REARVIEW MIRROR REFLECTIVITY AND THE TRADEOFF BETWEEN FORWARD AND REARWARD VISION

Michael J. Flannagan
Michael Sivak
Andrew W. Gellatly

The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109-2150
U.S.A.

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Michael J. Flannagan, Michael Sivak, and Andrew W. Gellatly

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16. Abstract

In a laboratory study and in a mathematical modeling effort, we evaluated the effects of rearview mirror reflectivity on older and younger subjects' seeing ability under conditions designed to simulate night driving with headlamp glare present in the mirror. Rearview mirror reflectivity was varied while observers were required to detect both rearward stimuli seen through the mirror and forward stimuli seen directly. Lower reflectivity resulted in greater ability to see forward and reduced ability to see to the rear. The reduction in ability to see to the rear was much larger than the improvement in forward seeing. The results of the modeling and the laboratory study were in broad agreement, although there were some significant discrepancies. Although the present results cannot be used to make specific recommendations for rearview mirror reflectivity, they suggest that the reduction in rearward vision as reflectivity is lowered should be considered carefully.

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rearview mirrors, reflectivity, contrast threshold, vision modeling

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INTRODUCTION

The increasing availability of technologies such as electrochromics and liquid crystals for control of rearview mirror reflectivity promises dramatically improved control of glare from mirrors. These technologies allow mirror reflectivity to be set anywhere within a wide and continuous range, and allow automatic adjustment in response to changing lighting conditions. This improved level of control has increased the value of understanding the factors that determine optimal mirror reflectivity for a given set of lighting conditions.

We have framed the problem of determining optimal reflectivity in terms of three rearview mirror functions: (1) providing rearward vision, (2) protecting forward vision from the disabling effects of glare from the rear, and (3) protecting the driver from the discomforting effects of that glare. All three of these functions are affected by mirror reflectivity. The directions of these effects are such that the first, and most basic, function of providing rearward vision must be traded off with the other two: increased reflectivity leads to better rearward vision, but more disability in forward vision and more discomfort.

In these terms, the problem of optimizing reflectivity level is simple in principle. We simply have to know how to quantify the three functions in commensurable ways, and how to give them valid relative weighting. If we could do those things, the optimal reflectivity level for any given set of lighting conditions could be determined straightforwardly. In practice, however, the measurement and the weighting of those functions are problematical in a number of ways.

In an earlier study (Flannagan, Sivak, & Gellatly, 1991) we simultaneously measured rearward vision and discomfort glare and found that, contrary to a standard model of discomfort glare (Schmidt-Clausen & Bindels, 1974) but consistent with other work in our laboratory (Sivak, Flannagan, Ensing, & Simmons, 1991), discomfort seemed to be affected by rearward visibility. Specifically, the benefit in discomfort that resulted from reduced mirror reflectivity was less than predicted from the Schmidt-Clausen and Bindels model of discomfort glare. Our interpretation was that the reduction in illuminance at the eye from the glare source was partially offset by a reduction in ability to see to the rear.

Perhaps the most difficult problem for the reflectivity optimization problem as we have formulated it, however, is the difficulty of defining what a driver needs to see to the rear and how well he or she needs to see it. One simple view of the issue, which must be at least partially correct, is that rear vision is simply not a problem even at the extremely low, four-percent reflectivity level that is provided by the antiglare setting of prism mirrors. According to this view, the only important things drivers need to see in rearview mirrors are moving vehicles, and in the dark conditions in which glare reduction is an issue those vehicles will always be marked by lamps bright enough to be seen even at four-percent reflectivity. However, there is evidence that drivers need to see, or at least think they need to see, better than this view suggests. In a study of how drivers use prism mirrors (Flannagan & Sivak, 1990), we found that 33% of drivers restrict or forgo entirely the use of the low reflectivity setting because of inability to see to the rear.

There are a number of ways in which rear vision requirements may be more demanding than the analysis described above suggests. A view of headlamps alone, perhaps supplemented by running lights, may not provide what drivers believe to be adequate information about the speeds, distances, or types of following vehicles. The quality or salience of information about following vehicles, beyond whether it is in principle available at all, may be especially important to drivers in situations with high mental workload, such as changing lanes in dense traffic. Unfortunately, situations with high traffic density, and therefore high workload, are the situations in which the problem of rearview mirror glare is worst. It is possible that the ability to see empty pavement, as a positive indication of the absence of a vehicle, is important to drivers. There are also situations in which a vehicle's headlamps are out of the field of view provided by a mirror, but the side of the vehicle is still in. In those situations potentially useful information could be obscured by low mirror reflectivity.

Beyond the difficulties involved in measuring discomfort and rearward vision, there is the closely related problem of how to assign meaningful relative weights to those factors and to forward vision. Unless all of these issues are adequately addressed it will not be possible to solve the reflectivity optimization problem as we have formulated it. In view of the difficulties, it is tempting to abandon the attempt to achieve a formally rational, quantitative answer to the problem of how to control mirror reflectivity, and adopt a reasonable heuristic. Specifically, the ill-defined nature of rearward vision needs—and the fact that in an informal, nonquantitative sense the proper weighting for forward vision must greatly exceed the proper weighting for rearward vision—lead naturally to the heuristic of establishing a minimum acceptable level of forward vision and then adjusting reflectivity to maintain at least that level with no actual evaluation of how rearward vision is being affected. This is essentially the approach of Helder (1987), who argued that a minimum acceptable level of forward seeing is naturally established by a strong nonlinearity, described by Olson and Sivak (1984), in the function relating the threshold for forward seeing at a given ambient luminance to glare from rearview mirrors.

