DRIVER PERCEPTUAL ADAPTATION TO NONPLANAR REARVIEW MIRRORS

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16. Abstract

This study examined perceptual adaptation to nonplanar (spherical convex and aspheric) rearview mirrors. Subjects made magnitude estimates of the distance to a car seen in a rearview mirror. Three different mirrors were used: plane, aspheric (with a large spherical section having a radius of 1400 mm), and simple convex (with a radius of 1000 mm).

Previous research relevant to perceptual adaptation to nonplanar mirrors was reviewed. It was argued that, in spite of some cases of explicit interest in the process of learning to use nonplanar mirrors, previous research has not adequately addressed the possibility of perceptual adaptation.

The present experiment involved three phases: (1) a pretest phase in which subjects made distance judgments but received no feedback, (2) a training phase in which they made judgments and did receive feedback, and (3) a posttest phase with the same procedure as the pretest phase.

Initially subjects showed substantial overestimation of distance with the convex mirror relative to the aspheric mirror, and with the aspheric mirror relative to the plane mirror. At the beginning of the training phase, overestimation with the convex mirror quickly diminished, but after about one hour of experience the convex and aspheric mirrors still showed significant overestimation relative to the plane mirror.

The present results demonstrate the existence of a rapid, but incomplete, form of adaptation. Whether there is a further mechanism that might operate over a longer time, but lead to more complete adaptation, is an open question that should be addressed by further research. Future research should also address the question of what forms of experience or training are most conducive to adaptation. If substantial adaptation is indeed possible, the use of nonplanar rearview mirrors would be strongly encouraged.

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Contents

Introduction

Convex rearview mirrors permit larger fields of view than plane mirrors of the same size. They thereby offer a possible solution to the existence of blind spots in current U.S. mirror systems, which currently are required to have plane mirrors except in the exterior right (passenger-side) position. However, convex mirrors alter information about the size and distance of objects (Seeser, 1974). The most important effect is probably a reduction in image size that may lead to an increase in the perceived distances to objects. This has lead to a concern that drivers who use convex mirrors may misjudge the locations of other vehicles.

Many studies have addressed the effect of convex mirrors on distance perception (Flannagan, 1988), and many countries other than the U.S. have accumulated a large amount of experience with convex mirrors, but their use remains controversial (Flannagan & Sivak, 1993). The purpose of the present paper is to suggest that an important aspect of the effects of convex mirrors on distance perception—how those effects change with drivers' experience—has received insufficient attention from the research community, and to report preliminary results from a study that we believe addresses that issue more directly than previous work.

Human visual perception is in many ways highly adaptable, including, under at least some conditions, adaptation to minified images seen in convex mirrors (Rock, 1966, chap. 5). Understanding to what extent, and under what conditions, drivers may be able to adapt to minified images in rearview mirrors therefore seems an important issue.

Previous research

Several studies have explicitly raised the issue of perceptual adaptation to convex mirrors, but none has yet provided clear information about the most important aspect of such adaptation, namely how experience may affect the average signed error of distance judgments (i.e., the tendency to underestimate or overestimate distances). Smith, Bardales, and Burger (1978) gave subjects a moderate amount of explicit training regarding the distances of objects seen in a convex mirror with a radius of 50 inches (1270 mm). The training consisted of four sessions of 45 to 60 minutes each. Subjects in a laboratory viewed films of an approaching car through the convex mirror and, when cued, made judgments about the speed and distance of the car. The primary form of training consisted of feedback on some of the trials about the actual speed and distance of the vehicle. Absolute errors decreased during the course of the study, but there was no consistent trend in net error or in the proportions of over- and underestimates. Training appeared to reduce the variability of subjects' judgments, but not to shift them higher or lower. However, the effects of a minified image, and adaptation to it, ought to produce distance judgments that are initially high and then shift toward lower values.

