# ON-THE-ROAD VISUAL PERFORMANCE WITH ELECTROCHROMIC REARVIEW MIRRORS

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16. Abstract

This study was part of a series of studies on variable-reflectance rearview mirrors. Previous work included laboratory studies of human visual performance, field collection of photometric data, and mathematical modeling of the visual benefits of variable-reflectance mirrors. We extended that work in this study by collecting photometric and human-performance data while subjects drove in actual traffic.

Three mirror conditions were investigated: (1) fixed-reflectance mirrors in the center and driver-side positions, (2) a variable-reflectance mirror in the center with a fixed-reflectance mirror on the driver side, and (3) variable-reflectance mirrors in both positions. The fixed and variable reflectivities were produced by the same mirrors by overriding the circuitry that normally controlled reflectance in the variable mode.

Results indicated that variable-reflectance mirrors provided a substantial reduction in discomfort glare without a measurable reduction in subjective ratings of rearward seeing ability. They did not cause major improvements in forward seeing (in agreement with previous laboratory and modeling results).

The present study is inconclusive with respect to the benefits of a variable-reflectance driver-side mirror relative to a fixed-reflectance mirror with 50-percent reflectance. The reason for this is that the particular driver-side mirror used in this study became noticeably green in the low-reflectivity state, and thus low reflectivity was confounded with a color change. The effect of the driver-side mirror should be clarified by further research.

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# Contents

# Introduction

Over the past several years the growing availability of variable-reflectance rearview mirrors has offered drivers a new option for limiting glare from rearview mirrors that is more flexible than that provided by two-state, mechanically switched, prism mirrors. Much of the past work on the effects of rearview mirror reflectivity on driver vision suggests that variable-reflectance mirrors offer drivers improved visual performance, primarily because the low-reflectance level of prism mirrors (4 percent) is too low for most conditions (Mansour, 1971; Olson, Jorgeson, & Mortimer, 1974; Ueno & Otsuka, 1988).

The potential refinement in glare control offered by variable-reflectance mirrors relative to prism mirrors has increased the need to understand the visual factors that might determine the optimal level of mirror reflectivity for a given set of lighting conditions. We have undertaken a program of research to identify, quantify, and comprehensively model those factors (Flannagan & Sivak, 1994). The present study is a field test of some of the conclusions that have emerged from that work.

Our previous work has been based on a working hypothesis that optimal rearview mirror reflectivity is determined by a tradeoff among three factors: (1) subjective discomfort caused by glare from mirrors, (2) forward seeing ability, and (3) rearward seeing ability. The first two factors are improved by reducing mirror reflectivity; the necessity to make a tradeoff arises because the third is harmed by reduced reflectivity. In previous studies, we have argued for a number of tentative conclusions about the effects of mirror reflectivity, including that 4-percent reflectivity is in fact needlessly low for glare protection in most circumstances (Flannagan & Sivak, 1990), that the limits on glare required to preserve forward seeing ability are normally dominated by the limits needed to reduce subjective discomfort (Flannagan, Sivak, & Gellatly, 1992), and that flexible control of reflectivity is needed for both the center and driver-side mirrors to achieve optimal control of discomfort (Flannagan & Sivak, 1994).

Those conclusions have been based on measurements made in the laboratory and under controlled field conditions, combined with mathematical models of visual performance. In the present study we had drivers make assessments of the three factors involved in the central tradeoff (discomfort from rearview-mirror glare, forward seeing ability, and rearward seeing ability) while they drove an instrumented vehicle in actual nighttime traffic. The vehicle was equipped with variable-reflectance mirrors in the center and driver-side positions. Control circuitry allowed the mirrors to be set to fixed reflectivity levels that are typical of the high-reflectivity levels of conventional mirrors (80 percent for the center mirror and 50 percent for the driver-side mirror), or to vary in response to prevailing lighting conditions. In the variable-reflectivity mode the reflectivity levels of the mirrors were determined by control circuitry, supplied by the mirror manufacturer, that was responsive to both ambient light level, as detected by a forward-oriented sensor, and glare from the rear, as detected by a rearward-oriented sensor.

The vehicle was instrumented to collect photometric information about the luminance of the forward pavement and about illuminance from rearward sources of glare (primarily the headlamps of following vehicles).

All measurements were made in actual traffic at night. Subjects drove a planned course that included a mix of conditions: city streets, expressways, and rural roads. The levels of traffic and fixed lighting varied considerably.