This or similar heuristics are probably quite good in most situations, but it seems to us that it nevertheless may be worth pursuing the more formal approach to see what insights even a partial solution might give. Specifically, we are concerned that without a formal consideration of rearward vision needs, that function (which is after all the only basic function of rearview mirrors) may be implicitly undervalued in the way reflectivity is controlled. This may be especially important in situations in which glare from the rear and the need to see to the rear are both high, such as when attempting a lane change on a multilane highway in dense traffic.

Our approach has been to use mathematical modeling to explore the broad outlines of the reflectivity optimization problem. Although there are no precise answers to questions about what stimuli drivers need to see behind them, how often they need to see them, and how well they need to see them, we have made some assumptions about what type of stimuli might matter, and then used this type of modeling to explore the effects of changing reflectivity.

There exist mathematical models that can be used to predict how reflectivity will affect each of the three functions of rearview mirrors discussed above. They have been used extensively in the domain of headlighting (e.g., Bhise et al., 1977), and their extension to rearview mirrors is straightforward. However, as mentioned above, a standard model of discomfort glare seems to be systematically violated in the case of glare from rearview mirrors of changing reflectivity (Flannagan et al., 1991). For this reason, we have concentrated on a portion of the overall optimization problem: the tradeoff between forward and rearward seeing.

The visibility modeling that we have done is based on a model published by the Commission Internationale de l'Eclairage (CIE) (1981). Our formulation follows the use of the model as described by Farber (1988) for use in modeling headlamp performance. The factors taken into account by the model are: the age of the observer, the percentile of the observer within his or her age group in terms of visual performance, the size of the stimulus to be detected (in terms of solid angle subtended), the luminances of the stimulus and of the background against which it appears, the illumination at the observer's eye by a glare source, and the angle subtended at the eye of the observer between the glare source and the stimulus. We extended the model to mirrors simply by multiplying all the photometric measures of images seen through the mirror by the reflectivity of the mirror.

In the remainder of this report we will describe an exploration of the tradeoff between forward and rearward seeing in a specific scenario that we designed to be reasonably representative of actual driving. We implemented this scenario as a laboratory experiment and used mathematical modeling to generate predictions based on the specific parameters of the laboratory setup. In the scenario, a driver using low beam headlamps on a straight, level road without fixed lighting is exposed to glare from an interior rearview mirror while attempting to see a forward stimulus (representing a pedestrian standing beside the road) and a rearward stimulus (representing the side panel of a vehicle in an adjacent lane). Mirror reflectivity is varied and its effects on the luminance contrast necessary to see each of the stimuli are observed. In the discussion to follow, we will compare the results of the experiment to the mathematical predictions; and discuss the implications of the results of this experiment in particular, and this type of modeling in general, for mirror performance in actual driving.

METHOD

Subjects

Twenty paid subjects served in this experiment, ten in a younger group (20 to 25 years old) and ten in an older group (over 60). All subjects had natural or corrected visual acuity of 20/30 or better as measured by a test using Landolt rings.

Equipment

A schematic diagram of the laboratory setup is shown in Figure 1. The subject was seated in a mockup of a 1985 Chrysler Laser equipped with an electrochromic rearview mirror. The mirror was connected to a voltage source that allowed any one of three preset voltages to be applied to the mirror, thereby setting its reflectivity at one of three levels. The reflectivity levels were chosen to be spaced approximately equally on a logarithmic scale: 0.73, 0.21, and 0.06. There was no window glass in the mockup.

In front of the subject, at a distance of 3.66 m from the subject's eye point, there was a white screen. A second white screen was located behind the subject. The distance to that screen was also 3.66 m, measured as the sum of the distances from the eye to the mirror and from the mirror to the screen.

Three slide projectors were used. Two were random access projectors, mounted on top of the automobile mockup. They were stacked one above the other as diagrammed in Figure 1, and each was aimed at one of the two screens. The third projector was positioned behind the rear screen, with its lens aimed through a small circular hole in the screen. This projector was used to provide a source of glare that would be visible to the subject through the rearview mirror. All three projectors were equipped with electronically controlled shutters.

Stimuli

The front and rear screens were indirectly, and approximately evenly, illuminated by a set of incandescent lamps shielded by baffles. Each screen had a luminance of 1.0 cd/m^2. This value has been offered as characteristic of the state of visual adaptation of a driver using low beam headlamps on a road with no fixed lighting (Olson, Aoki, Battle, & Flannagan, 1990).

