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16. Abstract

A static, indoor study was conducted to assess the effects of rear window defroster/defogger line width and separation on the identification of obstacles located to the rear of a motor vehicle. Additional independent variables included participant age, rake angle of the rear window, and target location in the rearward field of view. The targets used in this simulated backing/reversing task, as seen through the interior rearview mirror, were a trash can (low contrast) and a child's bicycle (high contrast). The dependent variables were reaction time to correctly identify the target, and subjective ratings of how easily targets could be seen through the simulated defroster/defogger line patterns.

There were two main findings. First, neither the width nor separation of the opaque lines affected participant reaction time to correctly identify a target, even when the percentage of the rearward view that was obscured by the lines reached 50%. Second, subjective ratings of the ease with which targets could be seen were significantly affected by both the width and separation of the defroster/defogger lines. These results suggest that drivers will object to the increased width and decreased separation of lines before target identification is significantly affected.

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CONTENTS

INTRODUCTION

Background

Although an SAE recommended practice exists concerning the use of electrical circuits on motor vehicle glazing (SAE J216, 1995), very little empirical research has been conducted that investigates their ability to affect visual performance. Electrical circuits located on the surface of, or imbedded in, motor vehicle glazing are most frequently used to promote visibility by removing moisture condensation, frost, and ice films. However, these circuits can also be used as antennas, to carry current for lighting, or other purposes. These circuits can be either opaque or transparent. The SAE recommended practice defines opaque circuits as "small conductive elements (e.g., wires) in or on the plastic interlayer of the laminated safety glazing material or conductors integral with the surface glazing material." The recommended practice further states that "opaque conductors shall be of low reflectivity and of neutral or unobtrusive color." Transparent types of electrical circuits are generally thin electrically conductive films that cover the entire surface of the window, and must comply with Federal Motor Vehicle Safety Standard (FMVSS) 205 regarding luminance transmittance.

This research report examines the effects of the width and separation of opaque rear window circuits on driver visual performance. These circuits are used most frequently for defrosting/defogging rear windows, and often appear to have been painted on the interior surface of the rear window. These opaque electrical circuits will be referred to in this report as "lines." This report does not address transparent electrical circuits, nor does it address the effects of tinted windows or privacy glass.

SAE J216 acknowledges that the use of opaque electrical circuits on the rear windows of motor vehicles may interfere with seeing items in the rearward scene. However, it indicates that "until substantial research data are obtained, which do not exist at the present, limitation in use of electrical circuits must be based on manufacturing processes, practices, and existing data on field of view." Furthermore, SAE J216 states that "this document will be reviewed periodically and revised as additional information becomes available." The specific (and to some extent tentative, in view of the above) recommendations in SAE J216 concerning the use of electrical circuits on rear windows are as follows:

> Opaque electrical circuits shall not exceed 5% of the primary rear vision area of the safety glazing material defined as the field of view of the inside rearview mirror by SAE

J834a and shall consist of conductors no greater than 1 mm (0.04 in) wide and no closer together than 25.4 mm (1.00 in). Defrosting or demisting wire conductors up to 0.035 mm (0.0014 in) in diameter or width, in a "zig-zag" sinusoidal or straight form, with a density of up to 10 wires/cm if vertical and 7 wires/cm if horizontal, are acceptable but shall not impair the vision areas requisite for driving visibility before, during, or after a power cycle.

In other rear vision areas, opaque electrical conductors shall not exceed 6.5% of the remaining area of the rear window.

One of the few pertinent studies on the effects of defroster circuit width and separation (Triggs, 1988) was based upon the effects of wire-mesh stone guards used to prevent broken windshields (used often in Australia). The author reports three experiments that examined whether the presence of a stone guard (wire separation 12 to 13 mm and wire thickness about 1 mm) affected a driver's ability to detect targets of varying size in a driving scene (static test). Triggs hypothesized four possible mechanisms that could affect a driver's ability to detect targets when a stone guard is present: improper accommodation (as had been previously reported by Mandelbaum, 1960), binocular disparity, the need to filter out irrelevant stimuli (as suggested by Treisman, et al., 1983), and an interruption in the global analysis of the scene.

The targets that Triggs used were presented for 300 ms, and could appear in one of four locations. The results of three separate experiments led him to suggest that the effect was not the result of either accommodation or binocular disparity. In one experiment he ruled out the accommodative mechanism, as target detection performance was not affected by eye-to-stone-guard distance (ranging from 0.5 m to 2.5 m). In another experiment, Triggs ruled out binocular disparity as target detection was significantly better in a binocular condition than when it was seen monocularly. In the remaining experiment Triggs reported that the presence of the stone guard (1 m from the subject), as compared to a condition without the stone guard, resulted in a significant reduction in the detection of targets. Triggs therefore concluded that the reduction in target detection was most likely due to either having to filter out the stone guard or the interference of the stone guard with the global analysis of the scene. It has been suggested by Clark (1996) that effects similar to those observed by Triggs could result if drivers attempt to detect obstacles through the interior rearview mirror when items such as restraint systems for parcels or animals are present in the rear of the vehicle.

