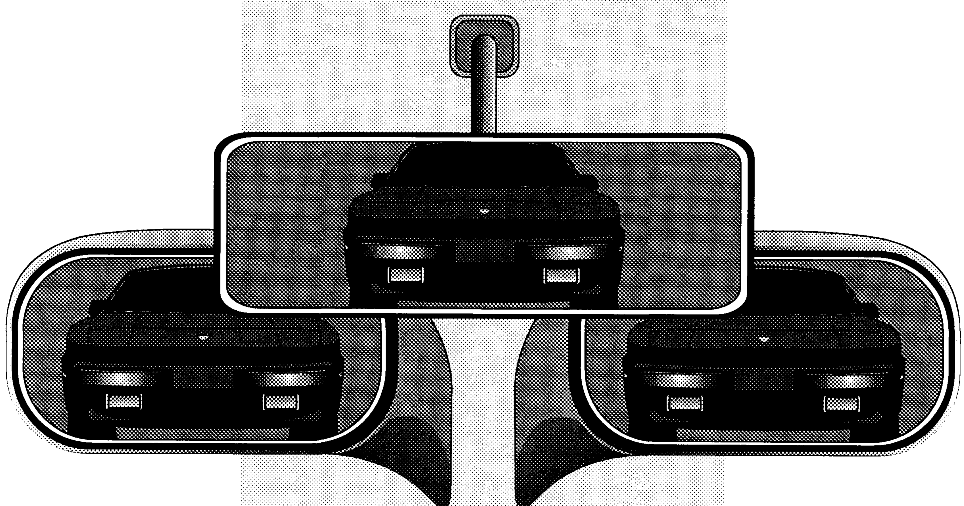
FINAL REPORT

THE EFFECT OF REDUCED TRANSMITTANCE WINDOW TINTING ON DRIVERS' ABILITY TO DETECT TARGETS IN THEIR REAR-VIEW MIRRORS



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Supplementary Notes

Abstract

This study addressed the degree to which motor vehicle window tint films impede drivers' ability to detect targets in their vehicle's rear-view mirrors. Twenty-four subjects participated. Each sat in the driver's seat of one of four experimental vehicles and attempted to detect a stationary pedestrian in one of the three rear-view mirrors. Errors in detecting targets and the distances at which detection occurred were recorded. One experimental vehicle had no aftermarket tinting, and three were tinted to varying degrees.

In general, this study found that increased levels of window-tinting were associated with an increase in the number of failures to detect a pedestrian in rear-view mirrors and with a decrease in the distance needed to detect this target. In addition, increased levels of window tinting were associated with an increase in between-subject variability, meaning that window tinting interfered with target detection more for some subjects than for others.

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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

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In general, this study found that increased levels of window tinting were associated with an increase in the number of failures to detect a pedestrian in rear-view mirrors and with a decrease in the distance at which the target could be detected. In addition, increased levels of window tinting were associated with an increase in between-subject variability, meaning that window tinting interfered with target detection more for some subjects than for others.

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INTRODUCTION

Legislating maximum levels for motor vehicle window tinting has been debated in state legislatures. Under current federal regulations, new vehicles cannot be manufactured with windows that allow less than 70% of the light striking them to pass through. After purchase, the owner may have all windows tinted. The Commonwealth of Virginia allows tinting of the front side windows to reduce the passage of light up to 50%. The rear and rear side windows may be tinted to a limit of 35% light transmittance. The Superintendent of State Police may allow individuals with certain documented eye or medical conditions to apply aftermarket tinting to the front windshield to reduce light transmittance to as low as 70%.

The 1993 session of the Virginia General Assembly set the current level of aftermarket window tinting. Traffic safety concerns led to Senate Joint Resolution No. 293, requesting a study of window tinting. The resulting report concluded that window tinting reduces the ability to detect targets that would be difficult to see through untinted glass, and that this could be a safety liability, especially when ambient light is low (Proffitt, Jernigan, Lynn & Parks, 1994). That report also recommended further empirical studies on the influence of window tinting in a number of different contexts. The first empirical study investigated whether window tinting would present a hazard to police officers approaching a stopped vehicle on foot (Proffitt, Joseph, Bhalla, Durgin, Bertamini, Lynn, & Jernigan, 1995). That study found that, in general, higher levels of window tinting made seeing inside a vehicle more difficult. This current research addresses whether increased levels of window tinting reduced the subjects' ability to detect human targets through their rear-view mirrors.

PURPOSE, SCOPE, AND LIMITATIONS

The purpose of this study was to assess whether the application of different values of window tinting would influence the detectability of a target in a situation representative of everyday driving. Except for Freedman et al. (1991), all previous investigations applied tints to the windshield and assessed target detectability by a forward-looking driver. Since by Virginia law aftermarket tinting cannot be applied to factory-tinted windshields, a more realistic situation would be target detection through the side or rear windows. In everyday driving, the most frequent situation that entails looking through tinted glass is when the driver looks in the rear-view mirrors while driving in a forward direction.

During the day, most important targets are of high contrast, and legal amounts of window tinting would not affect target detection significantly. At night, the most important targets are approaching vehicles whose headlights would be clearly visible through legal tinting films. Thus, the study was conducted at dusk when targets are near threshold for detection in an untinted vehicle, and consequently might be below threshold when viewed through lower-transmittance glass.