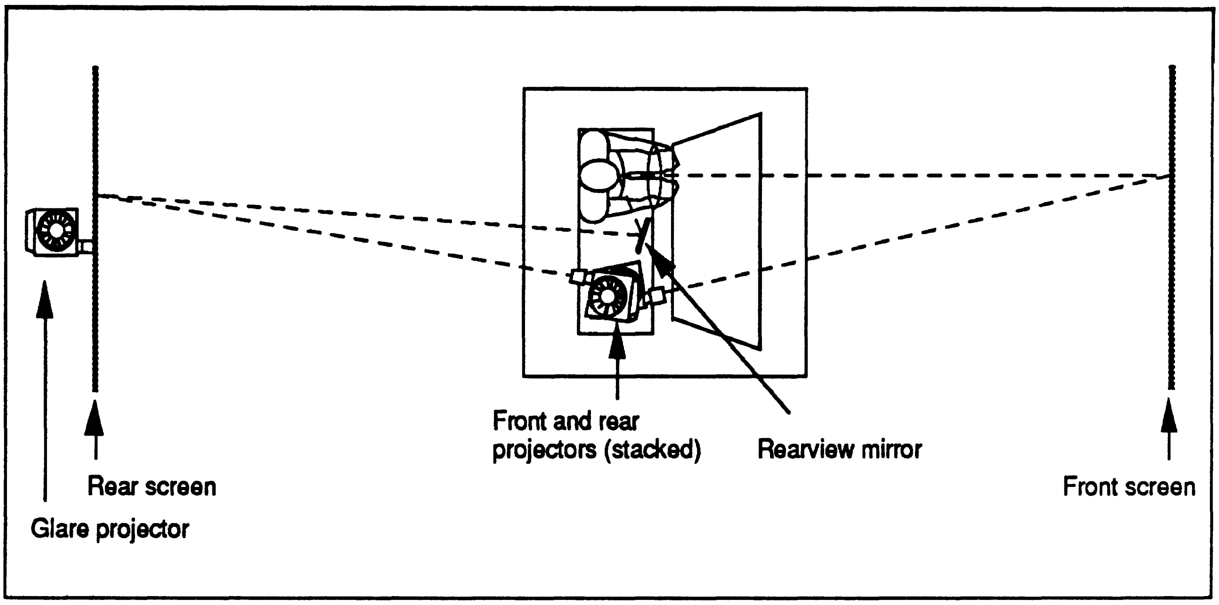

Figure 1. A diagram of the experimental setup. Dimensions are approximately to scale. The dotted lines represent the subject's lines of sight to the stimulus positions (directly to the front stimulus and through the mirror to the rear stimulus) and the projection paths.

The front screen was marked in black ink with lines depicting the side and center markings of a two-lane road. The lines were drawn to appear as they would from the perspective of a driver on an actual road. We used the lines primarily to give the subject a stable frame of reference to aid in focusing attention on the location where the stimulus to be detected would appear. The random-access slide projector pointing toward the front screen projected a pedestrian silhouette, shown in Figure 2. The size and location of the silhouette were consistent with the image of an actual pedestrian 1.83 m tall, standing 0.91 m beyond the right edge of a lane 3.66 m wide, 137 m from the driver's eye point on a straight and level road. The image was 49 mm high, subtending vertically a visual angle of 0.76 deg. The total solid angle subtended by the irregularly shaped figure was 0.15 deg^2. The silhouette appeared as a brighter white area on the white screen. The approximate geometry of the subject's forward view is shown in Figure 3. The visual angle between the glare source and the pedestrian silhouette was about 42 deg.

The subject's view to the rear is shown in Figure 4. (Each eye actually had a slightly different view. Figure 4 shows the view approximately as it would be seen from the midpoint between the subject's eyes.) The glare source was centered in the mirror vertically and horizontally. The second random access projector was used to project a rectangle onto the rear screen. Like the pedestrian silhouette, this stimulus appeared as a brighter white area on the white screen. The rectangle appeared to the left of the glare source from the subject's point of view through the mirror (i.e., if the subject had reversed his or her right-left perspective by turning to look directly at the stimulus it then would have been seen to the right of the glare source). The rectangle was 16.4 cm high (subtending 2.57 deg of visual angle) and 26.4 cm wide (4.13 deg). It subtended a solid angle of 10.6 deg^2. Its center was at the same height as the glare source. Its near and far edges were 20.3 cm (3.17 deg) and 46.7 cm (7.27 deg), respectively, from the center of the glare source.

To control stimulus luminance, the projectors for the front (pedestrian silhouette) and rear (rectangle) stimuli were each equipped with a variable voltage control for the bulb and a set of 21 neutral density filters, mounted in a standard slide tray. The voltage to the bulb was set only at the beginning of a subject's session, and was used as a coarse adjustment to get the stimuli near the subject's detection threshold. During the session, luminance levels were controlled by using the random access mechanism to select among the neutral density filters. The sets of filters were the same for both projectors. They ranged from density values of 0.0 (actually an empty slide holder) to 2.0 in 0.1 steps. That corresponds to a range in transmission from 100% to 1% in steps that differ by a constant factor of 1.26.

During actual stimulus presentation subjects saw the images from the projectors as luminance increments over the existing background levels. In order to measure the luminance increments of the front and rear stimuli we measured them with no other lights on. For the younger subjects the maximum luminance increments (using the 0.0 density slides) were set to 0.095 cd/m^2 for the front stimulus and 0.80 cd/m^2 for the rear stimulus. With these levels, the adjustment permitted by the neutral density filters was sufficient to encompass the thresholds of all the younger subjects.

Because we expected the older subjects to vary more in their detection thresholds, we set the projector voltages individually for each subject by using a quick method-of-limits procedure just before the staircases began. We determined each subject's front and rear thresholds approximately and then set the voltages so that the ranges of neutral density filters would be roughly centered on those thresholds. The maximum luminance increment levels (using the 0.0 density slides) set in this way averaged 0.14 cd/m^2 for the front stimulus and 0.76 cd/m^2 for the rear stimulus. After making these individual voltage settings, the adjustment permitted by the neutral density filters was sufficient to encompass the thresholds of all the older subjects as well.