Another related study was performed by Southall and Burnand (1991). That research examined whether electrically heated windshields, containing fine wires imbedded in the glass, would affect a driver's ability to see during either normal or inclement weather. They conducted laboratory tests of visibility under nighttime driving conditions to examine any effects of glare from oncoming headlamps due to reflection by the wires. In addition, the study also examined whether the driver's ability to see was impaired as a result of reduced light transmission or obscuration of stimuli by the wires under daytime conditions in which visibility was already reduced by fog or snow. Of the 20 subjects, only 6 stated that they noticed the wires imbedded in the windshield, and only one reported any visibility problems associated with their presence. Yet 3 of the 20 subjects stated that they would not want a heated windshield in their cars. There was no measurable change in subjects' visual acuity associated with the use of the electrically heated windshield, nor was there any increased rating of fatigue or discomfort.

The Present Study

This research examines the effects of opaque lines (varying in width and separation) on a driver's ability to rapidly identify a target when using the interior rearview mirror to look through the rear window. On the basis of results reported by Triggs (1988), it might be predicted that visual performance (in this case, target identification) would be degraded by the presence of opaque rear window defroster/defogger lines. For the present study, we created simulated defroster/defogger lines that varied in width and separation. For different combinations of line width and separation, different percentages of the rearward field were obscured from the driver's view. This form of masking—partial obscuration—differs from the use of tinting on motor vehicle windows. Tinting, or privacy glass, has the effect of reducing the luminous transmittance of the entire rearward field of view. In contrast, the lines of defrosters/defoggers typically only affect a small total percentage of the reward view, but where lines are present vision is completely obscured rather than merely reduced.

The task used in the present study was selected to represent a driving situation that is reasonably common and might be influenced by the partial obscuration of the rearward view by defroster/defogger lines. Other tasks, such as detecting the closure rate of following vehicles, would have been reasonable alternatives, but the task used here represents at least one important aspect of driving visual performance. Furthermore, the visual task of stimulus identification is basic enough to make it reasonable to suppose that the results in this task will generalize—at least in a broad outline—to most visual tasks.

METHOD

Participants

Twelve paid participants, all licensed drivers, took part in this study. Six were in a younger age group (23 to 30, mean = 27 years), and six in an older age group (61 to 73, mean = 66.8 years). The participants were balanced for sex.

Equipment and Setup

Participants were seated in a stationary research vehicle. The vehicle was located inside the vehicle-service area of UMTRI. The rear window of this sedan had been removed, and matte-black cloth was draped over the trunk and rear window deck to reduce veiling glare and the superimposition of images. Replacements for the rear window were constructed of 4.7 mm-thick, nontempered, noncoated plate glass. Each piece of glass measured 1.07 m by 0.61 m.

In all, nine rear windows were constructed. Each of them was one of the nine combinations of three line widths (1, 2.5, or 5 mm) and three line separations (5, 15, or 25 mm). Table 1 lists the combinations of line width and separation, and the percentage of the rear window area that was obscured by the simulated defroster/defogger lines. The percentages of obscuration are valid for all rake angles because thickness of the lines (in the dimension normal to the glass surface) was negligible relative to their widths and separations (in the dimension parallel to the glass surface) for the range of rake angles used here. Rake angle always affects width and separation proportionately, leaving percent obscuration unaffected.

The lines were accurately “scribed” onto the plate-glass surfaces by first applying wide strips of opaque, matte-black tape to the glass surface. Using a vernier height gauge on a surface plate, the individual lines were scribed into the tape. This process cut the tape such that the excess could be removed, leaving the remaining tape to form the simulated defroster/defogger lines. The dimensional tolerance for both line width and separation was approximately 0.20 mm. The dimensions provided for line separation in Table 1 are gap dimensions (i.e., the distance between lines) rather than centerline-to-centerline spacing. The nine line width and separation combinations are also represented to dimension in Figure 1.

Table 1
Characteristics of the nine rear windows examined.