A number of factors in this situation are different from the conditions actually encountered while driving. Approaching targets are most often another vehicle, motorcycle, or bicycle. Moreover, drivers are primarily concerned with controlling the vehicle and looking forward as opposed to sitting in a stationary vehicle engaged in the sole task of detecting targets in the rear-view mirrors. The generality of this study's findings is limited, but a completely naturalistic design in which subjects drive at dusk and detect rearward targets was deemed unsafe.

LITERATURE REVIEW

Optical and Visual Considerations

Among non-specialists, terms such as illumination, luminance, and contrast are sometimes used inconsistently, creating confusion. Terms relevant to this report are defined below.

Targets are objects that are important for a driver to see. Visual targets are of two sorts. An *illumination target* is a source of illumination, such as a headlight or traffic signal. Most targets are *illuminated targets,* meaning that they are visible because they are illuminated by some external source such as the sun, street lights, or headlights. The human subjects used in this research were illuminated targets.

For an illuminated target, *illumination* refers to the amount of light falling on it. The range of ambient illumination conditions within which the human visual system can function is quite extraordinary; a bright sunny day provides about 10 million times more light than a clear starlit night. When a target is illuminated, some of the light is absorbed and some is reflected. The light that is reflected from a target to the eye is called *luminance*. Target luminance is, thus, a function of two variables: ambient illumination and the proportion of illumination that the target reflects.

In order to see a target, it must contrast with its background. It is not sufficient for a target to be illuminated; there must be a sufficient difference between its reflected luminance and that of its background. *Contrast* is defined as the difference between target luminance and that of its background divided by the background luminance. Suppose, for example, that target luminance is 3 fL whereas its background is 2 fL. (fL denotes footLamberts, a standard metric for measuring light intensity.) Contrast in this case is (3 fL - 2 fL) / 2 fL = ½.

The critical term in window tinting is transmittance. *Transmittance* is the proportion of light incident upon the window that passes through the glass into the air on the other side. Federal and state regulations define transmittance limits as assessed by measuring the passage of light passing at a right angle through the window. This transmittance value is, in fact, measured at the most advantageous angle for light transmittance. Thus, if a window is rated as having a 50% transmittance value, it actually provides the driver with 50% of the incident illumination only when he or she is looking at a target along a line of sight that is perpendicular to the window. Any other viewing angle will cause transmittance to be less than 50%. There is very little reduction in transmittance at viewing angles of less than 20 degrees, whereas angles of over 60 degrees result in a substantial decrease in transmittance. Obviously, the most severe viewing angles are to be found for a driver who is looking over his or her shoulder in order to see out of a rear side window.

Window tinting films do not reduce contrast. Consider the example given above in which a target presented 3 fL of luminance against a 2 fL background resulting in a contrast of ½. Since tinting films reduce transmittance proportionally, the target/background contrast is constant across all transmittance levels. Window tinting films impede visual performance by reducing overall luminance, not by reducing contrast.

The fundamental constraints on visual performance are contrast sensitivity and visual acuity. *Contrast sensitivity* is the amount of contrast needed to detect a target at some level of overall luminance and light adaptation. *Visual acuity* refers to the ability to detect small spacings of contrast such as is required to detect that a letter is a C and not an O.

Contrast sensitivity and visual acuity improve with overall luminance. As everyone knows, people can see better during the day than at night. The contrast between a target and its background is unaffected by differences in ambient illumination, such as whether illumination is provided by stars or the sun. The critical variable for visual performance is the overall luminance that reaches the eyes. It is this property -- the overall luminance reaching the eyes -- that is adversely affected by window tinting. It is a general property of vision that, within the range of natural illumination conditions, the greater the overall luminance reaching the eyes, the better the visual performance.

Studies of the Influence of Window Tinting on Driver Performance

If contrast sensitivity and visual acuity improve with increased levels of illumination (Van Nes & Bouman, 1967), a reduction in transmittance is an impediment to visual performance. This conclusion is warranted from what is known about the performance of the visual system. The practical issue is whether the reduction in visual performance incurred by the application of window tinting films is sufficiently large to make a difference in driving performance.

Haber (1955) performed a theoretical analysis of the loss in contrast sensitivity due to tinted glass and the resulting loss in a driver's ability to detect objects with increases in distance. As Dunn (1973) pointed out, Haber's analysis was constrained to the simplifying assumptions and specific parameters employed, and it would be inappropriate to draw general conclusions from it other than to note that distance perception must be reduced by the introduction of window tinting. Dunn performed a more general theoretical analysis of the probability of target detection at twilight and night luminance under varying conditions of contrast and window tinting. He showed analytically how the probability of target detection decreased with reduced contrast and transmittance values. Importantly, he showed that contrast sensitivity decreases at a higher rate for transmittance values below 80%.

The expected deleterious effects of window tinting on visual performance were clearly demonstrated by Wolf, McFarland, and Zigler (1960). These authors performed experiments on the influence of window tinting on five visual functions. *Dark adaptation* refers to the visual system's increased sensitivity that occurs after prolonged exposure to low illumination. It was found that, for a given level of dark adaptation, the threshold for detecting light was raised when viewing through tinted glass by an amount corresponding to the reduced transmittance value. In other words, it took 30% more light to see a target through 70% transmittance glass. *Recovery from light "shock"* refers to the reduction in light sensitivity that occurs after exposure to a bright light. It was found that viewing the bright light through a tinted filter reduced the loss of light sensitivity; however, this was completely offset by the concomitant reduction in target luminance. Thus, window tinting has no effect on recovery from exposure to a sudden bright light source.