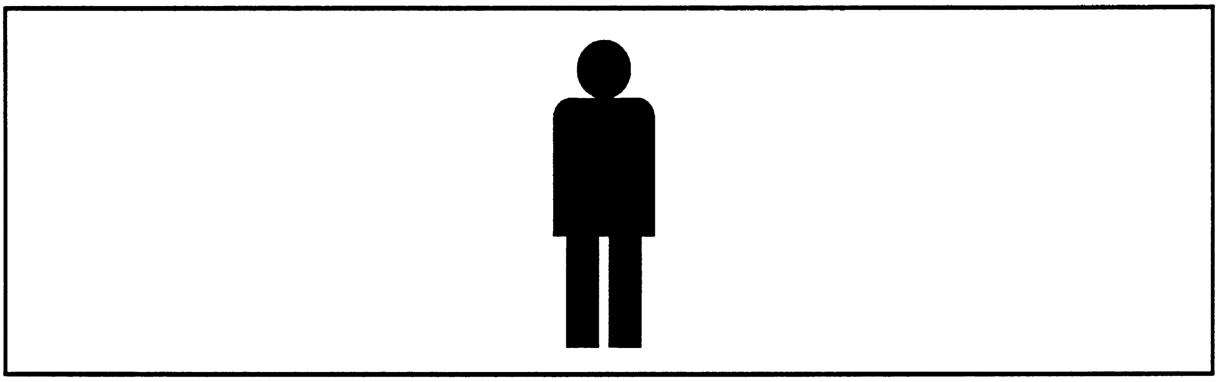

Figure 2. The pedestrian silhouette that was projected onto the front screen.

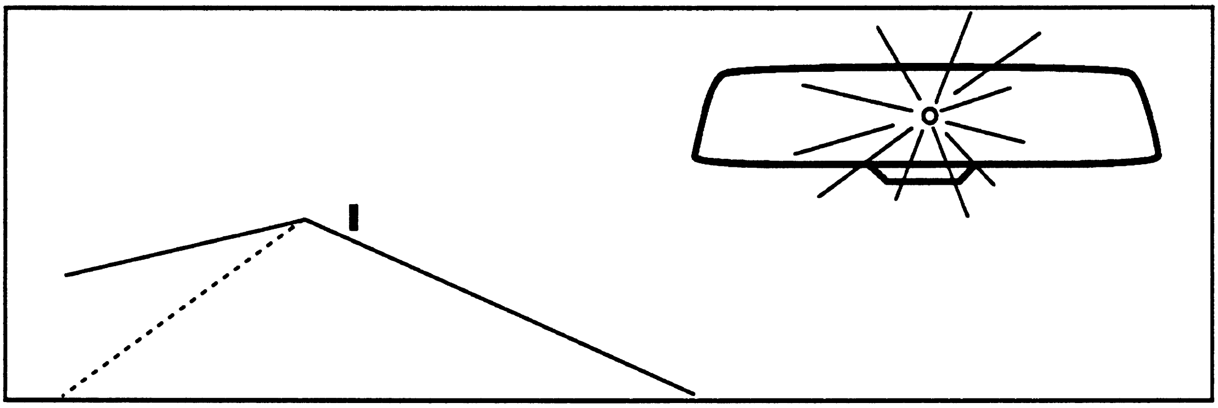

Figure 3. The subject's forward view, approximately to scale, showing glare from the rearview mirror. The small black rectangle represents the size and position of the pedestrian silhouette. The silhouette was projected as a white luminous increment on an evenly lighted white screen. The road edge and center lines were drawn on the screen permanently in black ink.

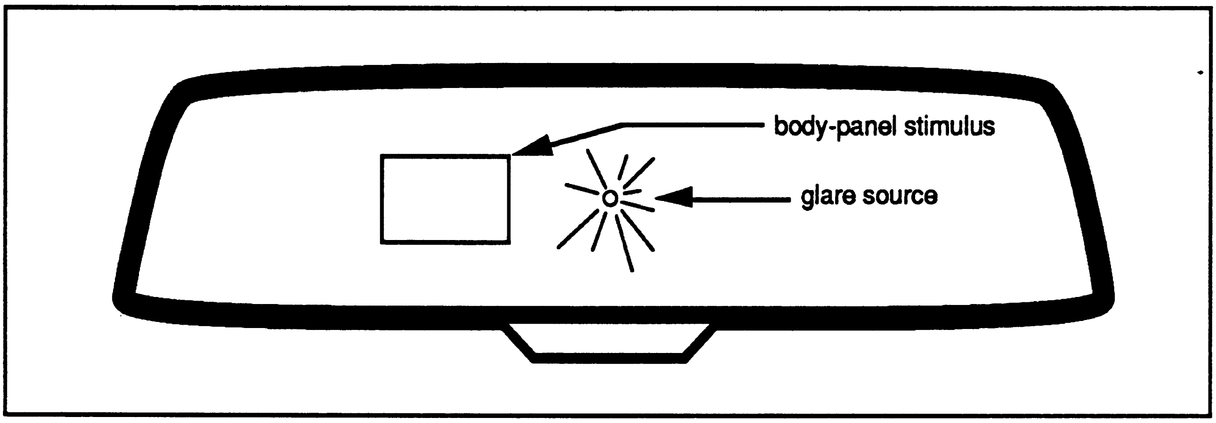

Figure 4. The subject's rearward view, showing the locations and sizes of the glare source and the rectangular body-panel stimulus.