Window #	Line Width (mm)	Line Separation (mm)	Obscuration (%)
1	1.0	25.0	3.9
2	1.0	15.0	6.2
3	2.5	25.0	9.0
4	2.5	15.0	14.3
5	5.0	25.0	16.4
6	1.0	5.0	16.7
7	5.0	15.0	25.0
8	2.5	5.0	33.3
9	5.0	5.0	50.0

A matte-black aluminum frame held the glass in place during each trial, and could be adjusted to represent different rake angles (30, 50, and 70 degrees from vertical). The frame was mounted to the rear-window deck and trunk lid of the sedan (Figure 2). The viewing distance between the seated driver and the interior rearview mirror was 0.45 m. The viewing distance between the interior rearview mirror and the base of the simulated rear window was 2.1 m. Because of the way the frame was hinged, the viewing distance between the interior rearview mirror and the top of the rear window varied as a function of the rake angle. However, the distance from the mirror to the bottom of the window remained relatively constant.

A piece of black cloth was used to "frame" the uppermost portion of the rear window such that the opening was approximately 50 mm narrower than with the stock rear window in this vehicle. However, the cloth was only slightly wider than the shade band on the window's edge and did not obstruct the targets.

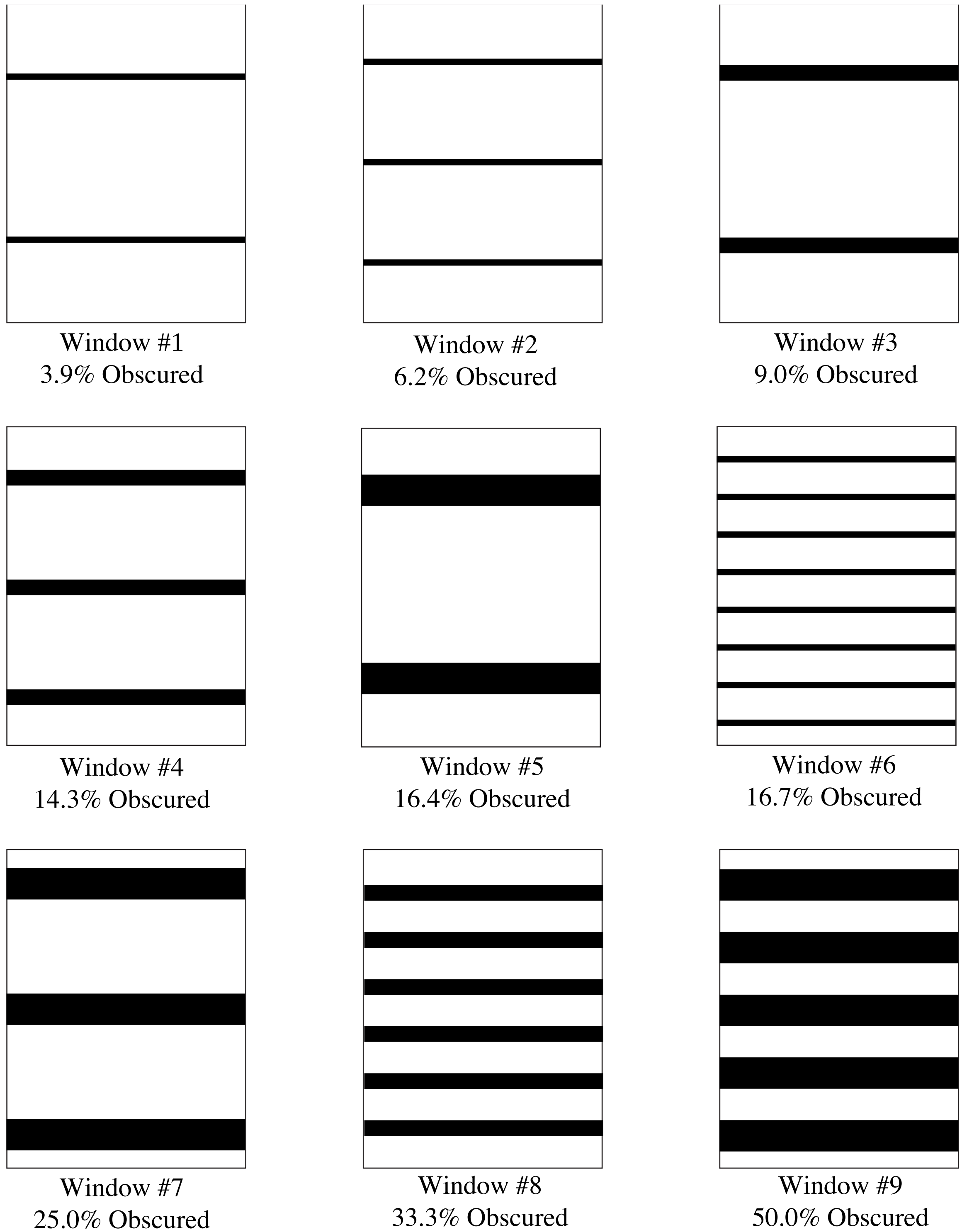

Figure 1. Drawings demonstrating the rear window conditions, showing actual line width and separation dimensions. The overall dimensions for each piece of glass were 1.07 m by 0.61 m.