Visual acuity is also reduced for targets viewed through tinted filters (Wolf, McFarland, and Zigler, 1960). Transmittance values used in this study ranged between 65% and 72%. The visual test required observers to detect the location of a gap in C-shaped figures of various sizes. It was found that the filters reduced visual acuity such that the targets needed to be 10 to 20%

larger to be detected. Stereo *depth perception* is influenced by overall luminance, and depth perception was reduced by 25 to 30% when the 65-72% filters were introduced. *Vision in the context of glare* was also assessed. Glare reduced visual acuity equally with or without the presence of a tinted filter. Disability glare, a function of contrast, was unaffected by decreasing transmittance.

Both the theoretical analyses and the empirical demonstrations lead to an indisputable conclusion: *Window tinting is an impediment to visual performance when targets are near threshold without the presence of the tint filters.* A target near threshold is just barely detectable. The question remains, however, as to the likelihood that a driver will encounter such conditions. This question has motivated a number of studies on the effects of window tinting in situations comparable to everyday driving.

The initial studies on window tinting were directed at the effect of newly introduced windshield tints that could result in transmittance values as low as 70%. Heath and Finch (1953) assessed viewing distances at which targets were detected at night by drivers in vehicles with 89% versus 71% windshield transmittance. Given the 45° angle of the windshield, the effective transmittance values were 86 and 69%, respectively, meaning that there was a 17% difference in transmittance. Testing was done at night with headlight illumination, and a variety of targets were placed on a new road that had not yet been opened to the public. It was found that targets needed to be about 4.5 meters closer, on average, before they were detected. Subject variability was high. Roper (1953) conducted a similar study at night on an airstrip. His two vehicles were equipped with windshields differing in transmittance by 18%, and he tested target detection under driving conditions with and without a glare source provided by the headlights of an oncoming vehicle. Relative to the tinting manipulation, he found a 6% reduction in viewing distance without glare and a 2% reduction with glare. In the glare condition, there was no difference in performance once the targets were within 152 meters of the vehicle. Doane and Rassweiler (1955) replicated Roper's design in the glare condition and used targets that were harder to detect. They found that standard heat-absorbing windshields reduced detection distance by about 3%, a result similar to Roper's. Dunn (1973) used a stationary vehicle cab testing device that was placed on a private road. Targets were near threshold and their detection distance was assessed under nighttime headlamp illumination conditions. Two windshields were employed, one clear (96% transmittance), and one tinted (78% transmittance). Viewing distances were found to be greater with the clear glass by less than 4.5 meters. As with the previous studies, variability among the subjects was very high.

These studies suggest that there is a small detrimental effect for tinting windshields to a 70 - 80% transmittance level. This impediment has only been demonstrated in nighttime situations and for targets that are difficult to see. Even under these less than optimal viewing conditions, the effects of this level of tinting are small.

The most relevant study for the purpose of assessing the influence of window tinting below 70% transmittance levels was conducted by Rompe and Engel (1987). They used a driving simulator equipped with interchangeable windshields with transmittance values of 89.0, 76.4, 58.0, and 40.0%. Following a 20 minute learning phase, subjects drove the simulator over a projected road for 12 minutes. During this test phase, single square targets appeared for 2 seconds at one of two randomly selected locations along the horizon. There were a total of 50 targets and each had an opening on one of its four sides. Targets were presented at four different contrast levels. Background luminance simulated twilight driving conditions. Subjects were divided into two groups based on whether they wore spectacles. The subjects' task was to indicate the location -- left/right or up/down -- of the opening as fast as they could. The dependent measures consisted of the percent of trials correct for detection of the target's opening and the associated reaction time. This study also included a condition in which a glare source was present.

For the normal-sighted subjects, percent correct was near 100% for the three highest contrast targets at all levels of window tinting. For the lowest contrast targets, percent correct was about 80% for the 89%, 76%, and 58% transmittance windshields, but dropped to below 60% correct for the 40% transmittance windshield. The spectacle wearers were unaffected by transmittance level for the three highest contrast targets; however, for the lowest contrast targets, they exhibited a decline in detection for both the 58% and 40% windshields. For spectacle wearers, detection rates for the 40% windshield were below 40% in the lowest contrast condition. Target contrast had an effect on reaction time, but transmittance level did not.

The presence of glare yielded a similar pattern of results. Normal-sighted subjects were unaffected by transmittance level except at the 40% level where detection rate dropped significantly. Spectacle wearers showed a steady decline in detection rate at each level of transmittance reduction. There was no evidence that low transmittance windshields reduced the influence of disability glare. This study clearly indicates a reduction in low-contrast target detection at low levels of transmittance for normal-sighted people, and a pervasive and increasing reduction in visual performance for spectacle wearers at levels below 70%. Boyd (1991) noted that both Volkswagen and Flachglas AG used this study as the basis for advocating a minimal transmittance level of 70 to 75% for the forward 180° field of view.

IIT Research Institute conducted a study sponsored by the tint manufacturing industry (Wakeley, 1988) assessing reaction times to detect high-contrast targets with varying levels of window tinting at different times of day. The effects of window tinting on reaction time were quite minimal, and although no statistical evidence was provided to support this conclusion, Wakeley concluded that the 50% film yielded better response times than the 70% film. Not only was this conclusion unsupported by statistical analyses, but it makes no theoretical sense. The detection of high-contrast targets should be unaffected by window tinting and an examination of the figures provided in this report suggest that this is what was found.