Glare

No standard slides were used in the glare projector. Instead, it was fitted with a large stop so that it would produce a wide cone of light directed at the automobile mockup and centered on the rearview mirror. It was fitted with a neutral density filter that remained in place throughout the experiment. The intrinsic intensity of the glare source in the direction of the mirror was thus constant throughout the study. That intensity would have produced 7.65 lux at the observer's eyes if the mirror reflectivity had been 1.0. This level is probably often encountered in the real world (Olson & Sivak, 1984). The opening of the shutter on the glare projector was circular and 2.54 cm in diameter. The glare source thus subtended 0.40 deg at the subject's eye point.

Three glare levels were produced by the combination of the three rearview mirror reflectivities and the single glare source intensity. The lux values at the subject's eye point are given in Table 1.

Table 1
Lux values at the subject's eye point corresponding to the three levels of mirror reflectivity.

Reflectivity	Illuminance (lx)
0.73	5.58
0.21	1.60
0.06	0.45

Staircases

Visual detection thresholds were determined using random double staircase procedures (Cornsweet, 1962). A staircase procedure involves an algorithm to adjust a stimulus level over a series of trials. On each trial the subject makes one of two responses (as in this case the subject said that the stimulus could be seen or not). The stimulus level presented on the next trial of the staircase is stepped up or down based on the subject's response. In this case the luminance level was increased when the stimulus was not detected and decreased when it was.

Eventually the staircase should stabilize at the subject's threshold, providing a measure of that threshold. In the variation of this procedure used here—a random double staircase—there are two independent sequences of stimuli, each following the rules outlined above. In the order of stimuli presented to the subject, trials from the two sequences are randomly intermixed so that it is difficult or impossible for the subject to notice the contingencies between responses and subsequent stimuli.

A pair of staircases was run for each combination of mirror reflectivity level and direction of stimulus (front or rear). In each pair one staircase started with the 2.0 neutral density filter and one started with the 0.0 filter. Luminance levels were initially stepped up or down by 0.3 density units. When each staircase produced its first reversal (e.g., for the staircases that started with the 0.0 density slide the first reversal was always the first failure to detect the stimulus in that staircase after a initial string of detections) the step size was changed to 0.1 density units. Trials continued to be chosen randomly from the two staircases until a stopping criterion of five reversals in each staircase was reached. The threshold estimate was derived by computing the geometric mean of the luminance values presented on the trials that produced the last four reversals in each individual staircase. Because each staircase had at least five reversals this eliminated any effect of the change in step size.

Design

Each subject was given all six combinations of the three levels of mirror reflectivity and the two stimulus directions (front or rear). Note that mirror reflectivity and glare level covary. There was one major between-subjects variable, age.

Procedure

Subjects were tested individually. At the beginning of a session the subject was seated in the automobile mockup and the overhead lights were turned off, leaving the relatively dim light level that was used during data collection. While the subject was adapting to this light level, the experimenter read a set of instructions to the subject and attended to a variety of details. Data collection began after about 10 minutes of adaptation.

During the instructions the front and rear stimuli were shown to the subject. The instructions emphasized that the stimuli would stay the same in shape, size, and location; but that they would vary in intensity from trial to trial. The subject was asked to adjust the rearview mirror so that the glare source would appear centered, and then not to move to avoid the glare when it appeared. The subject always knew before a trial in which location a stimulus would appear, and he or she was asked to look at that location and to avoid looking directly at the glare source.

Trials were run in six blocks, one for each of the combinations of mirror reflectivity and stimulus direction. The subject was informed about the location of the relevant stimulus at the beginning of each block, but was not told explicitly about the reflectivity of the mirror. Because each block involved running a double staircase until the stopping condition was met, the number of trials per block varied. The number of trials per block was typically about 25, and the interval between trials averaged about 15 seconds. The order of the six blocks was randomized for each subject.

Before each trial, the experimenter selected the proper neutral density filter for that trial, gave a verbal reminder that a trial was about to occur, and then started a timer that operated the shutters on the slide projectors. Two shutters opened on each trial: the shutter on the glare projector, and the one for the stimulus to be detected on that trial. The shutters opened and closed simultaneously, staying open for two seconds. After each trial the subject indicated verbally whether he or she had seen the stimulus.

RESULTS AND DISCUSSION

The staircases for one of the younger subjects never stabilized in the rear-stimulus, low-reflectivity condition. His thresholds in the other conditions were consistent with those of the other subjects. Because we could not measure a threshold for him in one condition, he was dropped from the summaries reported here.

The dependent variable reported here is the contrast for a stimulus at the threshold of detection, defining contrast as

$$\frac{L_t - L_b}{L_b}$$

where L_t is the luminance of a stimulus to be detected and L_b is the luminance of the background against which it appears. Note that because the backgrounds used here had unitary luminance values (1.0 cd/m^2), the numbers reported here are equivalent to the luminance-increment threshold in cd/m^2. The reader can therefore think of these numbers in either sense. Because it is more common to express results in terms of contrast values, we will label the variable contrast threshold.

The predicted values discussed here were generated by the type of visibility modeling described in the introduction. The parameters used were chosen to reflect the conditions used in the laboratory as directly as possible. In a few cases, however, decisions had to be made that would not be obvious from reading the above Method section. We chose to take age into account by modeling one old and one young observer, each with the average age of the corresponding group, rather than modeling each subject individually. We designated these observers as 50th percentile in visual performance for their age groups. Because the rear stimulus was large and close to the glare source, the most appropriate value for the visual angle between the stimulus and the glare source was not obvious. We chose the angle between the center of the source and the far edge (7.27 deg). Informal observations of the stimulus configuration suggested to us that subjects' detection thresholds would be based primarily on the visibility of that edge, because it was the portion of the stimulus least subject to glare. All other geometric parameters and all photometric parameters used in the mathematical modeling followed the description of laboratory method straightforwardly.