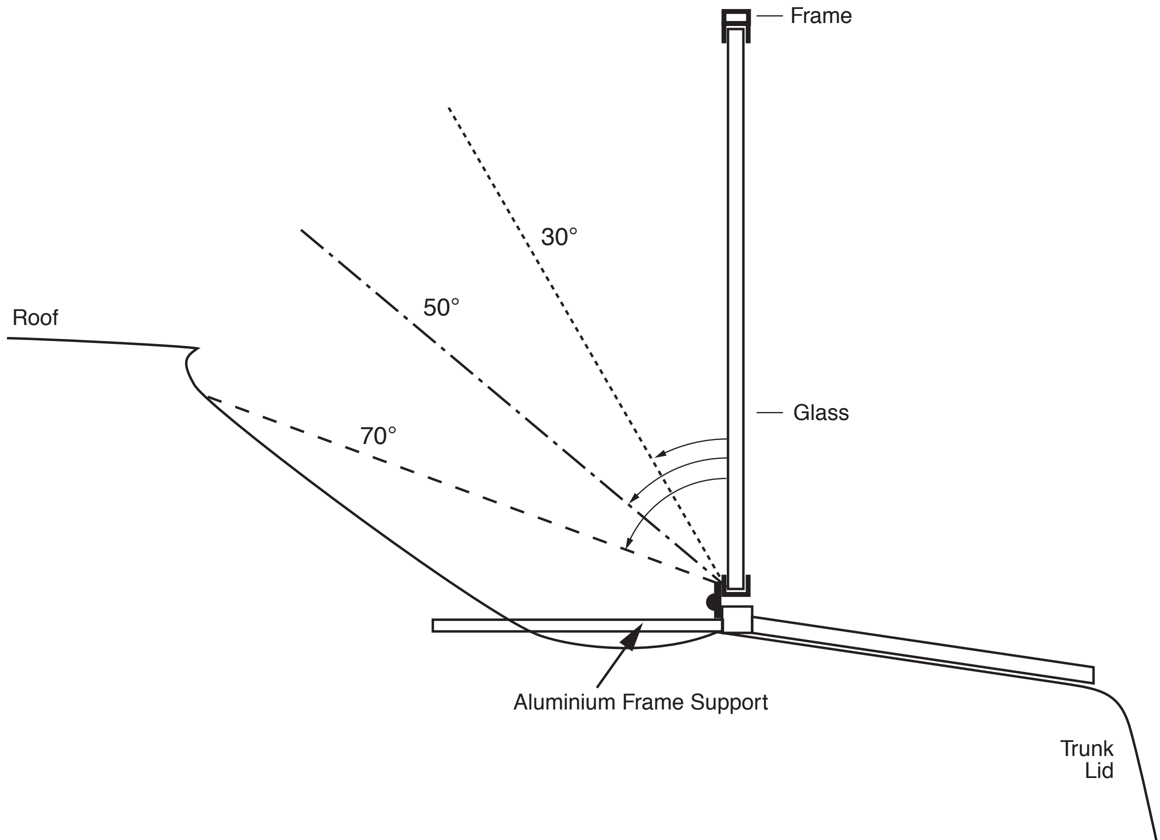

Figure 2. A diagram of the frame that housed simulated rear windows for rake angle adjustment.

The interior, overhead lighting in the test location was on for the duration of the study. The ambient illumination provided by the overhead fluorescent lamps, measured on the vertical surfaces of the targets facing the subject, was about 750 lux. The ambient illumination inside the passenger car cabin, on a vertical surface at the driver's eye location, was about 65 lux.

A neutral background was used as the backdrop for the experiment. This backdrop encompassed the entire rear scene as viewed through the rear window via the interior rearview mirror. Both exterior rearview mirrors were covered to prevent their use by participants. Two objects that were of similar sizes, and thought to be representative of what might be found in a residential driveway, were used as targets. The first object, a plastic gray trash can (0.6 m in diameter and 0.9 m in height), was a low-contrast object relative to the background. The second target, a pink and white child's 16-inch bicycle with training wheels (0.76 m in height at the handlebars and 0.58 m in height at the seat) was selected as a high-contrast target. The targets were placed 10 m behind the rear bumper of the stationary vehicle in one of two locations, 1 m to the left or 1 m to the right of the vehicle's centerline (Figure 3). The location in which targets were presented was balanced across trials for each participant.