## Method

### *Subjects*

There were two age groups, each with an equal number of males and females. There were six people in the younger group, ranging from 18 to 25 with a mean age of 22.0, and six in the older group, ranging from 59 to 66 with a mean age of 63.5. All were licensed drivers. None had previous experience with variable-reflectance mirrors.

### *Instrumented vehicle*

The vehicle was a 1993 Nissan Altima. It was equipped with photometers to measure simultaneously the luminance of the pavement in front of the vehicle and illumination from the rear that could cause rearview-mirror glare (primarily from the headlamps of following vehicles). We had used the vehicle previously, in a slightly different configuration, to collect photometric data in a rearview mirror study that did not involve human subjects (Flannagan & Sivak, 1994). The configuration of photometers on the vehicle is shown in Figure 1.

The luminance of the pavement in front of the vehicle, as viewed from approximately the driver's eye position, was measured with a Minolta LS-100 luminance meter with a 1-degree field of view and a nominal sensitivity limit of 0.001 $cd/m^2$. The meter was positioned so that the far edge of the field of view was aligned with a point on level pavement 50 m in front of the driver's eye position, and directly ahead of the driver. The patch of pavement measured by the luminance meter extended from that point toward the vehicle for about 21.7 m, with a maximum width of 0.7 m, as is shown in Figure 2. This area contains the mean visual fixation point for drivers on straight roads using U.S. low-beam headlamps as measured by Graf and Krebs (1976).

The luminance meter was mounted near the front passenger-seat eye position, as show in Figure 1. It was turned slightly to the left (about 1 degree) so that it was aimed at the pavement directly in front of the driver. It was aimed through the windshield, with approximately the same line of sight as the driver, except for being displaced laterally to the passenger seat.

Illuminance from the rear that could potentially cause rearview mirror glare was measured by a Minolta T-1 illuminance meter, fitted with a standard cosine receptor. The meter has a nominal sensitivity limit of 0.01 lx. It was installed inside a set of baffles on the roof of the vehicle, just above the rear window, as shown in plan view in Figure 1. In the rooftop position the photometer assembly did not interfere with the driver's field of view. The baffles excluded light that originated from locations that would not be visible to a driver through the interior rearview mirror. In order to check the angles of acceptance of this configuration, we made a series of static tests in which we compared lux readings from the photometer in the roof position to lux readings taken at the position of the center rearview mirror. We positioned a glare vehicle behind the instrumented vehicle at distances of 1, 2, 3, 4, 5, 7.5, 10, and 50 m. The glare vehicle was located either directly behind the instrumented vehicle or laterally displaced to the left or right by the width of a typical lane (3.7 m). We took measurements for both the low- and high-beam headlamps of the glare vehicle. Although the absolute levels were not in perfect agreement, largely because of rear-window transmittance, the overall correlation between readings taken at the two positions was very high, even for the shorter separations at which the parallax difference between the two photometer positions was greater. The readings are shown in Figure 3.

### *Mirrors*

The rearview mirrors in the center and driver-side (left) positions were electrochromic mirrors. They were supplied specifically for the test vehicle by a mirror manufacturer. They were configured with standard control circuitry, including both a forward-oriented light sensor for measuring the level of ambient illumination and a rearward-oriented sensor for measuring potential glare light from the rear. The sensors were both mounted on the center mirror, and in normal operation the reflectance of the driver-side mirror was controlled by the same signal as the center mirror. The passenger-side mirror was a conventional convex mirror. For half the subjects it was effectively eliminated by covering it with an opaque shield. For the other subjects it was used normally.

Additional control circuitry could override the normal operation of the electrochromic mirrors. Overall there were three control modes: (1) the driver-side mirror was at a fixed reflectance of 50 percent and the center mirror was at 80 percent (hereafter designated the 50/80 condition), (2) the driver-side mirror was fixed at 50 percent and the reflectance of the center mirror varied according to the normal control signal (the 50/Var condition), or (3) the reflectance of both the driver-side and center mirrors varied with the normal control signal (the Var/Var condition). All reflectance levels were measured with a standard tungsten-halogen headlamp bulb as the light source.

The center and driver-side mirrors differed somewhat in color in their low-reflectivity states. Spectral reflectance functions for the two mirrors are shown in Figure 4.

### *Test route*

The main test route consisted of a mix of expressways, city streets, and rural roads in and around the city of Ann Arbor. It was 96 km long. A separate, shorter route (13 km) was used for practice trials.