An analysis of variance was performed on log-transformed contrast threshold values, using age, mirror reflectivity, and stimulus direction (front or rear) as factors. This yielded four significant effects.

The effect of age was significant, $F(1,17) = 12.40$, $p = .0026$. Overall, the older group required higher contrast for detection (0.11) than the younger group (0.05). This effect is graphed in Figure 5 along with the predicted values. Note that the predicted threshold contrast for the younger group is reasonably accurate, but the prediction for the older group is too high (i.e., the older subjects did better than predicted). The error bars on the observed values in Figure 5 are 95% confidence intervals based on the variabilities within each group of subjects. Note that the confidence interval is wider for the older subjects, reflecting the fact that performance varied more among the older subjects than among the younger subjects, but that the confidence interval nevertheless excludes the predicted value, indicating that the violation of the model is significant. This may have been caused by self selection. Among the older population, those with better vision may be more likely to volunteer for studies of this kind.

The main effects of stimulus direction, $F(1,17) = 140.92$, $p = .0001$, and mirror reflectivity, $F(2,34) = 12.86$, $p = .0001$, were both significant, as was their interaction, $F(2,34) = 40.49$, $p = .0001$. All three of these effects can be seen in Figure 6. The top panel shows results and predictions for the younger group, and the bottom panel shows results and predictions for the older group.

The main effect of stimulus type is such that more contrast is required to detect rear stimuli. This is probably partly because of the general dimming of the rearward scene by the mirror, which even at its brightest had a reflectivity of only 0.73, and partly because the visual angle between the rearward stimuli and the glare source was much less than the corresponding angle for the front stimuli.

Inspection of Figure 6 shows that the significant main effect of mirror reflectivity is incidental to a strong interaction of reflectivity and stimulus direction. The main effect of reflectivity is almost entirely caused by a decrease in threshold for rear stimuli as mirror reflectivity increases (meaning that rearward vision improves as reflectivity increases). Threshold for the front stimuli also changes but in the opposite direction; front stimulus threshold increases with increasing mirror reflectivity (meaning that forward vision becomes worse as mirror reflectivity increases). That change is so small relative to the change in rear threshold that it is difficult to see when they are plotted, as they are here, with a common scale. It is somewhat more obvious in the data from the younger group, but it is in fact present in both groups (and is statistically significant, as will be demonstrated below in an analysis of slope parameters). Although opposite in direction, the relative magnitude of the effect of reflectivity for the front stimuli is too small to prevent the effect for the rear stimuli from dominating the main effect of reflectivity. The pattern of interaction appears to be roughly the same for both the younger and older subjects, as supported by the lack of a significant three-way interaction of age, stimulus direction, and reflectivity, $F(2,34) = 1.35$, $p = .27$.

In comparing the observed values in Figure 6 to the model predictions, we can again see a circumstance that was evident in Figure 5: the predictions for the older group are generally too high. In other respects, however, the fit is rather good. The basic aspects of the pattern of interaction that we have described in the observed data are also present in the model predictions. Threshold for the rear stimuli is predicted to decline rapidly as mirror reflectivity increases; and although it is not easy to see in the figure, threshold for the front stimuli is predicted to increase with mirror reflectivity. As in the observed data, these two trends are markedly different in absolute magnitude.

To explore further the changes in threshold with mirror reflectivity, we summarized the data in Figure 6 in a different form. Because the changes are approximately linear in log-log terms, we fit linear models for log contrast threshold as a function of log reflectivity for each stimulus direction and each subject. The fits were generally good. Our main interest was in the slope parameters of those models. They are summarized in Figure 7, which shows the mean slope values for front and rear stimuli over all subjects, combining young and old. Also shown are 95% confidence intervals for those means, and slope values based on the predicted values shown in Figure 6. As can be seen by examining Figure 6 closely, the predicted relationship between log contrast threshold and log reflectivity is very nearly, but not quite, linear. The predicted slope values in Figure 7 were obtained by collapsing the predicted threshold values over subject age and performing a linear regression of log contrast threshold on log reflectivity, as if the predicted threshold values were empirical data.

The confidence intervals in Figure 7 do not include zero, indicating that the average slopes for front and rear stimuli both differ significantly from zero. The confidence intervals also exclude the predicted slope values (although only barely so in the case of front stimuli), meaning that these data significantly violate the visibility model.

The aspects of the data in Figure 7 that are most important for optimal control of mirror reflectivity are the absolute magnitudes of the slope parameters. In both the empirical results and the model results, the absolute values of the slope parameters for rear stimuli are substantially greater than those for the front stimuli. (The same aspects can be seen in less abstract form in Figure 6.) This means that the predicted or observed benefits in forward seeing as mirror reflectivity is decreased (thus affording protection from glare) are small relative to the corresponding costs in rearward seeing.

Although the observed values are broadly in agreement with the predictions, the ways in which they differ are important for our understanding of the tradeoff between forward and rearward seeing. In the empirical results the benefits in forward seeing as reflectivity is reduced are greater than predicted, and the costs in rearward seeing are lesser than predicted. Both of these discrepancies make the observed disparity in cost and benefit less extreme than the predicted disparity. In the observed results, costs in rearward seeing are still large relative to corresponding benefits in forward seeing, but not as extremely as predicted.