The focus of all of these studies was primarily on the influence of window tinting on driving in a forward direction. One study, conducted by Freedman, Zador, and Staplin (1991) investigated the effect of window tinting on detecting objects while backing a vehicle. Four levels of window tinting were applied to the rear side and rear windows of a laboratory vehicle cab: 69%, 53%, 36%, and 22%. Three 1.8 X 2.7 meter projection screens were placed behind the vehicle onto which natural scenes were projected at a size appropriate for the viewing distance. One of five targets was present on some of the trials. The targets were a vehicle, cyclist, pedestrian, child, and road debris. These targets differed in their size and contrast levels. The subject was given 10 seconds on each trial to determine whether one of the targets was present. Subjects ranged in age from 18 to 90 years of age. The vehicle was always detected. The probability of detection for the child and debris targets decreased with reduced transmittance values. Probability of detection also decreased with the subject's age. The authors of this study concluded that the study may have understated the magnitude of the visibility deficits that are caused by high levels of window tinting because the subjects were not actually driving the vehicle, and thus, had no distractions during the full 10 seconds that they had to respond.

In summary, it can be concluded that a reduction in transmittance reduces the ability to detect targets that would be difficult to see through a clear window. There is no evidence that this reduced visibility is of any consequence to driver performance during well-illuminated daytime conditions, when essentially all important targets are considerably above threshold for detection.

Reduced transmittance can be a liability when ambient illumination is low. Visual acuity and contrast sensitivity decrease with the dark adaptation levels that are required to see at twilight and nighttime. As the sun sets, the number of important targets that are difficult to see increases. Reduced transmittance makes such targets more difficult or impossible to detect.

The adverse effects of window tinting become increasingly pronounced as transmittance values go below 70% (Dunn, 1973; Rompe & Engel, 1987). This is especially true for people who wear spectacles (Rompe & Engel, 1987). The elderly generally have poorer night vision than younger individuals and window tinting can have an especially detrimental impact on their visual performance (Freedman, Zador, & Staplin, 1991; McFarland, Domey, Warren, & Ward, 1960).

METHOD

Subjects

Twelve males and 12 females volunteered to participate in this study. Subjects were recruited from the University of Virginia community via the electronic mail network. They were paid $10 for participating. All subjects had normal or corrected-to-normal vision and a valid driver's license at the time of the study.

Materials and Apparatus

The study was conducted in an empty, unmarked parking lot on the grounds of the University of Virginia. It was a rectangular area with foliage and trees on one side and a building on the other. The parking lot was illuminated by three street lights situated along two of its four sides.

Four 1987 Dodge Aries K four-door sedans were used as test vehicles. Except for window tinting, they were all identical, with blue exterior paint, dark blue interiors, and black dashboards. Vehicle 0 had no aftermarket tinting applied. The tinting levels for Vehicle 2 represented the maximum reduction in transmittance allowed by Virginia law, and the tinting values of Vehicle 1 were chosen to be intermediate to those of Vehicles 0 and 2. The prescribed levels of tinting for Vehicle 3 were the maximum reduction of transmittance allowed by any state in the country, Florida. Table 1 shows the tinting specifications for the four test vehicles as ordered and described by the tinting company that applied the films. Also shown in Table 1 are the transmittance values as assessed by a one-piece tintmeter used by the Virginia State Police. The prescribed and assessed transmittance values are quite close except for Vehicle 3, in which the measured values are lower than ordered for the back side window.

The target that the subject was instructed to detect was an experimenter positioned along one of three straight trajectories behind the vehicle. The target wore dark colored pants or shorts and a dark top. A Sonin Combo Pro Electronic Distance Measuring Tool (with a resolution of 6.3 mm and an accuracy of 99.5% +/-12.7 mm in normal weather conditions) was used for measuring all distances. Small black bean bags, not visible to the subject seated in the vehicle, were used to mark the starting points of the three trajectories. An Armitron digital stopwatch was used for all timing.

Table 1. Tinting Specifications for the Four Test Vehicles

	Target Transmittance			Actual Transmittance[b]	
Vehicle	Windshield	Front Side	Rear and Rear Side	Front Side	Rear Side
0	[a]	[a]	[a]	88	88
1	[a]	50	50	53	53
2	[a]	50	35	53	38
3	[a]	35	20	40	13

Note: The values in the table are percent transmittance for each window.
[a] This information was not available from the manufacturer
[b] Rear window transmittance could not be measured with a 1-piece tintmeter

Design

The between-subjects variable was level of tinting (one level corresponding to each of the four vehicles) and the within-subject variable was mirror (rear-view, left, and right). Each subject was run through 32 trials (four conditions x eight repetitions). The four conditions corresponded to the three different trajectories on which the target was stationed (one per mirror), and the condition when no target was on any of the trajectories (the target absent condition). The order in which the trials were run was randomized for each subject. Six subjects (three males and three females) were run per vehicle, yielding 24 subjects in total.

Testing occurred once a day at dusk (the half-hour period starting 5 minutes after sunset as stated in the weather report of that day's Washington Post newspaper) from September through December, 1994. There were two positions in which the vehicle was parked for the study, either facing the east end of the parking lot or the west end. For half of the subjects, the vehicle faced the east end and for half it faced the west end. This was done to balance out any effects that the background and differences between artificial and natural lighting would have on the detectability of the target. The target person was male for half of the subjects and female for the other half.

Procedure

Each subject was either met at the location of the experiment or was brought to the location by the experimenters. Before the experiment began, the vehicle to be tested was parked facing east or west, leaving enough room behind the vehicle for the three 61 meter trajectories of the target. After the subjects signed a consent form, the experimenter provided some background and familiarized the subjects with the experimental task of detecting a stationary human target in one of the three mirrors of the vehicle in a two-second period. This took about 5 minutes. The experimental setup is shown in Figure 1.