A similar set of results was obtained in a related study (Burger, Mulholland, Smith, & Sharkey, 1980) in which subjects viewed stimuli through each of four convex mirrors that ranged in radius from 20 to 80 inches (510 to 2030 mm). The test situation was a "semidynamic" one in which subjects sat in a stationary car that was approached from the rear by another car. Subjects performed several tasks, including one in which they pressed a switch to indicate when they judged the approaching vehicle to be at one of several criterion distances behind them, ranging from 10 to 115 feet (3.0 to 35.1 m). Each subject experienced nearly 1000 trials in a variety of conditions. Over the course of that experience, average absolute error of distance judgments decreased, but the authors do not report a trend for net distance error. As in the previously cited study, this suggests that subjects' judgments became more internally consistent with experience, but did not shift toward longer or shorter distances.

The possible implications of this study for perceptual adaptation are also limited by the fact that it used a repeated measures design in which all subjects saw a large variety of mirror systems over the course of the study. Thus, although each subject was given a large overall amount of experience, the amount with any one mirror system was small.

In their development of a rear vision test protocol, Burger and Ziedman (1987a, 1987b) considered the possible effects of learning on the figure of merit produced by the protocol. Their protocol was designed to evaluate rearview mirrors by having human subjects make judgments about the distance and displacement of model cars in scenes presented with 35-mm slides and viewed through the rearview mirrors to be evaluated. Using the protocol, they obtained pilot data for plane, convex, and aspheric rearview mirrors. They suggested that subject performance was stable after about two sessions, and they recommended that final data for the figure of merit be collected just after that point in applications of the protocol.

Although possible changes in distance judgments are clearly of practical interest for implementing such a protocol, the nature of any changes cannot be determined from the reports of their pilot data. Also, the nature of the task used in this protocol may not be appropriate for investigating possible shifts in distance judgments. The distance judgment task requires subjects to estimate the distance to a model car seen in the slides in terms of car lengths, and they are explicitly told that the stimuli will range from zero to ten car lengths. In the context of that instruction, the subjects' task may be too constrained to reflect possible changes in the range of distances they perceive. An alert subject could presumably constrain his or her answers so that the labels "zero" to "ten" would always span the range of perceived distances, whatever that range might actually be.

Design of the present study

The goal of the present study was to measure as sensitively as possible any changes in distance judgments over the early course of experience with nonplanar rearview mirrors. We used a semidynamic field setup in which subjects sat in a stationary car and viewed the rearward scene through one of three types of outside left (driver-side) rearview mirrors. Each subject experienced only one type of mirror: (1) plane, (2) spherical convex with a 1000 mm radius of curvature, or (3) aspheric with an inboard section that was spherical with a 1400 mm radius of curvature and an outboard section in which the radius of the horizontal curvature decreased toward the outer edge.

The subjects' task was to estimate the distance to a car seen through the rearview mirror. On each of a series of trials, the rearward car was positioned at one of five distances, ranging from 5 m to 40 m behind the left rearview mirror of the subjects' car. A third car was positioned 20 m in front of the subjects' car to serve as a reference for the distance judgments. Subjects were told to regard that distance as 100 on an otherwise arbitrary scale of distance, and to make their judgments about the rearward car proportionately. This was done so that subjects' judgments would all be reasonably well calibrated to a common real distance, rather than to any idiosyncratic impressions they might have of how feet, meters, or other conventional units ought to look in a road environment. This task is a specific version of the conventional psychophysical method of magnitude estimation (e.g., Marks, 1974). This method was selected because it has been demonstrated in a large variety of psychophysical studies to be a simple, fast, and reliable way to measure human perceptions.