To evaluate the practical significance of this disparity for the selection of optimal mirror reflectivity, it is necessary to know more about the typical photometry of important forward and rearward stimuli, and the distances and other circumstances under which they most need to be seen. It is also necessary to have a valid relative weighting scheme for forward and rearward seeing. As we mentioned earlier, it seems clear informally that any valid set of weights would strongly emphasize the ability to see forward, in the direction of travel. In spite of these limitations, the extreme disparity in predicted costs and benefits is thought provoking. Even a small relative weight for rearward seeing, combined with this extreme disparity in forward benefits and rearward costs, might lead to the conclusion that mirror reflectivity should be kept relatively high.

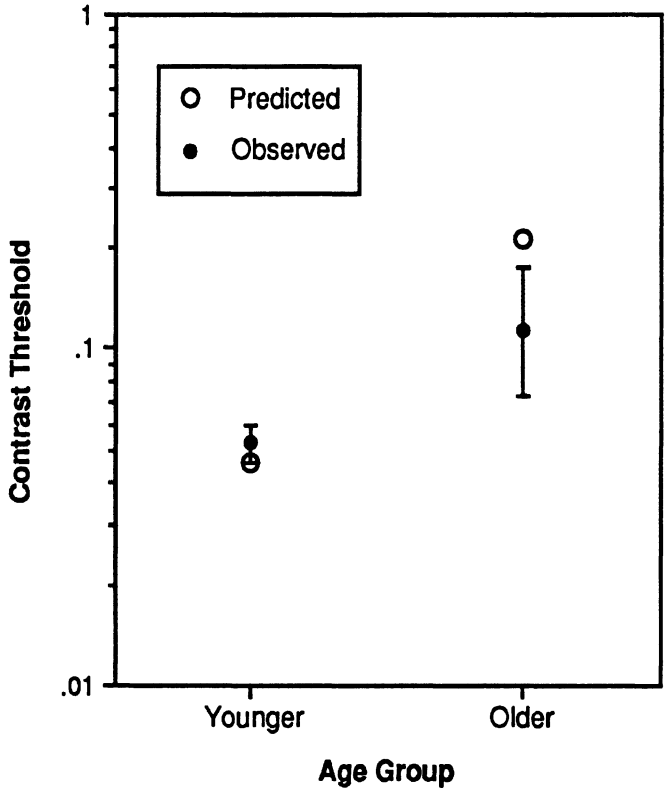

Figure 5. Predicted and observed values for the main effect of age. Error bars for observed values are 95% confidence intervals.