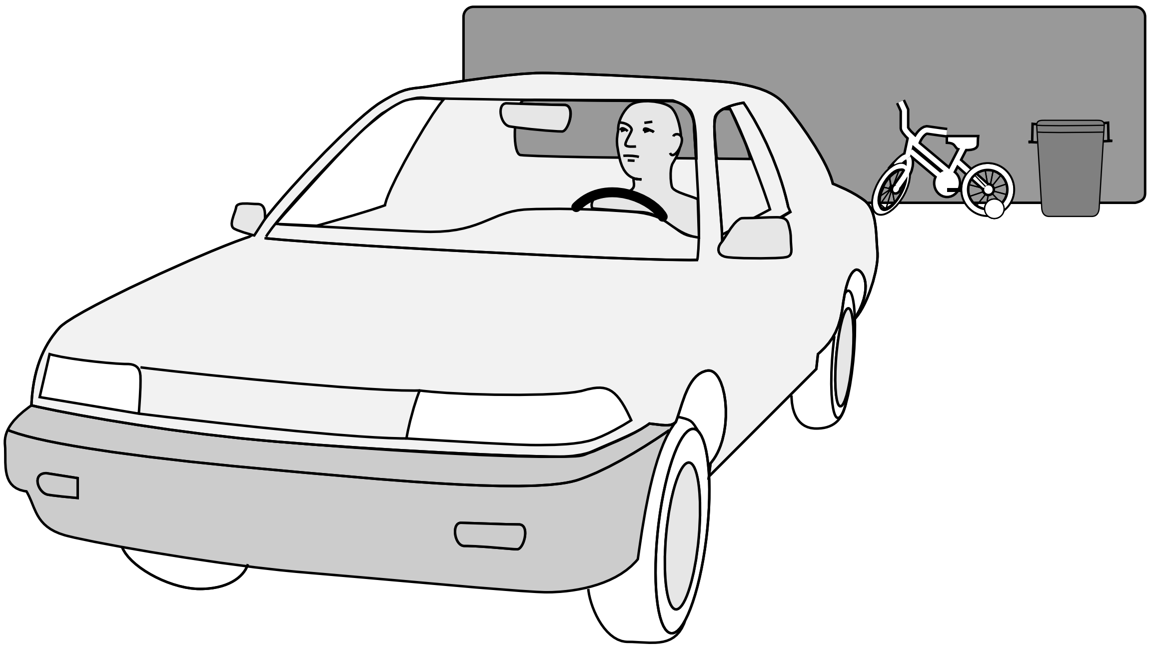

Figure 3. A diagram of the experimental setup. (On each reaction time trial only one of the objects was presented, and its location was either to the left or right of the vehicle centerline.)

Task

The task was a two-alternative forced choice. Participants sat in the driver's seat of the research vehicle and were instructed to look up at the interior rearview mirror at the sound of a computer-generated tone. Further, they were instructed to indicate, through the use of a button box, which target they detected in the rearview mirror. The two buttons on the button box were labeled "Trash Can" and "Bicycle." Each participant experienced several practice trials. The complete instructions were as follows:

> Your task will be to look in the interior rearview mirror and indicate whether you see a child's bicycle or a trash can. When looking in the rearview mirror, please indicate the presence of a bicycle or a trash can by pressing the appropriate button on this button box. Between trials, I will ask you to look down at the car's floorboard. Whenever you hear a computer generated tone, please look into the rearview mirror and as quickly as you can, determine whether there is a bicycle or trash can present, and press the appropriate button.
> Remember to respond as quickly as you can and only look up at the rearview mirror once you have heard the tone.

Each participant experienced 108 trials (9 defroster/defogger line combinations x 3 rake angles x 2 targets x 2 target locations). Trials were presented in nine blocks, each for one combination of line width and separation. The order of these blocks was randomized for each participant. Within each block, the order of the twelve trials (the combinations of rake angle, target, and target location) were randomized.

After each participant completed all 108 reaction time trials, he or she viewed each of the simulated defroster/defogger line combinations, at each of the three rake angles, in order to make subjective assessments regarding the ease with which one could see objects through the various simulated rear windows. Subjective assessments were reported verbally and recorded by an experimenter. Both targets (the bicycle and the trash can) were presented for each of the subjective assessment trials. Assessments were made using the following 9-point scale:

Rate the ease with which you can see objects through the rear window.

1	2	3	4	5	6	7	8	9
very difficult								very easy

RESULTS

Age

Preliminary analyses showed that participant age had no effect on either reaction time or subjective ratings. As a result, in order to increase the power of the remaining analyses, the results were collapsed across participant age, and participant age was eliminated as an independent variable in the remaining analyses.

Reaction Time

For each trial, reaction time and response type (either trash can or bicycle) were recorded. All incorrect responses (there were only 10 incorrect responses for 1296 trials) were omitted from the data analysis. For each participant, mean reaction times were computed for each of the experimental conditions (9 defroster/defogger line combinations x 3 rake angles x 2 targets).