In this preliminary study, subjects experienced only one session of about one hour. The previous studies reviewed above had suggested that interesting changes might happen even with that relatively limited amount of experience. The procedure was a conventional one for any study of learning: it involved a pretest phase, a training phase, and a posttest phase. In the pretest phase, subjects were instructed to estimate the distance to the rearward car while seeing only the view through the rearview mirror. They were instructed not to make a direct look to the rear. During the training phase, they again made distance estimates on each of a series of trials, but they were instructed to make a direct look to the rear after each estimate and to note the position of the rearward car. Thus, the training phase provided a simple, direct form of feedback about the distance to the rearward car immediately after each judgment. During the posttest phase, subjects were again instructed not to make direct looks to the rear.

Method

Subjects

Twenty-four subjects participated in the experiment. There were 12 subjects in each of two age groups, a younger group ranging from 20 to 30 with an average age of 26.5, and an older group ranging from 67 to 78 with and average age of 71.2. Each age group had six males and six females. All subjects were active, licensed drivers.

Each subject was assigned to one of three groups, corresponding to the three rearview mirror types. Six subjects (three young and three old) were assigned to the plane mirror, nine (four young and five old) to the spherical convex mirror, and nine (five young and four old) to the aspheric mirror. The sexes were approximately evenly represented in each combination of mirror and subject age.

Test site

The experiment was conducted on a newly paved parking lot. The surface was new asphalt with no markings. The positions of the three vehicles are shown in Figure 1. All three cars faced in the same direction, simulating the spatial relationships that might occur for three vehicles traveling in the same direction in two adjacent lanes. The subject's car was stationary throughout the experiment. The anchor car was also always stationary, 20 m in front of the subject's eye position. On each trial, the rearward stimulus vehicle was positioned at one of five distances from the subject's car (5, 10, 20, 30, or 40 m from the exterior rearview mirror to the front of the rearward car). The rearward stimulus vehicle was offset 3.7 m to the left of the subject's car (the width of a standard lane).

Mirrors and fields of view

The dimensions of the three mirrors were as follows: (1) The plane mirror was 170 mm wide by 90 mm high, with an infinite radius of curvature. (2) The aspheric mirror was 170 mm wide by 100 mm high, with a 120-mm-wide inboard spherical section that had a constant 1400-mm radius of curvature, and a 50-mm-wide outboard section that varied in radius of horizontal curvature from 1400 mm at the border with the spherical section to 175 mm at the outer edge. The radius of the vertical curvature was 1400 mm throughout the mirror surface. (3) The spherical convex mirror was 175 mm wide by 100 mm high, with 1000 mm radius of curvature.

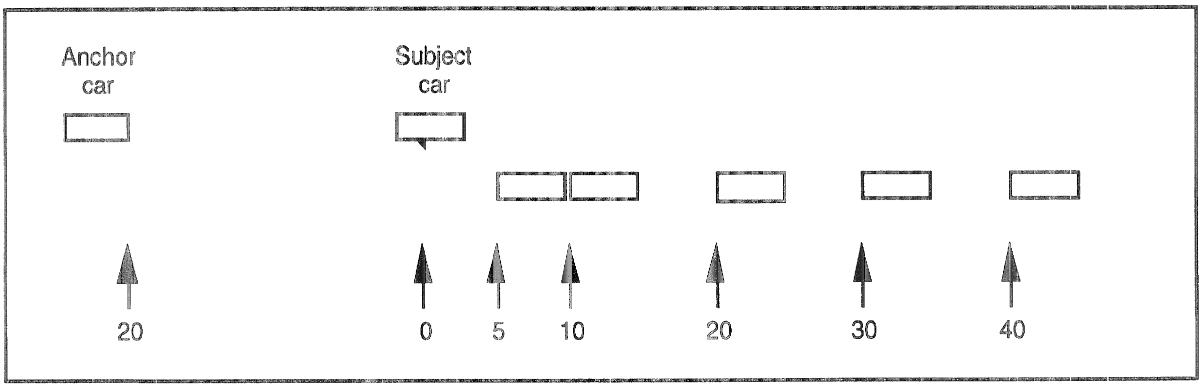

Figure 1. An overhead view of the experimental setup. The fronts of all three vehicles are to the left in this diagram. The anchor car was stationary, 20 m in front of the subject's eye position. On each trial, the rearward stimulus vehicle was positioned at one of five distances from the exterior rearview mirror. The arrows show distances in meters. The rearward stimulus vehicle was offset 3.7 m laterally from the subject's car (the width of a standard lane).