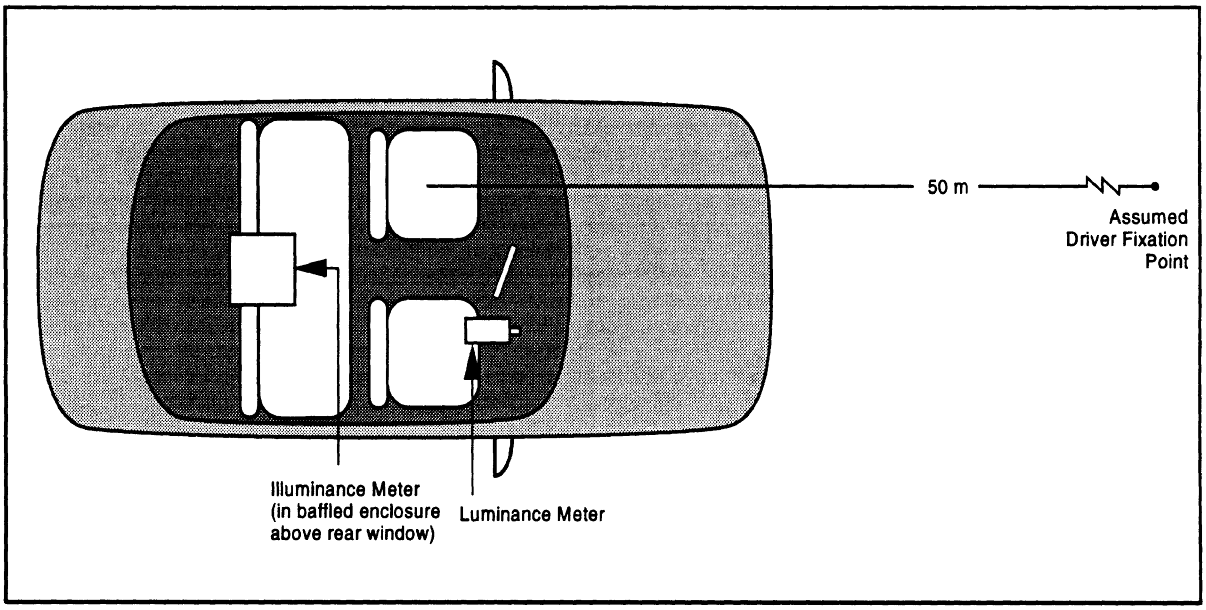


Figure 1. Plan view of the on-board photometric instrumentation.

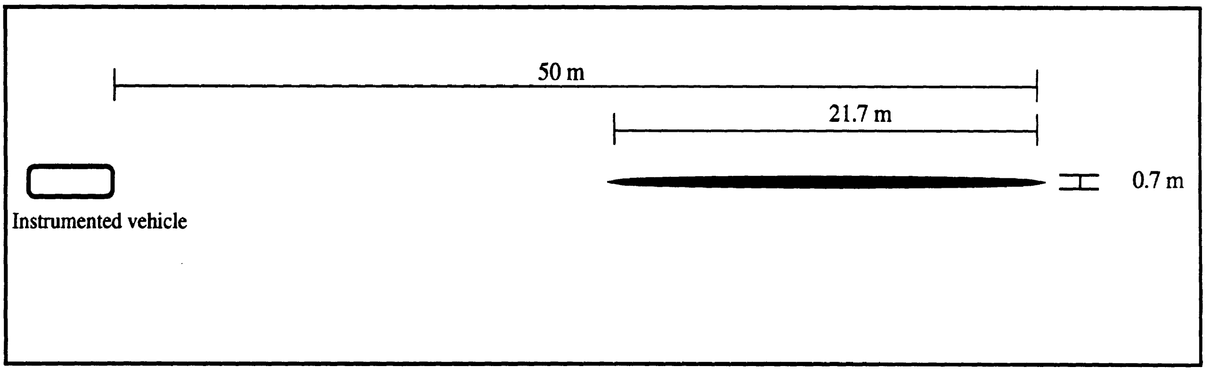


Figure 2. Plan view of the area of pavement from which luminance was measured by the spot photometer. The thin black oval is the projection of a round, 1-degree field of view directed approximately along the driver's line of sight.