An analysis of variance (ANOVA) was performed on the mean reaction times to examine the effects of defroster/defogger line width, line separation, rake angle, and the target viewed. The findings of greatest interest from this analysis were that neither line width nor line separation had a statistically significant effect on reaction time.

The main effect of rake angle was statistically significant, $F(2, 22) = 3.51$, $p < .05$. Mean reaction times to both targets were shorter for rake angles of 30 degrees than they were for either 50 or 70 degrees (see Figure 4). A Student-Newman-Keuls post-hoc analysis showed that the comparison between mean reaction times to the 30 and 70 degree rake angles (1022 versus 1051 msec) was the only statistically significant pairwise difference.

The main effect of target was also statistically significant, $F(1, 11) = 26.84$, $p < .001$ (see Figure 5). Mean reaction time to the bicycle (high-contrast) was shorter than for the trash can (1011 versus 1060 msec).

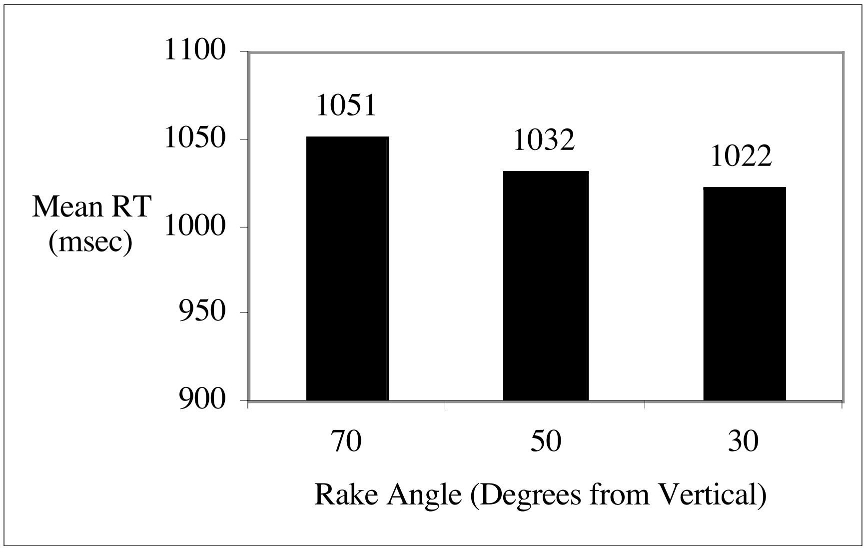

Figure 4. Mean reaction time by rear window rake angle.

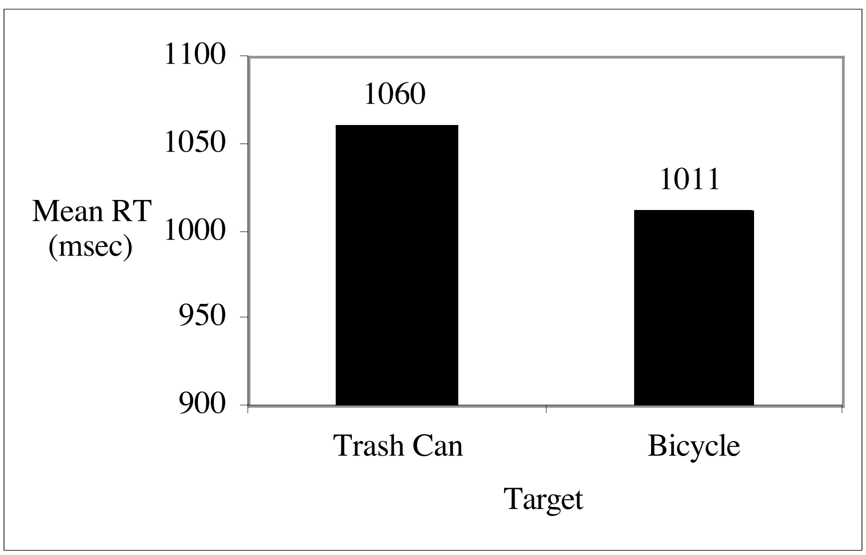

Figure 5. Mean reaction time by target.

Ratings

An analysis of variance (ANOVA) was performed on the subjective ratings to examine the effects of defroster/defogger line width, line separation, and rake angle. The ANOVA resulted in a statistically significant main effect of line width, $F(2, 22) = 28.62$, $p < .0001$. A Student-

Newman-Keuls post-hoc analysis revealed statistically significant differences between all pairwise comparisons of line width (see Figure 6).

In addition, there was a statistically significant main effect of line spacing, $F(2, 22) = 39.37$, $p < .0001$ (see Figure 7). A Student-Newman-Keuls post-hoc analysis revealed that all of the pairwise comparisons between levels of line spacing were significant. The effect of rake angle was not statistically significant.