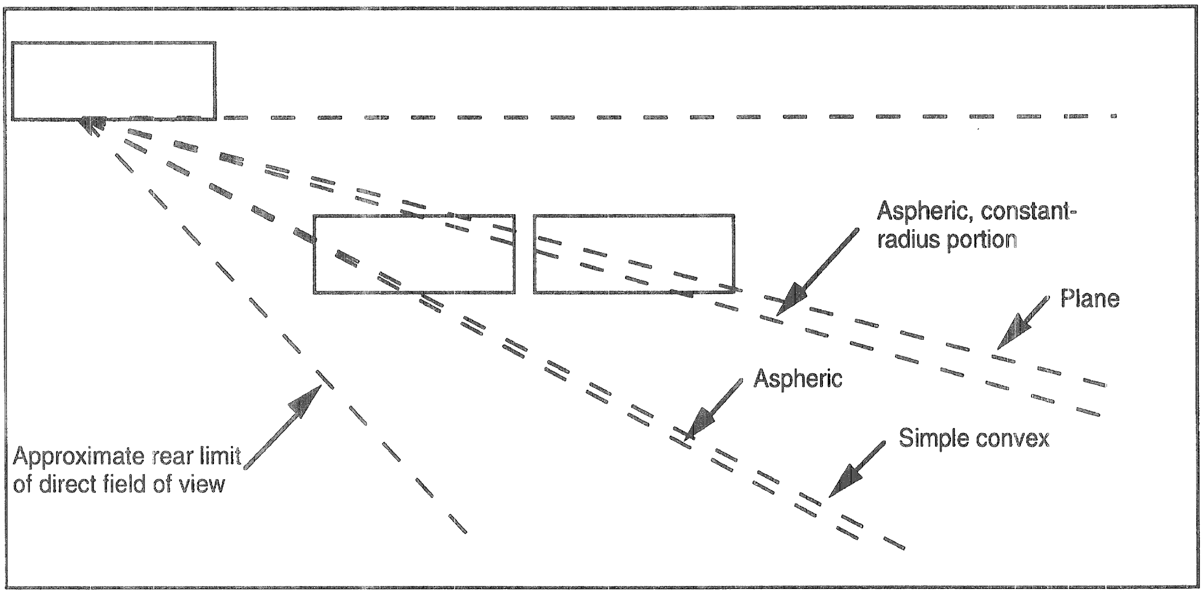

Figure 2. The fields of view provided by the three types of mirrors, and the limit of the direct field of view that a subject would have while looking directly at the outside rearview mirror, relative to the two closest positions of the rear stimulus car.

The mirrors were aimed by each subject at the beginning of his or her session. They were instructed to aim the mirror so that the side of their own vehicle would be just visible at the inboard edge of the mirror. The horizontal field of view was measured for each subject. Average horizontal fields of view are shown in Table 1, along with a summary of the radii of curvature.

The center and passenger-side rearview mirrors of the subject's car were covered during the experiment.

Figure 2 is an enlarged view of part of Figure 1, showing the relationships among the two closest rear-vehicle positions and the fields of view of the three mirrors. As can be inferred from Figure 1, the farther three rear-vehicle positions were entirely contained in the fields of view of all three mirrors. Note that although all five vehicle positions are at least partially visible with each of the mirrors, the front position is only partially visible even in the wider fields of view, and only a small portion is visible in the field of view of the plane mirror. Also, in the second closest position, the rear vehicle is only partially visible in the field of view of the plane mirror, and it is also only partially visible in the spherical portion of the aspheric mirror.