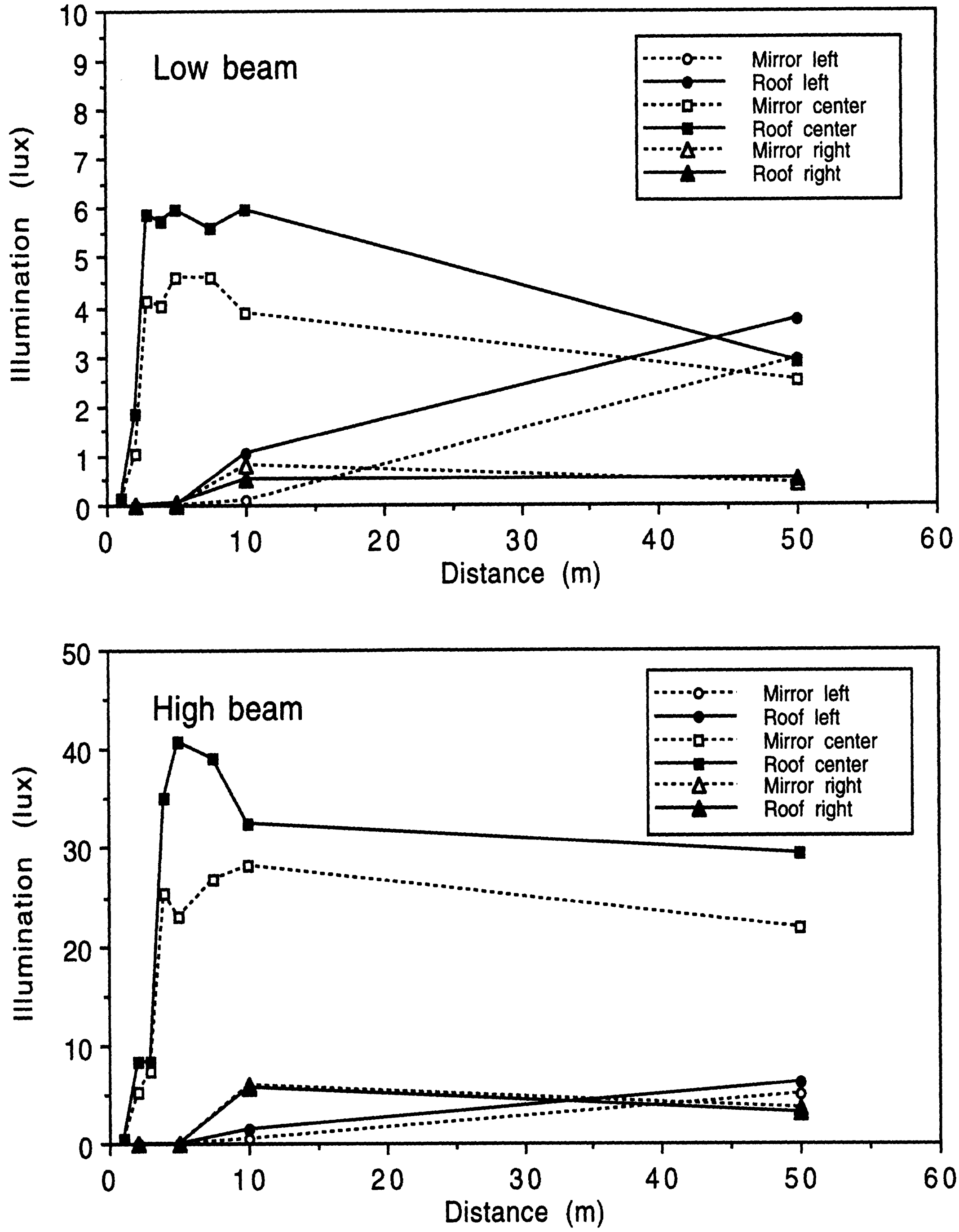


Figure 3. Illuminance readings (lux) taken by the baffled photometer at the position of the center rearview mirror and at the rooftop position, which was used so as not to block the driver's view of the center mirror. Illumination was provided by a single vehicle using either low or high beams, at various distances behind the instrumented vehicle, and in the same lane or displaced one lane to the left or right. The labels in the legend refer to the location of the photometer on the instrumented vehicle and the lateral location of the glare vehicle relative to the instrumented vehicle. The upper panel shows data for the low beams of the glare vehicle and the lower panel shows data for the high beams.