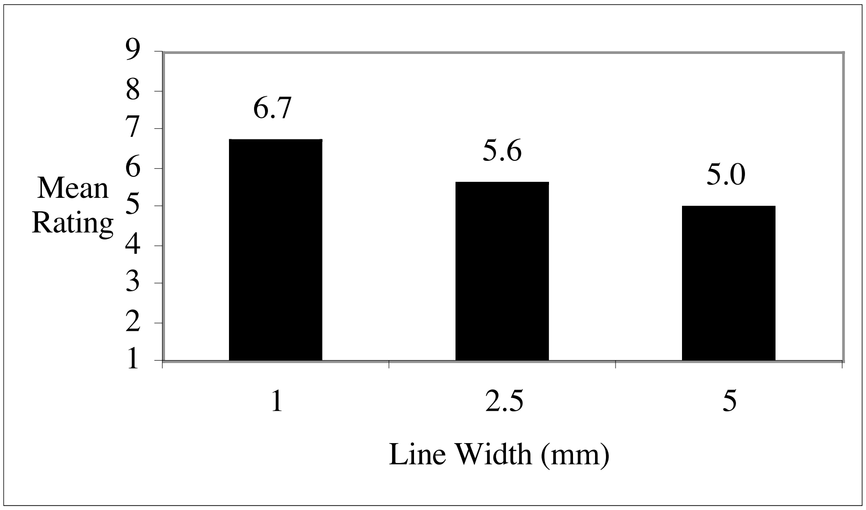

Figure 6. Mean rating by line width (1 = very difficult, 9 = very easy).

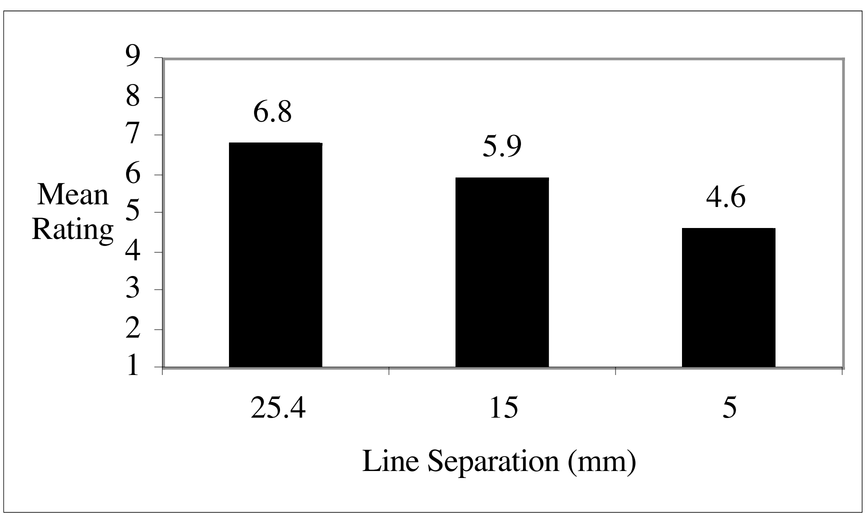

Figure 7. Mean rating by line separation (1 = very difficult, 9 = very easy).

DISCUSSION

Effects of Line Width and Separation

The main findings of this study are that neither line width nor line separation affected participant reaction times, but both affected participant subjective ratings concerning the ease with which targets could be seen. These results suggest that (1) drivers will object to increased width and decreased separation of defroster/defogger lines before target identification is significantly affected, and (2) neither reaction time nor subjective visibility rating alone provides a comprehensive assessment of the ability to see through defroster/defogger lines. Thus, these two measures supplement each other. Furthermore, to the extent that the identification task used in this study captures the essence of real-life visual demands (see below), the present findings indicate that subjective preferences will not allow the use of line widths and separations that would interfere with visual performance.

Validity of the Identification Task

The target-identification task selected for the present study represents one way driver vision might be influenced by obscuration due to defroster/defogger lines. Other scenarios, such as detecting the closure rate of following vehicles could also be considered. However, the visual demands of most situations are probably reasonably well represented by the conditions used here. Moreover, even in cases in which visual demands do differ, the general conclusion of this work—that subjective aspects of driver acceptance will be more sensitive to line width and separation than objective visual performance—may still hold.

The present study was conducted statically, rather than dynamically. Although it might be argued that driving is a dynamic task by its very nature, it is likely that most backing/reversing maneuvers are performed after an initial examination of the rearward scene has been made with the vehicle stationary.