Figure 2 also shows the approximate limit of the direct field of view that the subjects had when their heads were turned toward the left outside rearview mirror. This is based on an assumed total field of view of 180 degrees, and a head direction 45 degrees to the left of the straight ahead. That is approximately the direction the subjects would have been looking if they turned their heads directly toward the mirror. Even in the closest position, no part of the vehicle was directly visible unless the subject turned further than 45 degrees.

Table 1
Radius of curvature and horizontal field of view for each of the three mirrors.

Mirror	Radius (mm)	Field of view (degrees)
Plane	∞	13
Aspheric	1400[1]	26
Convex	1000	27

[1] inboard section

Procedure

Subjects were run individually. Each session lasted about one hour. One experimenter sat in the rear seat of the subject's car, giving instructions and recording responses. A second experimenter drove the rear stimulus car, moving it among the five rearward positions between trials.

The type of the left exterior rearview mirror was set at the beginning of each subject's session and remained the same throughout that subject's participation.

At the beginning of a session, the subject was seated in the car and the experimenter read the instructions to the subject. Subjects were informed that the study concerned an innovative rearview mirror, but otherwise were not told about the purposes of the study or the nature of the mirrors.

The car parked in front of the subject's car was pointed out, and the subject was told to regard the distance to the rear of that car as 100 units on an otherwise arbitrary scale of distance. The subject was told that he or she would be estimating distances to the rearward car by selecting any positive real numbers that seemed appropriate to represent that distance proportionately, given that distance to the forward vehicle was designated 100.

On each of a series of trials, the rearward vehicle was positioned while the subject looked forward at the reference vehicle, and held up a card that blocked his or her view of the left exterior mirror. When the rearward vehicle was in the proper position, the experimenter in the subject's car asked the subject to lower the card, turn toward the left exterior mirror, and look at the image of the rearward vehicle. The subject was then to make a numerical estimate of the distance to the rearward vehicle by saying an appropriate number.

There were three phases in each session: pretest, training, and posttest. During the pretest phase, after making a distance estimate, the subject was to again raise the card that blocked the view of the mirror, and again look toward the forward vehicle. The subject was not permitted to make a direct look to the rear at any time during the pretest phase. During the training phase, the subject was instructed to look directly to the rear after making each distance estimate and to note the appearance of the distance to the rear vehicle in this direct view. The subject thus received a form of feedback about the distance judgment that he or she had just made, but the distance was never actually identified in terms of either the rating scale referenced to the forward vehicle, or in terms of any conventional units of distance. During the posttest, the subject was again not permitted to make direct looks to the rear.

There were 15 trials in the pretest, 30 during training, and 15 during the posttest. Each of the five distances appeared once in each set of 5 trials, in random order.

The experiment was conducted during the day, during mostly cloudy weather. The subject's vehicle was a Honda Accord, the forward stimulus vehicle was a Toyota Corolla, and the rearward stimulus vehicle was a Nissan Altima.

Results and Discussion

Pretraining performance

Figure 3 shows average distance estimates for each of the three mirror types as functions of actual distance, for the pretraining phase (the first 15 trials). The distance estimates are approximately linearly related to actual distance. The dashed line in Figure 3 indicates where estimates would fall if they were perfectly calibrated to the anchor stimulus (the forward vehicle, at an actual distance of 20 m, that was assigned a value of 100). In the pretraining phase performance with the aspheric mirror shows the best calibration to the anchor, and the plane mirror is associated with a marked underestimation of distance. However, it is probably not a good idea to make strong interpretations of the calibration of estimates to the anchor; there are many factors that could affect subjects' calibration.