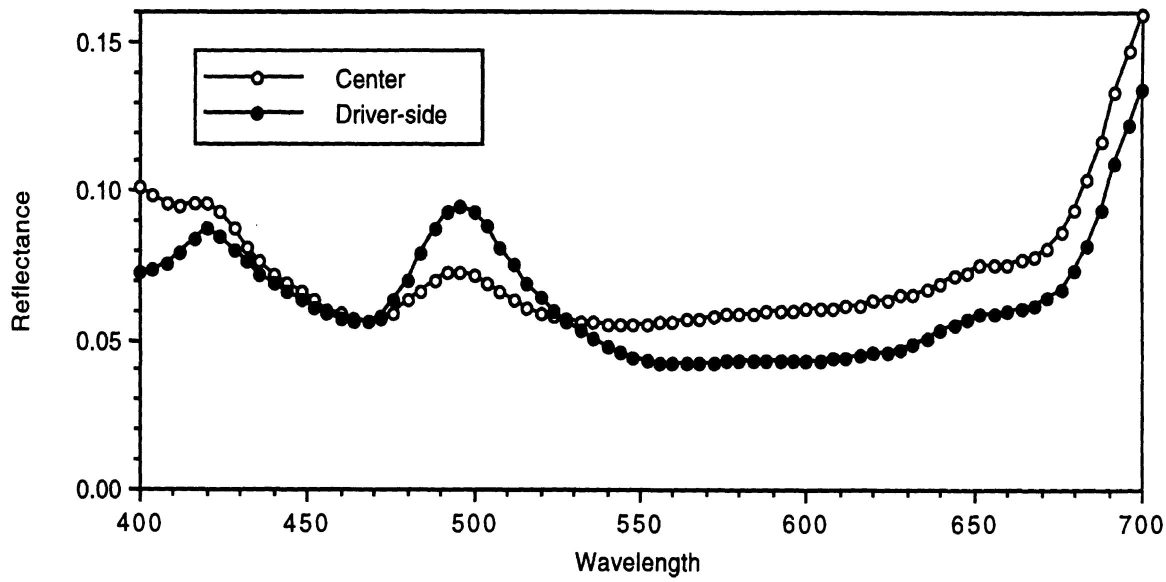


Figure 4. Spectral reflectance functions in the visible region for the center and driver-side rearview mirrors in low-reflectivity states.

## *Procedure*

Subjects were run individually. Sessions began about a half hour after sunset and lasted about two and a half hours. The subjects drove the instrumented vehicle on a predetermined route. Two experimenters rode with them to collect data and to instruct them about the route. Subjects first drove a short practice route for about 20 minutes and then the main test route for about 90 minutes.

Subjects were informed that the study concerned an innovative rearview mirror system, but otherwise were not told about the purposes of the study or the nature of the mirror system.

Every two minutes during the practice and main driving periods, the photometers collected the current forward pavement luminance and the current level of illumination from the rear. At the same times, the subjects made ratings of three visual quantities: (1) the level of discomfort that they were currently experiencing from rearview-mirror glare, (2) their ability to see the road ahead of them, and (3) their ability to see to the rear. They made their three ratings in that order, using numerical scales from 1 to 10 that had been described to them in the initial instructions. Each of the scales had two verbal anchors, for the values 1 and 10. The anchors for the discomfort scale were "Very little" (1) and "Very much" (10). For both of the seeing-ability scales the anchors were "Very poorly" (1) and "Very well" (10). The instructions emphasized that for discomfort glare subjects should, as much as possible, rate the combined effect of glare from all the mirrors and disregard any discomfort that they believed was attributable to glare from oncoming traffic.

The main driving period was divided into nine 10-minute blocks. Because trials occurred every two minutes there were five trials per block. The mode of mirror operation (50/80, 50/Var, or Var/Var; as described above) was changed between blocks. The order of mirror modes was balanced across subjects, and the ordering was always such that each mirror condition occurred once in each third of the main driving period (once among the first three 10-minute blocks, once among the second three, and once among the third three).

The transitions between mirror modes were not identified for the subjects. The subjects were not even informed that the mirrors would be operated in different modes. Our intent was that on each trial the subjects should simply rate their current experience, with no explicit knowledge of the experimental manipulation of the mirrors.

For half of the subjects the convex passenger-side (right) mirror was covered with an opaque shield. For the other half it was uncovered and (like the other mirrors) was adjusted for normal aim by the subjects before they began driving.

After they finished driving, the subjects were systematically debriefed with a written questionnaire that asked progressively more specific questions about mirror performance. The questionnaire consisted of two pages, with a single general question on the first page and three more specific questions on the second. Subjects were not allowed to see the second page until they had answered the first, more general question. The questions are shown in Table 1.