The subjects were then asked to sit in the driver's seat and fasten the 3-point safety belt, to create a situation as similar as possible to driving. The subjects adjusted the seat and the three mirrors (rear-view, left and right) as they would for driving. To find a trajectory that would put the target in the center of each mirror, the target walked some distance behind the vehicle, taking care to remain visible to the subjects in a particular mirror. The subjects then had the target adjust his or her position to be visible in the center of one mirror, and not visible in the other two mirrors. The target then moved to the starting point 61 meters away (measured with the help of the other experimenter), maintaining his central position in the mirror. The starting point of each of the three trajectories for the target was always set at 61 meters from the front of the vehicle. The angle of the trajectory was slightly different for different subjects depending on their height and the mirror adjustments of individual subjects.

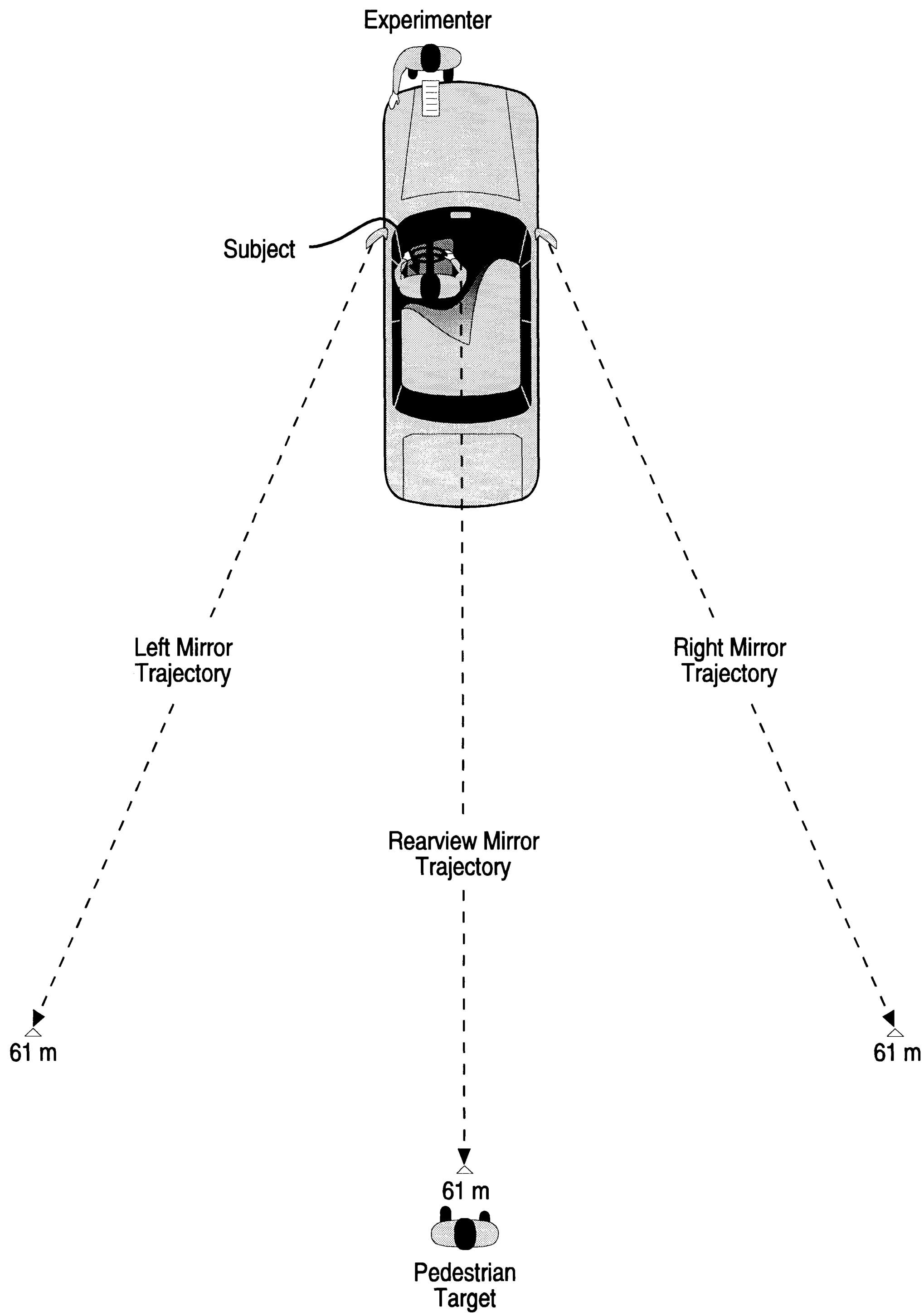

Figure 1. Experimental setup.

The subjects were then given detailed instructions about the task involved. After completing the instructions, the experimenter ran the subjects through two practice trials to ensure that they understood the task and had no questions about it. The practice trials were run in the same manner as the actual experimental trials. Each experimental trial began with the subjects having their head down and their eyes closed. Once the target was stationed at the appropriate location for the trial, and after both the experimenter in front of the vehicle and the target person signaled readiness, the experimenter said "Look up." This prompted the subjects to open their eyes and look out of the windshield at the experimenter, taking care not to glance at the mirrors. At this point the experimenter said "Start," and the subjects had 2 seconds to check the 3 mirrors (center, left, and right) for a target (without turning around or looking out of the windows directly and with minimal body movement). If the subjects were able to detect the target, they pointed to the mirror in which the target was detected, and then closed their eyes and put their head down. The experimenter made note of the response (correct or incorrect) and then signalled to the target to move to the next location. To avoid bias, the experimenter did not look at the target. If the subjects did not see anything after 2 seconds, the experimenter said "Stop," and the subjects stopped checking the mirrors and signalled to the experimenter that they had not detected the target. This indicated the end of the trial for the subjects, and they closed their eyes again, put their head down, and waited for the next trial to begin.