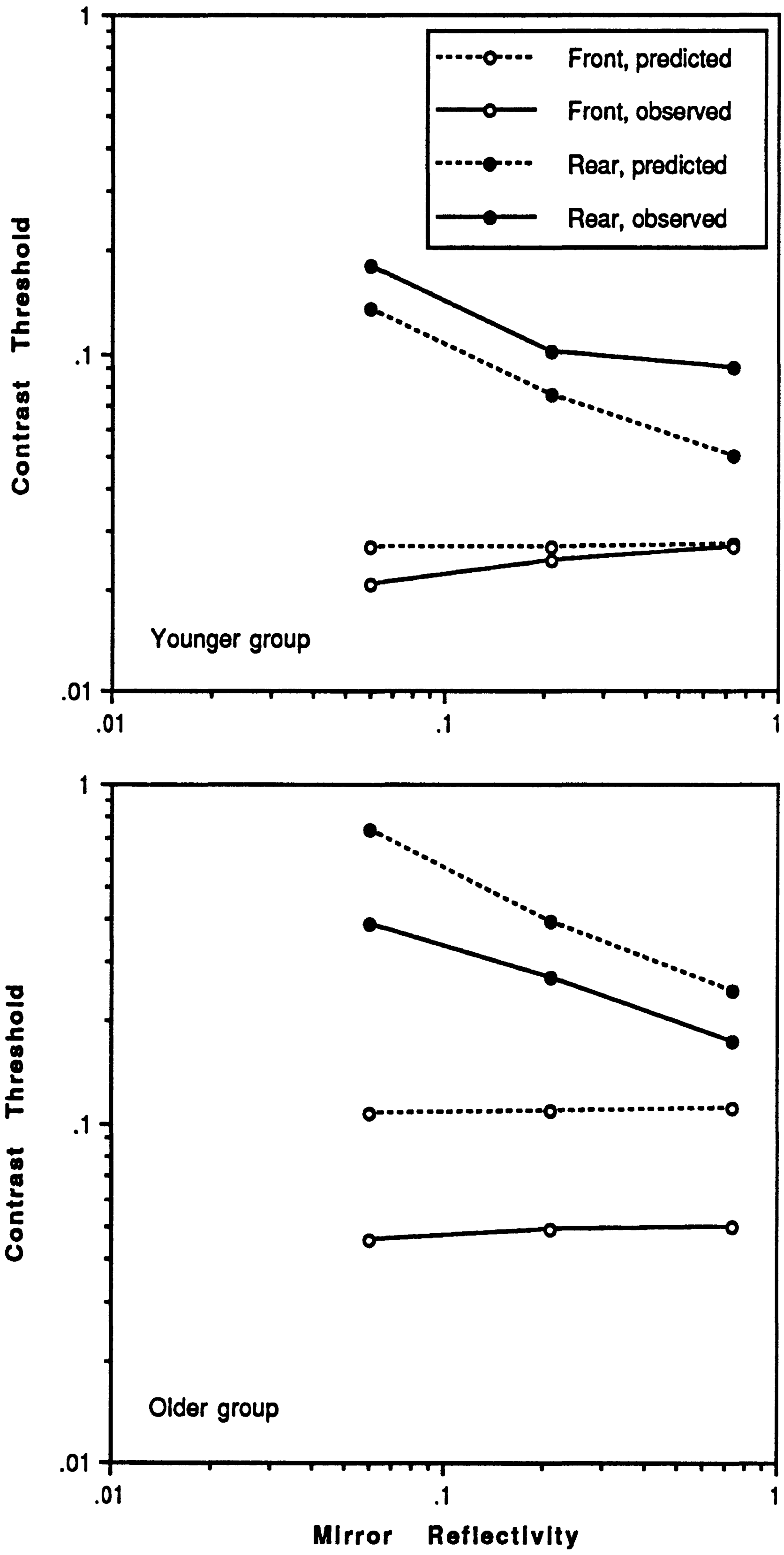

Figure 6. Predicted and observed contrast thresholds for front and rear targets, shown as functions of mirror reflectivity. The upper panel shows data for the younger subjects (n=9), and the lower panel shows data for the older subjects (n=10).

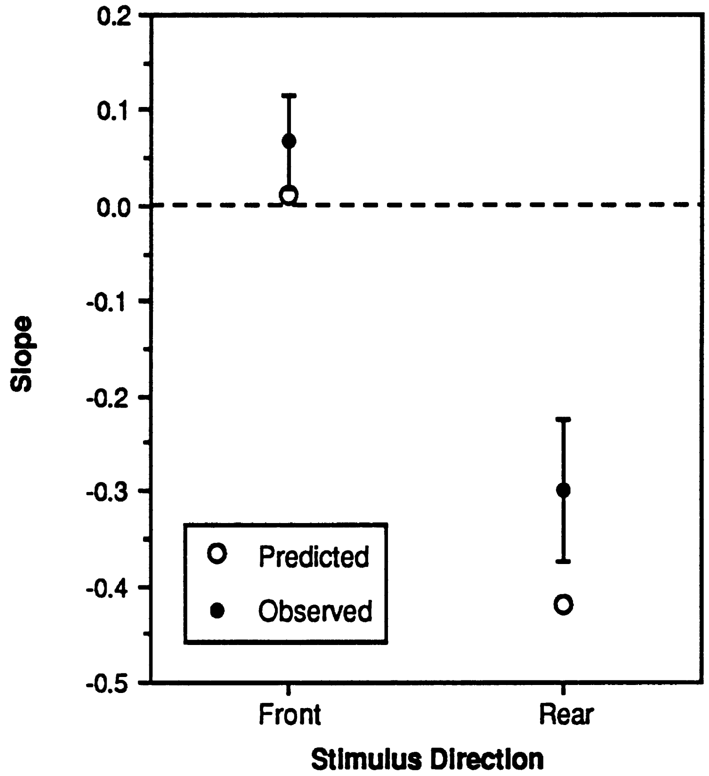

Figure 7. Mean slope parameters for models of log contrast threshold as a linear function of log mirror reflectivity. Models were fit for each stimulus direction and each subject. Error bars are 95% confidence intervals. Predicted values are derived from modeling of contrast thresholds. See text for details.

SUMMARY AND CONCLUSIONS

We have proposed that optimal mirror reflectivity should be based on consideration of how reflectivity affects three mirror functions: (1) providing rearward vision, (2) protecting forward vision from glare, and (3) protecting the driver from discomfort glare. We have evaluated the tradeoff between two of these factors (forward and rearward vision) in a mathematical simulation and in a laboratory study. Although there are interesting discrepancies between the simulation and the empirical results, they are in broad agreement as to the nature of that tradeoff: reduced reflectivity results in a benefit in forward vision, but at a cost in rearward vision that is substantially greater.

This result alone cannot serve as the basis for a specific recommendation about optimal mirror reflectivity, but the strength of the disparity in forward benefit and rear cost suggests that we should be cautious about effects of lowered reflectivity on rearward vision. The results that we have presented here indicate the potential for a problem with rear vision rather than conclusive evidence that one exists. The limitations of the present results include the fact that our dependent variable of contrast threshold, although it is well defined and easy to compare across forward and rearward stimuli, is only indirectly related to any final measure of costs and benefits. For example it would be reasonably straightforward, although complex, to translate the effects we measured on forward contrast threshold into seeing distance for pedestrians. But it would then be considerably more complex to generate a comparable measure for rearward vision, and to establish the proper relative weighting of the measures.

The implications of the present study are also limited because it does not include treatment of discomfort glare. As we mentioned earlier, standard models of discomfort glare cannot be applied directly to glare from rearview mirrors across changes in reflectivity (Flannagan et al., 1991). Without a better quantitative understanding of how discomfort is affected by mirror reflectivity, that factor cannot be included in a formal treatment of the problem of optimizing reflectivity.

The results of this study suggest that the approach of mathematical modeling of the effects of mirror reflectivity is reasonably valid, and useful at least for quickly exploring a wide range of conditions in order to direct empirical efforts. In the present case, mathematical modeling successfully predicted the general form of the tradeoff between forward and rearward vision, although not the exact values involved.

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