Table 1.
Questions on the written questionnaire given to subjects after they finished the driving task.

| |
|---|
| First page:<br><br>During the study you were using new advanced mirror systems on the car you were driving. Did you notice anything interesting about the mirrors? If so, what did you notice? |
| Second page:<br><br>The mirrors that you were using used new technology to change reflectivity during the study, so that at times they were more reflective than at others. Did you notice anything interesting about this reflectivity change? If so, what did you notice?<br><br>Did you have any preferences for different reflectivities? If so, what did you like? Dislike?<br><br>What further comments do you have on the mirror systems? |

# Results

## *Photometric Data*

Figure 5 shows histograms of the photometric data, combined over all subjects. Individual panels of the figure show illuminance values (in log lux) and luminance values (in log $cd/m^2$), summarized in terms of which mirror mode was activated at the times the measurements were taken. As would be expected, because of the counterbalancing of order of the mirror modes across subjects, the distributions are approximately the same for the three different mirror modes. The relationship between illuminance and luminance values, combined over all subjects and mirror modes, is shown in Figure 6. The pattern is very similar to previous data we have collected (Flannagan & Sivak, 1994). The overall correlation coefficient is .37. The nature of the relationship is that low values of glare illuminance and high values of pavement luminance do not occur together.

## *Subject ratings of visual performance*

Figures 6, 7, and 8 show the main effects of mirror mode on the three visual-performance ratings. There is a substantial and statistically significant effect on discomfort glare ratings, $F(2,16) = 6.75, p < .01$. In contrast to the mode in which both mirrors are of fixed reflectance and the center mirror reflectance is relatively high (50/80), both of the variable modes result in substantially reduced discomfort glare. However, there is no evidence for a further reduction in discomfort glare when the driver-side mirror is variable rather than fixed at 50 percent. In fact, there is a slight trend (not statistically significant) for more discomfort when that mirror is variable.

Neither the effect of mirror mode on forward seeing, $F(2,16) = 2.43$, nor the effect of mirror mode on rearward seeing, $F(2,16) = 0.80$, was statistically significant.

No interactions involving age or sex were significant, indicating that the pattern of results was similar for all combinations of age and sex.

There were no significant differences depending on whether the passenger-side mirror was covered or not.

# Discussion

These field results support a number of the conclusions about mirror performance that our previous laboratory and analytical work has suggested. Most importantly, they indicate that variable-reflectance mirrors are capable of substantially reducing discomfort glare without a significant reduction in the principal function of rearview mirrors—allowing drivers to see to the rear. There is a slight tendency, evident in Figure 9, for drivers to rate rearward vision lower when rearview-mirror reflectance varies rather than remaining fixed at a high level. However, the trend is not significant, indicating that any such difference is substantially less salient to drivers than the reduction in discomfort glare, which was significant when measured under the same conditions with the same statistical power.

Also in agreement with our previous work, there was no evidence for a perceived increase in forward seeing ability when glare was reduced by variable-reflectance mirrors. Modeling of the disability effects of glare based on a veiling luminance from light scattered in the eye predicts that to be the case (Flannagan et al., 1992). Although there should be some effect of rearview mirror glare on forward seeing ability, it should be much smaller than the effects of oncoming glare because of the much larger angles between the glare sources (i.e., the mirrors) and the stimuli to be seen (e.g., a distant pedestrian on the road ahead). For both the driver-side and center mirrors those angles are on the order of 45 degrees.

A discrepancy between these results and our previous work is the lack of evidence for a difference in rated discomfort glare depending on whether the driver-side mirror is fixed at 50-percent reflectance or variable. Our modeling, based on the work of Schmidt-Clausen and Bindels (1974), indicates that there should be a substantial further reduction in discomfort glare if a variable-reflectance driver-side mirror is added to a system with a variable-reflectance center mirror and a 50-percent driver-side mirror (Flannagan & Sivak, 1994). There are several possible explanations for the failure to find an effect. It is possible that subjects simply weight glare from the center mirror more highly. The Schmidt-Clausen and Bindels model weights glare sources equally if they are at the same visual eccentricity (as is approximately true for the driver-side and center mirrors). The instructions emphasized that subjects should rate glare from all mirrors together, but that may be a difficult instruction to follow.

Alternatively, the color of the driver-side mirror used in this study may have had an effect on drivers' discomfort glare ratings. On the written debriefing forms, which did not explicitly ask about color, eight of the twelve subjects spontaneously mentioned the green color of the driver-side mirror (which can be inferred from the data in Figure 4). Most of those comments were neutral, but two subjects explicitly connected the green color to an increased perception of glare. The green tint becomes more noticeable as the mirror reflectance goes down, and thus it may have partially counteracted what otherwise would have been a perceived reduction in discomfort resulting from the lower reflectance. Therefore, we do not consider the present results conclusive on the issue of fixed versus variable driver-side reflectance. The issue of how much additional benefit a variable-reflectance driver-side mirror adds to a system with a variable-reflectance center mirror should be studied further.