An aspect of defroster/defogger lines that is not considered in this research is the effect they may have on the ability of following drivers to see through a vehicle ahead of them. For example, would increased width or decreased separation of lines make it harder for a following driver to see the rear signals of vehicles further ahead (e.g., high-mounted stop lamps)? Another aspect that is not addressed is the possible effect of increased obscuration of rear windows on the ability of law-enforcement personnel to detect the presence of criminal activity in vehicles. Both of these issues have previously been raised with respect to reduced transmittance of vehicle glazing (e.g., privacy glass).

Possible Mechanisms for the Effect of Rake Angle

In contrast to the results for the line characteristics, rake angle had a significant effect on reaction time, but no effect on subjective ratings. The reaction time effects of rake angle could be due either to changes in width and separation of the lines or to changes in photometric properties of the rear window. As depicted in Figure 8, the apparent width and separation of rear window defroster/defogger lines decrease with increased rake angle of the rear window. (This effect will be slightly smaller at the top of the window than at the bottom because the top of the window moves closer to the driver with increasing rake angle. This decrease in distance partly offsets the effect of tilt itself on the projected width and separation of the lines.) Rake angle also influences reflectance, transmittance, and veiling glare. For example, as the rake angle of the rear window increases (relative to vertical), the amount of ambient light that is reflected, rather than transmitted, increases. In addition, the optical path that ambient light must travel through the glazing increases as the rake angle increases. The increases in optical path length and reflectance contribute to an overall reduction in light transmittance. Finally, increased rake angle also results in increased levels of veiling luminance (reflected/superimposed images) on the rear window (Schumann et al., 1996). The present study does not allow us to identify which of these aspects of rake angle may be the source of the effect on reaction time.

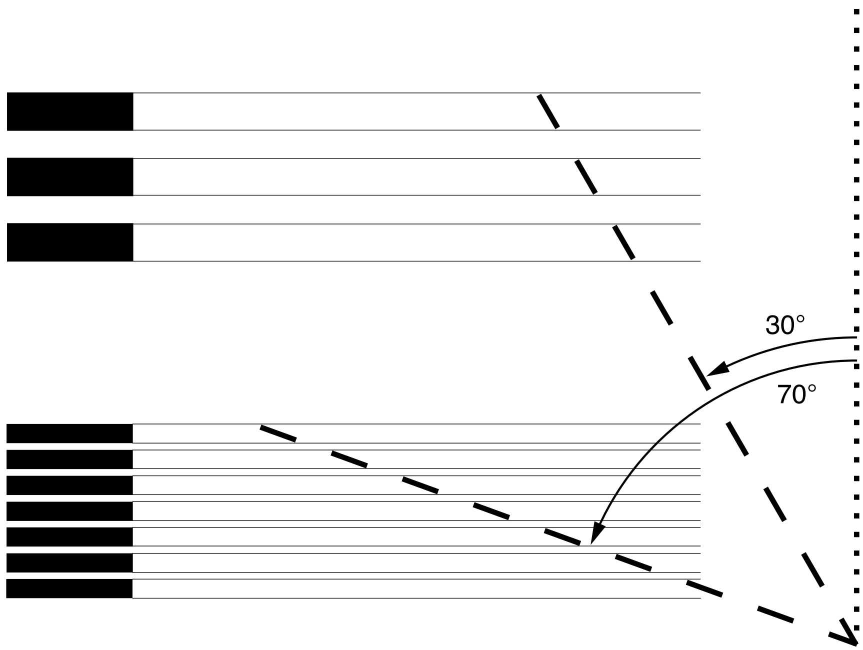

Figure 8. A schematic of the effect of rake angle on the apparent width and separation of rear window defroster/defogger lines. The dotted line indicates vertical. The two dashed lines represent side views of a set of lines at two different rake angles. The grids at the left of the figure represent a driver’s view of the rear window at those two rake angles. For illustrative purposes, the width/separation ratio of the lines has been made relatively high.

SUMMARY

A static, indoor study was conducted to assess the effects of rear window defroster/defogger line width and separation on the identification of obstacles located to the rear of a motor vehicle. Additional independent variables included participant age, rake angle of the rear window, and target location in the rearward field of view. The targets used in this simulated backing/reversing task, as seen through the interior rearview mirror, were a trash can (low contrast) and a child's bicycle (high contrast). The dependent variables were reaction time to correctly identify the target, and subjective ratings of how easily targets could be seen through the simulated defroster/defogger line patterns.

There were two main findings. First, neither the width nor separation of the opaque lines affected participant reaction time to correctly identify a target, even when the percentage of the rearward view that was obscured by the lines reached 50%. Second, subjective ratings of the ease with which targets could be seen were significantly affected by both the width and separation of the defroster/defogger lines. These results suggest that drivers will object to the increased width and decreased separation of lines before target identification is significantly affected.

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