It is perhaps reasonable to argue that performance with the plane mirror, whatever its form, is the most meaningful standard for "correct" judgments (e.g., that those judgments would be most predictive of safe and efficient performance in meaningful tasks such as gap acceptance in lane changes). There is a strong effect of mirror type, with both of the nonplanar mirrors leading to greater distance estimates than the plane mirror. The magnitude of these effects can be compared to a prediction based on a model in which the differences between subjects' distance judgments with the plane mirror versus either of the other two are based strictly on the relative visual angle subtended by the images seen in the mirrors. Such a prediction is shown in Figure 4. The dotted lines and open symbols represent predictions based on calculations of the relative subtended angles that were calculated using the method suggested by Platzer (1995, p. 3). The predicted distances are the distances required to make an object of fixed size subtend the minified visual angles caused by the nonplanar mirrors. The overestimation, although fairly large, is less than is predicted by a strict visual-angle model.

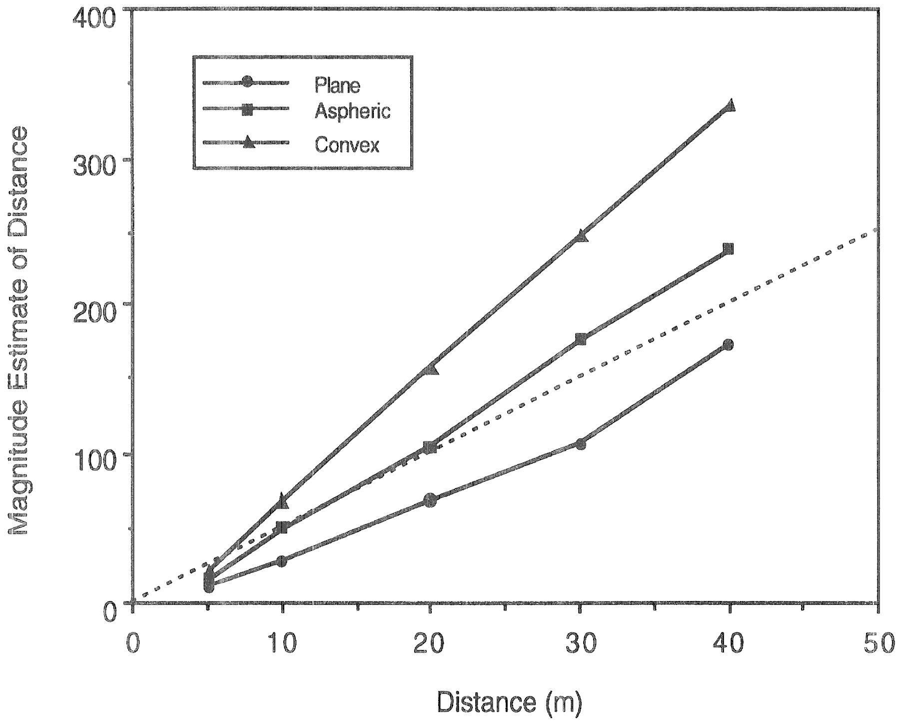

Figure 3. Magnitude estimates of distance for each mirror type as functions of actual distance prior to any training. These data are from the first three blocks (15 trials) of the magnitude estimation task. The diagonal dashed line is where estimates would fall if they were perfectly calibrated to the anchor used in the magnitude estimation task (a vehicle at 20 m was assigned a value of 100).