For the target-present trials, when the subjects correctly identified the location of the target, the trial ended and the target moved to the appropriate trajectory for the next trial. When the subjects did not correctly detect the target, or did not see the target when one was present, the trial continued at the same location. The target then moved toward the vehicle on the same trajectory by 9 meters and the trial proceeded as before. The trial ended when the subjects correctly detected the location of the target or when the target reached the back end of the vehicle. The experimenter made note of the subjects' responses and the distances at which detection of the target occurred. This distance was measured with the electronic distance measuring device.

For the target absent trials, the target was not stationed at any of the three trajectories, and was concealed from view. The subjects' task remained the same: to report whether they detected the target or not. The subjects' response was noted in the same way as before (correct or incorrect), but unlike the target present trials, the target absent trials ended whether the subjects were correct or not.

At the end of the experiment the subjects were debriefed about the purpose of the study, and paid for their time. The whole experiment, including instructions and debriefing, took about an hour.

It should be noted that this study was conducted in the field under real-world conditions, rather than in the laboratory where variables such as target luminance and contrast could be controlled. The targets used in this study were people. The pedestrian targets presented a complex pattern of contrasts (face, hair, neck, clothing, background). Not only is the pedestrian target a complex ensemble of contrasts, but the background is also a non-homogenous array of contrasts far too complex to catalogue. Since contrast is a ratio between the luminance of one surface versus another adjacent to it, it can be controlled in the laboratory; since this study was conducted in a parking lot, these variables were beyond experimental control, and changed with every trial, every day, and every surface used. Target size also varied with distance, since a target cannot be made to approach an observer without increasing in visual angle.

RESULTS AND DISCUSSION

The purpose of this study was to investigate the influence of window tinting on a driver's ability to detect a pedestrian behind a vehicle at dusk. The two performance measures of interest were (1) errors -- how many times the driver failed to detect the pedestrian in a particular mirror and (2) distance at detection -- how far the pedestrian was from the vehicle at the time of detection. In addition, subjects scanned all three mirrors to detect the target, which was visible in only one mirror. Thus, there were two independent variables: the level of tinting and the mirror in which detection was observed. Each of the two performance measures was submitted to a separate 4 (tinting level) x 3 (mirror - right, left, center) repeated measures ANOVA, with tinting level manipulated between subjects and mirror repeated within subjects. Each dependent measure is discussed separately below.

Errors

Figure 2 shows the mean number of errors per trial for the four levels of tinting. Errors increased as tinting level increased, but the effect was not statistically significant, $F(3, 20) < 1$. Although the trend was in the expected direction (more errors with more tinting), variability was quite high and increased with greater tinting (as shown in Figure 2 by the standard error bars). The lack of a significant effect of tinting was very likely due to this high variability among a relatively small number of subjects.

Another way to appreciate this increase in variability is to note the number of detection failures at a distance of 38 meters or less. For the untinted vehicle there was 1 failure, for Vehicle 1 there were 5, for Vehicle 2 there were 9, and for Vehicle 3 there were 20.

Most of the errors occurred in the right side-view mirror, as shown in Figure 3 [$F(2, 19) = 6.8$, $p < .01$]. This was expected, since the right mirror made objects appear smaller and farther away than they actually were. The effect of tinting was essentially the same for all three mirrors. Appendix A provides the ANOVA table for the analysis of errors.

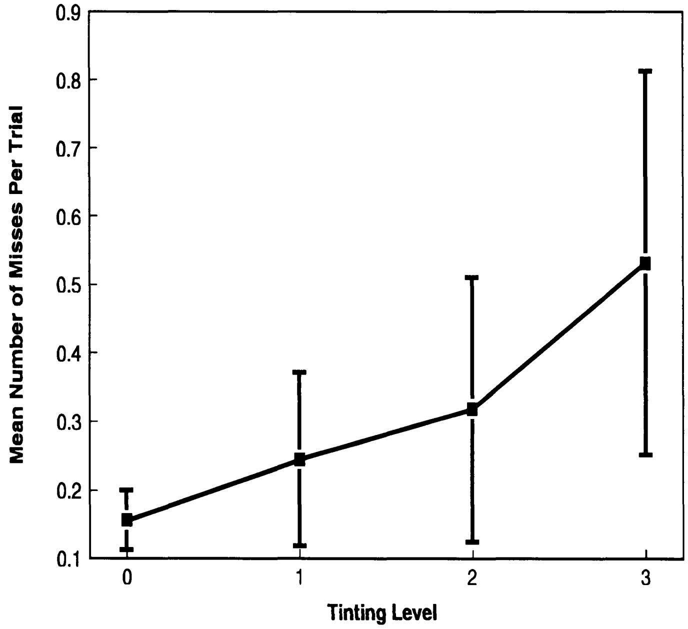

Figure 2. Mean number of errors per trial for the four levels of tinting.