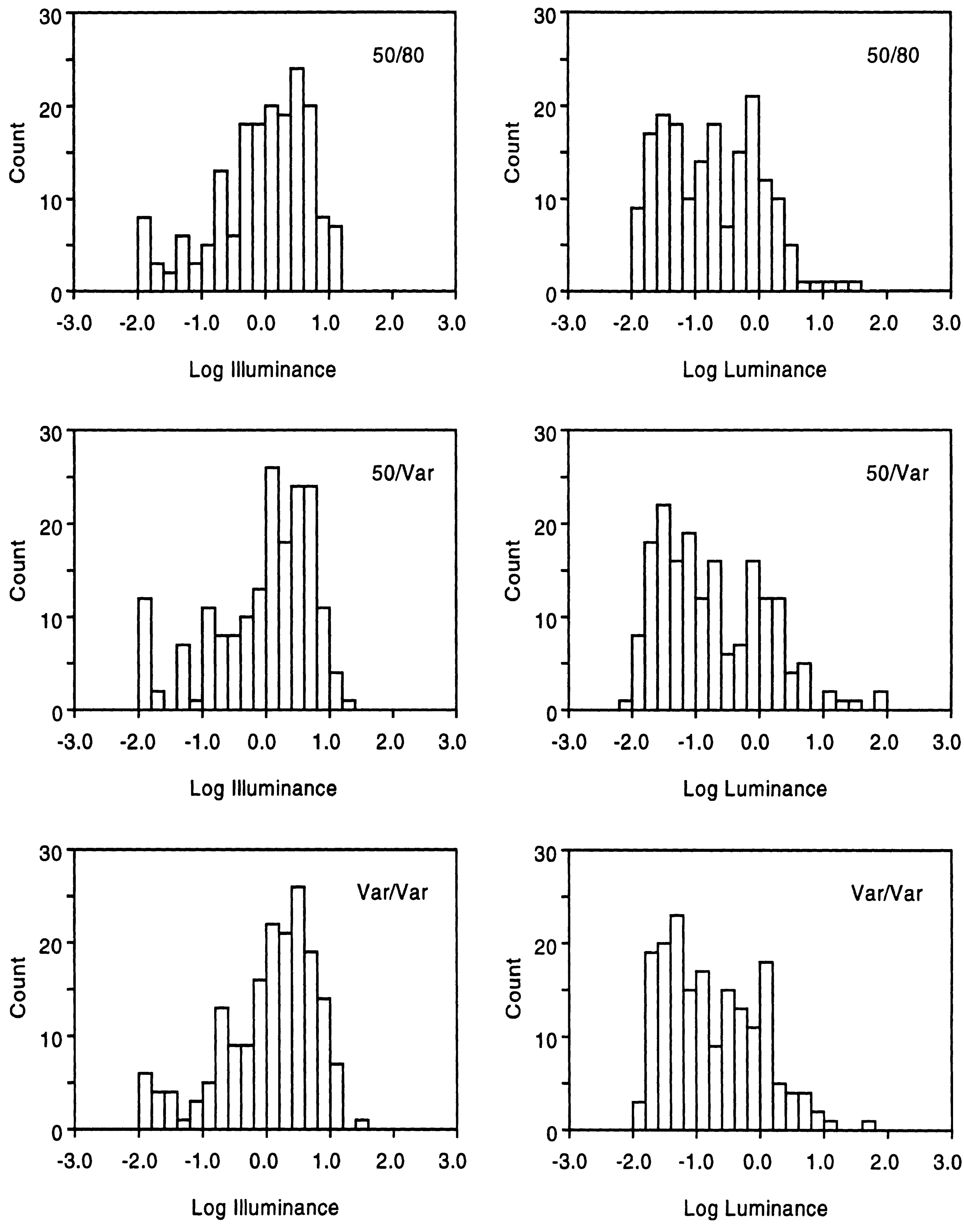


Figure 5. Histograms of photometry values (log illuminance [lux] from rearward glare sources and log luminance [cd/m2] of forward pavement) for the three mirror conditions.

