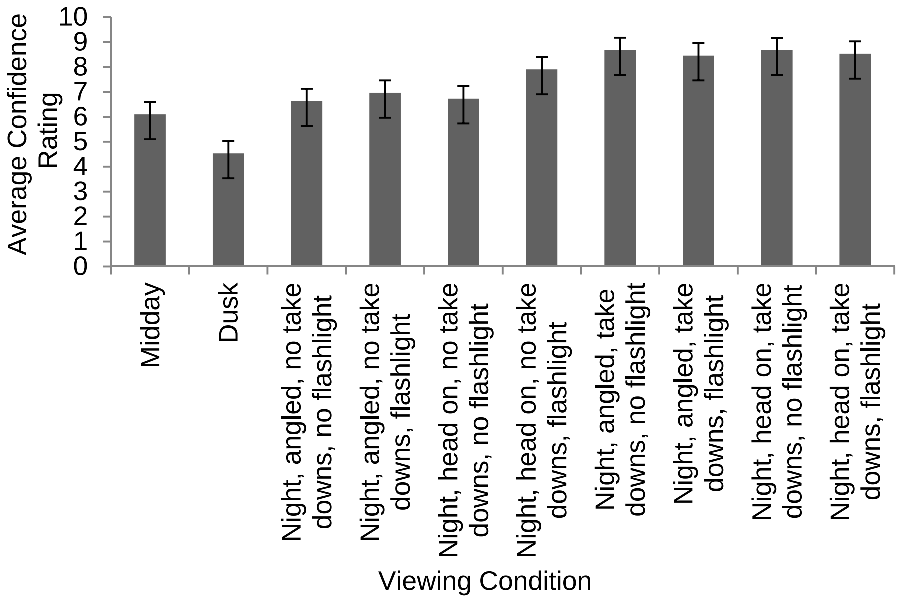

Figure 10. The effect of window tinting and viewing condition on confidence ratings for detecting mannequins when stopped at the back of the test vehicle.

Distance at Certainty

Distance at certainty was defined as the distance that participants stopped from the back of the test vehicle to report detection of three mannequins or to report a confidence level of 7 or greater. This dependent measure did not yield interpretable results due to the fact that 75% of participants either did not stop between the police and test vehicle or stopped but did not reach the criterion used for distance at certainty. For those participants, their distance was recorded as 0, indicating that they needed to be at the test vehicle to improve their confidence or detection performance. Therefore, sample sizes were limited and uneven across viewing conditions, response variability was high, and mean distance within each condition was compressed towards zero.

To test the effects of vehicle and viewing condition on distance stopped, a 2 (tinting level) X 10 (viewing condition) ANOVA was run. There were no main effects of tinting level, F (1, 296) = .74, p = .39, or of viewing condition, F (9, 296) = 1.37, p = .20, but there was a significant tinting level X viewing condition interaction, F (9, 296) = 2.45, p = .01. To explore this interaction, independent t-tests were run for each viewing condition comparing performance with the light- and dark-tinted vehicles. Distance at certainty decreased with increasing tinting level at night when the police cruiser was positioned head on, and neither auxiliary nor handheld lighting was used. However, distance at certainty increased with increasing tinting level at night when the police cruiser was positioned head on, and both auxiliary and handheld lighting was used. No other viewing conditions differed with tinting level. However, interpretation of this finding is qualified by the fact that most participants never stopped between the vehicles, therefore limiting sample size across conditions and increasing variability in responses.

CONCLUSIONS

Window tinting level had the largest impact on detecting and identifying the position of the driver's hands (see Table 2). Specifically, it was more difficult to detect and to correctly identify the position of the driver's hands when light transmittance was reduced to 35%. Participants were also more confident in their judgment when viewing the hands through the 50% tinted vehicle. These three effects were true independent of viewing condition.

Higher window tint also negatively impacted participants' abilities to identify objects within the vehicle, but only when testing occurred at midday. However, when the police vehicle was angled, handheld lighting was used, and auxiliary lighting was either on or off, object detection performance improved when viewing through the darker-tinted window. This suggests that darker window tint may only adversely affect object detection performance during the day, when reflectance from window glare is highest. At night, especially when handheld lighting is used, the effects of tinting level can be overcome. However, the robust effects of window tinting on driver's hand detection performance suggest tinting level has a partial effect on seeing inside a vehicle, regardless of extra lighting being used.

For certain performance measures (e.g., object detection performance and confidence, mannequin detection and confidence at 20 feet), performance improved when viewing the dark-tinted vehicle under specific viewing conditions (e.g., the police car was angled and a flashlight was used). However, general conclusions cannot be made about whether darker tint improves performance for two main reasons. First, the particular night condition(s) that showed higher performance in the dark-tinted vehicle varied across dependent measures. That is, a specific lighting and vehicle configuration showed higher performance in the dark-tinted car for one measure, but lower or no change to performance in the dark-tinted car for another measure. Second, better performance with the dark-tinted car did not apply to all night conditions, nor to a subset of the night conditions (e.g., always when a flashlight was used or always when take down lights were turned on). Therefore, there was no systematic variation to these effects.

In general, use of handheld lighting when at the test vehicle improved performance compared to when handheld lighting was not used. In fact, without handheld lighting, most participants did not detect any objects within the vehicle and driver hand position performance was particularly poor. Use of auxiliary lighting improved performance when viewing the test vehicle from a distance of 20 feet, because the mannequins were most illuminated under those conditions.

The effects of window tinting on mannequin detection at 20 feet and at the test vehicle were mixed. For these tasks, performance was highest at night when auxiliary lighting was used and poorest at midday, dusk, and at night without auxiliary lighting. Participants were less confident in their judgment from 20 feet when viewing the dark-tinted vehicle.

Increasing tinting level does not always impair performance, and in some select cases, performance even improved with lower transmittance levels. However, there is a significant impairment to detecting the driver's hands positions and confidence in these judgments across all viewing conditions when transmittance is reduced to 35%. Furthermore, detecting objects is impaired at midday with darker window tint. While it is true that under some viewing conditions, performance improved with higher levels of window tint, these improvements were not systematic and thus cannot be used to make a case for approving higher window tint levels. Overall, these findings highlight a potential safety risk to police officers if tinting levels were to increase, with the highest risk during daytime hours.

RECOMMENDATIONS

The following recommendations can be made, based on the results of this experiment.

1. Deciding whether to reduce transmittance levels to 35% for front-side window, should take into account that doing so would diminish police officer's ability to detect a driver's hand positions and confidence in that judgment. Object detection during daytime hours would also be affected.
2. At night, regardless of tinting conditions, detection performance is optimal when auxiliary lighting and handheld lighting are employed.
3. Reducing transmittance levels would likely diminish pedestrian and cyclists abilities to see a driver's face, and thus, ascertain whether the driver sees them and will yield the right of way. Further research is needed to assess this possibility.

BENEFITS AND IMPLEMENTATION PROSPECTS

This research will benefit police officers in that their safety will not be compromised when approaching the driver's side window if the allowable level of window tint remains at 50%.

These findings may have monetary costs for the window tint industry, such that motorists would be unable to purchase darker tinting for their vehicles.

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