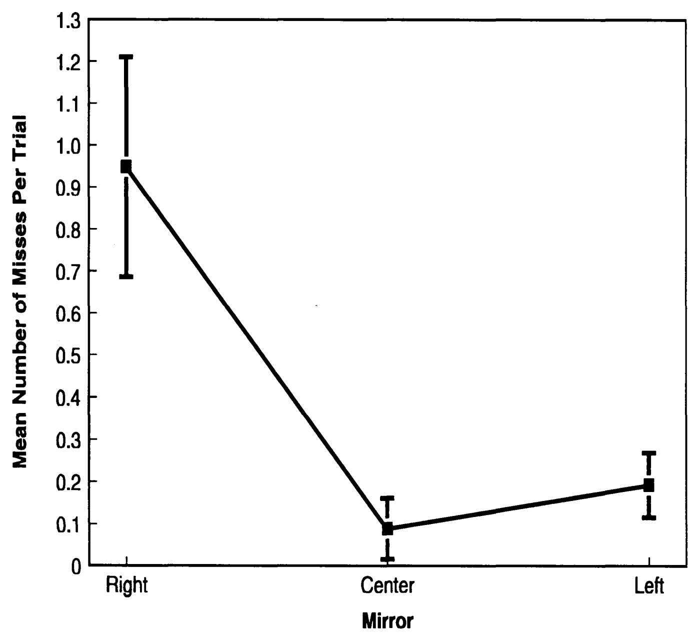

Figure 3. Mean number of errors per trial for the three mirrors.

Distance at Detection

Figure 4 shows the mean distance at detection for each of the four levels of tinting. Again, the trend was in the expected direction, with the target needing to be closer for the more tinted vehicles. However, this effect was not significant, $F(3, 20) < 1$, due to the high variability. The target needed to be closer to the vehicle to be detected in the right mirror compared to the other two mirrors, as shown in Figure 5. This effect was significant, $F(2, 19) = 5.9$, $p < .01$, but the tinting level/mirror interaction was not. Appendix B provides the ANOVA table for the analysis of distance at detection.

Additional Analyses

Figures 2 and 4 show that variability in performance increased with greater levels of tinting. This was problematic for finding a significant effect of tinting with ANOVA. The simple correlation between tinting level and error performance and tinting level and distance at detection was, therefore, examined. The correlations were significant, but low, for both dependent measures. For errors, $r = .18$, $p < .001$, $N = 576$, implying that more errors were associated with greater tinting levels. For distance at detection, $r = -.17$, $p < .001$, $N = 576$, implying that greater levels of tinting were associated with shorter distances at detection.

In determining the starting distance of 61 meters, a variety of constraints, such as the range of the measuring equipment, restrictions imposed by the activity in the parking lot, and the time available to complete the experiment during dusk were examined. At this maximum distance, 5 of the 24 subjects (3 of 5 on vehicle 3) achieved perfect performance (no errors on any of the trials), implying that their detection threshold was at least 61 meters. For exploratory purposes, we examined performance from the 19 individuals who did not achieve perfect performance, because their detection thresholds were less than 61 meters. Omitting five subjects left only 3 subjects in the Vehicle 3 group, rendering ANOVA less effective. Therefore, a linear regression analysis was conducted. This allowed the tinting variable to be treated as varying along a continuum rather than as four discrete groups. In these analyses, the slope coefficient for the tinting variable ($B = .23$) was significant at the .05 level for number of errors, and explained 21% of the variance in responses. In other words, for a one unit change in tinting level, the number of errors per trial increased by .23. Thus, the increase in total number of errors for the 24 target-present trials from one tinting level to the next was 5.5 (24 trials x .23 errors per trial). The coefficient for the tinting variable for distance at detection ($B = -7.5$) was marginally significant, $p = .05$. The model explained 20% of the variance in responses. So, for a one-unit change in tinting level, the change in distance was -2.3 meters, implying that the target needed to be 2.3 meters closer. For a three-unit change in tinting (comparing the untinted to the most tinted vehicle), the target needed to be 6.8 meters closer to the vehicle.

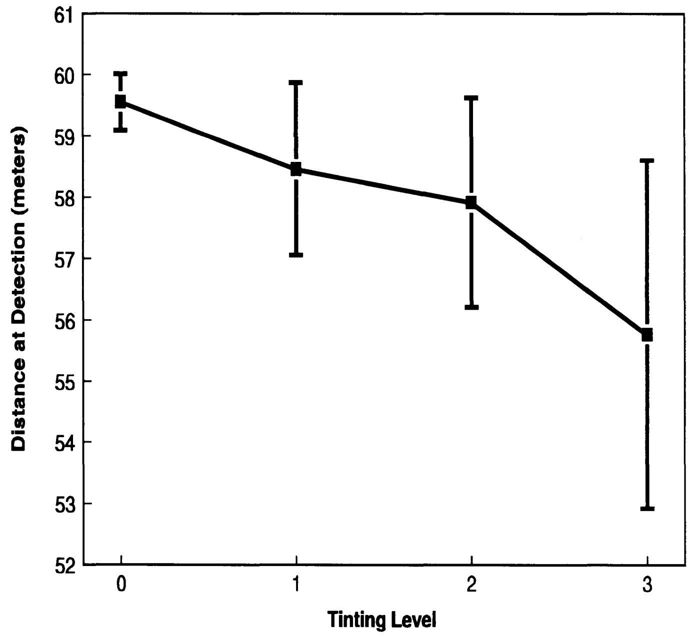

Figure 4. Mean distance at detection for each of the four levels of tinting.