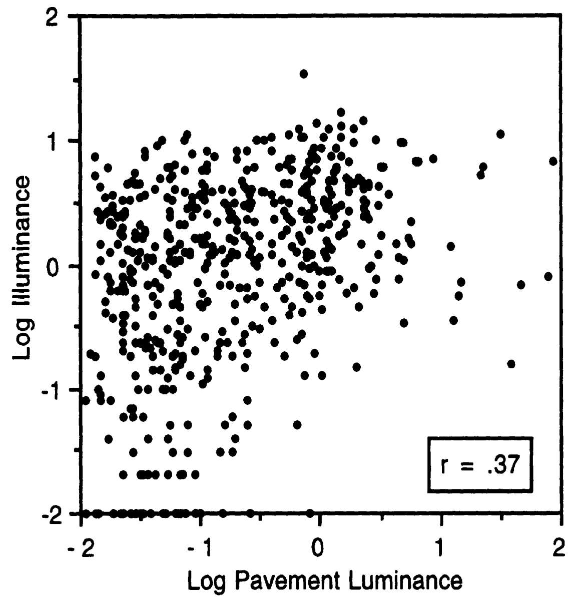


Figure 6. The relationship between log illuminance (lux) from the rear and log pavement luminance (cd/$m^2$) over all photometric measurements made in the study (540 pairs of values).

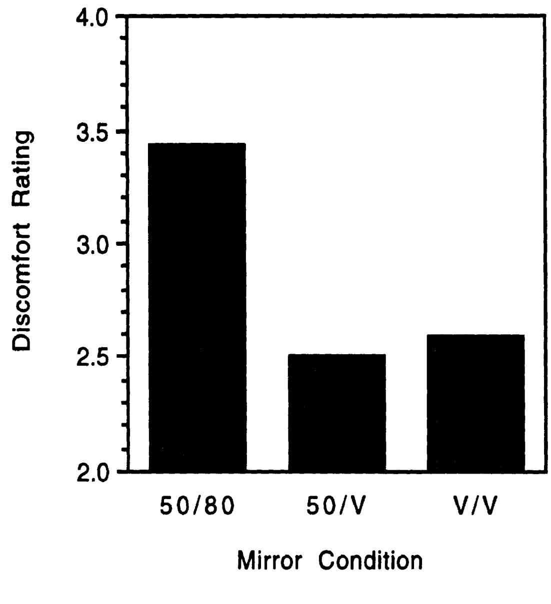


Figure 7. The main effect of mirror condition on ratings of discomfort from rearview mirror glare.

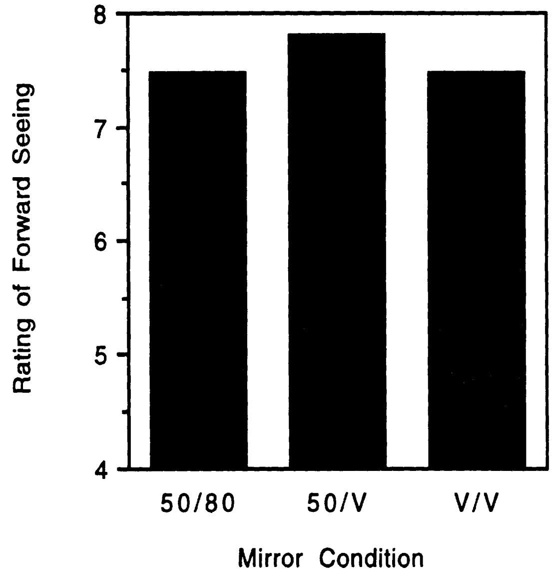


Figure 8. The main effect of mirror condition on ratings of forward seeing ability.

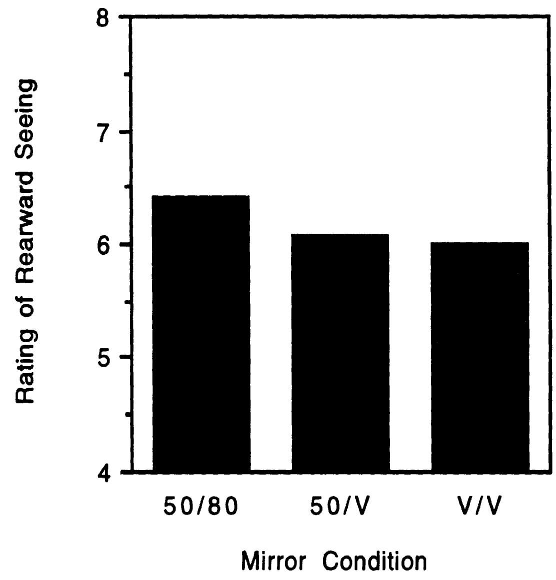


Figure 9. The main effect of mirror condition on ratings of rearward seeing ability.

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