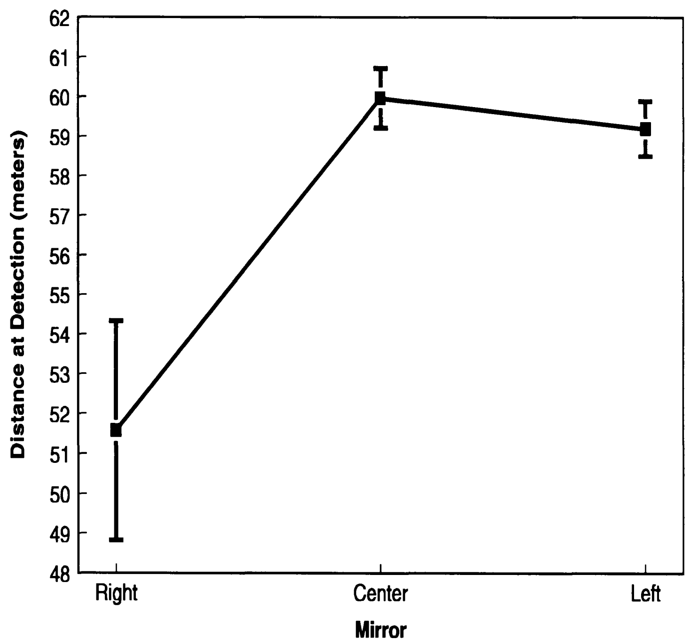

Figure 5. Mean distance at detection for each of the three mirrors.

SUMMARY AND CONCLUSIONS

Increased levels of window tinting were associated with a non-significant increase in the number of failures to detect a pedestrian in rear-view mirrors and with a decrease in the distance needed to detect this target. As in previous studies in which subjects looked forward through tinted windshields (Dunn, 1973; Heath and Finch, 1953), between-subject variability was very high. As can be seen in Figures 2 and 4, this variability increased considerably with level of tinting.

Overall, the study clearly shows that some people were influenced by the levels of window tinting in the experimental situation, and others were not. Five of the 24 subjects had perfect performance at the maximum 61 meter distance, and thus, their performance could not reflect on the influence of tinting. For the remaining subjects, increased levels of window tinting were associated with poorer performance and higher variability.

It is also possible that the order in which drivers normally check their mirrors could have affected performance. Since drivers normally look at the rear-view mirror first, the driver's side mirror second, and the passenger side mirror last, and since the subjects only had two seconds to make their observations, it is possible that less time was allocated to the right-mirror observations, affecting accuracy.

The increase in variability is especially interesting and indicative of the influence of window tinting on target detection. Window tinting interfered with target detection more for some subjects than for others. For the untinted vehicle, there was only one failure to detect the target at a distance of 38 meters or less, whereas for the most tinted vehicle there were 20 detection failures.

In theory, given that window tinting reduces the amount of light available to a driver, window tinting must reduce the likelihood of detecting targets that are near detection threshold without tinting. The current study supports this assumption, but also adds another important consideration. Increasing the level of window tinting is far more disruptive for some people than for others. Discussions about the maximum levels of window tinting should keep this finding in mind. On average, the influence of window tinting on errors and distance to detection was relatively small and non-significant, but its influence on variability was enormous.

Finally, this experimental situation was not representative of all aspects of driving. Most importantly, the subjects in this experiment performed only one task: target detection. In reality, drivers must divide their attention between visual navigation and maintaining an awareness of traffic approaching from the rear. This experimental situation probably exaggerated the distance at which targets would be detected. Whether divided attention would result in poorer performance with increased levels of tinting cannot be ascertained from this study.

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Appendix A

ANOVA Table for Effect of Tinting and Mirror on Mean Number of Misses Per Trial

Source	df	SS	MS	F-ratio	p
Between-subjects factors					
Tinting	3	2.53	.84	.82	.50
Error	20	20.62	1.03		
Total	23				
Within-subjects factors[a]					
Mirror	2	10.56	5.28	10.92	.01
Mirror x Tinting	6	2.28	.38	.78	.59
Error	40	19.33	.48		
Within-subjects factors[b]					
Source	*Num. df*	*Den. df*	*Wilk's lambda*	*F-ratio*	*p*
Mirror	2	19	.58	6.8	.01
Mirror x Tinting	6	38	.70	1.26	.30

[a] The SS and MS values are based on a univariate test.

[b] F-ratio is based on Wilk's lambda (λ), which is a multivariate test and is an estimate of F. F-ratio = $((1 - \lambda) \;/\; \lambda)$ (denominator df / numerator df). This value is reported in the text.

Appendix B

ANOVA Table for Effect of Tinting and Mirror on Distance at Detection

Source	df	SS	MS	F-ratio	p
Between-subjects factors					
Tinting	3	2,618.53	872.84	.77	.52
Error	20	22,694.79	1,134.74		
Total	23				
Within-subjects factors[a]					
Mirror	2	11,126.28	5,563.14	9.51	.01
Mirror x Tinting	6	2,323.21	387.20	.66	.68
Error	40	23,404.39	585.11		
Within-subjects factors[b]					
Source	*Num. Df*	*Den. df*	*Wilk's lambda*	*F-ratio*	*p*
Mirror	2	19	.62	5.94	.01
Mirror x Tinting	6	38	.72	1.13	.30

[a] The SS and MS values are based on a univariate test.

[b] F-ratio is based on Wilk's lambda (λ), which is a multivariate test and is an estimate of F. F-ratio = $((1 - \lambda) \;/\; \lambda)$ (denominator df / numerator df). This value is reported in the text.