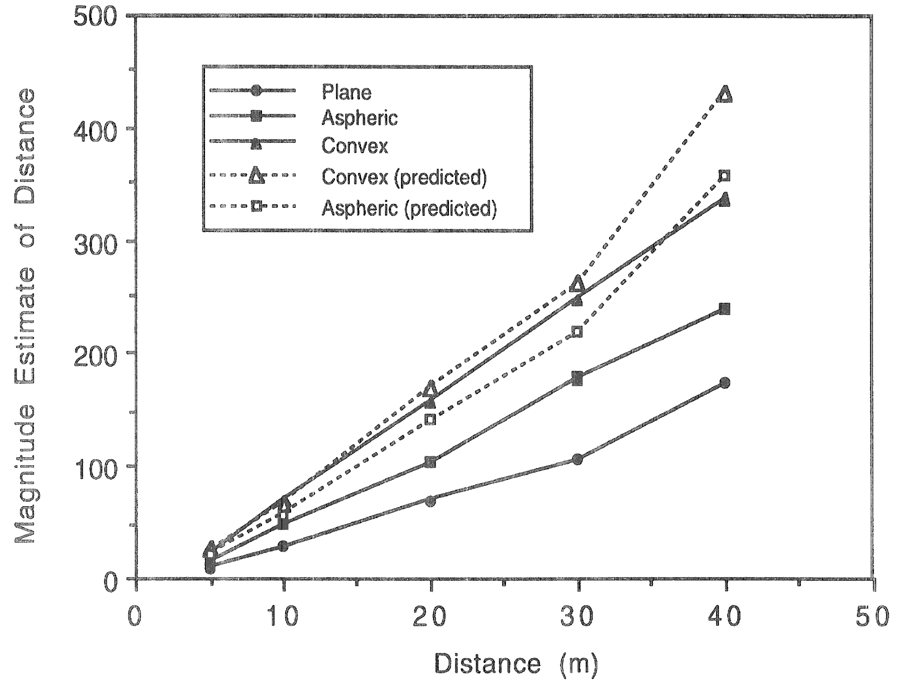

Figure 4. The same data as shown in Figure 3, along with predicted values for the aspheric and convex mirrors based strictly on the visual angles subtended by images seen in those mirrors relative to the visual angles of images seen in the plane mirror. The observed overestimation is less than predicted by such a model.

Because the rearward stimulus vehicle was not completely visible in all the mirrors at the nearest positions (5 and 10 m, see Figure 2), and because for those positions the vehicle was partly imaged in the section of the aspheric mirror in which the radius of curvature was relatively small and changing, the distance estimates for those conditions might have been anomalous. However, there is no indication that they were. (Figures 3 and 4 show only data from the pretraining phase, but the same pattern holds in the rest of the data as well.)

An analysis of variance on the distance estimates shown in Figures 3 and 4, using mirror type and distance as variables, confirmed that the main effect of mirror type, $F(2,18) = 9.25$, $p = .0017$, as well as the interaction of mirror type with distance, $F(8,72) = 4.42$, $p = .0083$ (this and all of the following tests involving repeated measures are based on the Huynh-Feldt adjustment), were highly significant.

Results combined over all distances

In order to provide a simple summary of results combined over all five distances, an index was constructed to represent the misestimation of distance on each trial relative to the actual distance presented on that trial. Each response was divided by the numerical response that would have been perfectly calibrated to the reference distance of 20 m being assigned a value of 100. That is, responses to the closest position (5 m) were divided by 25, responses to the second position (10 m) were divided by 50, and so forth. In order to examine trends in over- or underestimation during the course of the experiment, combined over the five distances, this index is shown in Figure 5 for each of the twelve blocks of five trials and each of the three mirror types.

Estimates seem to change over the course of the session for all three mirror types, although the change for the plane mirror condition is relatively subtle. The clearest change is in the convex mirror condition, where a substantial overestimation of distance that is present for the first three blocks (prior to any training) quickly diminishes at the onset of training, and then appears to continue to diminish for the rest of the session. The same pattern, in a weaker form, may be present for the aspheric mirror condition. An analysis of variance on these data, including age group, mirror type, block, and distance as variables, indicates a statistically significant main effect of block, $F(11,198) = 9.50$, $p < .0001$, as well as a significant interaction between mirror type and block, $F(22,198) = 2.13$, $p = .049$. The interaction of mirror type, block, and age was not significant, $F(22,198) = 1.323$, $p = .25$, indicating that the adaptation effects in Figure 5 apply to both young and old subjects. The interaction of mirror type, block, and distance was also not significant, $F(88,792) = 1.12$, $p = .29$, suggesting that the pattern in Figure 5 also applies reasonably well across the five distances.

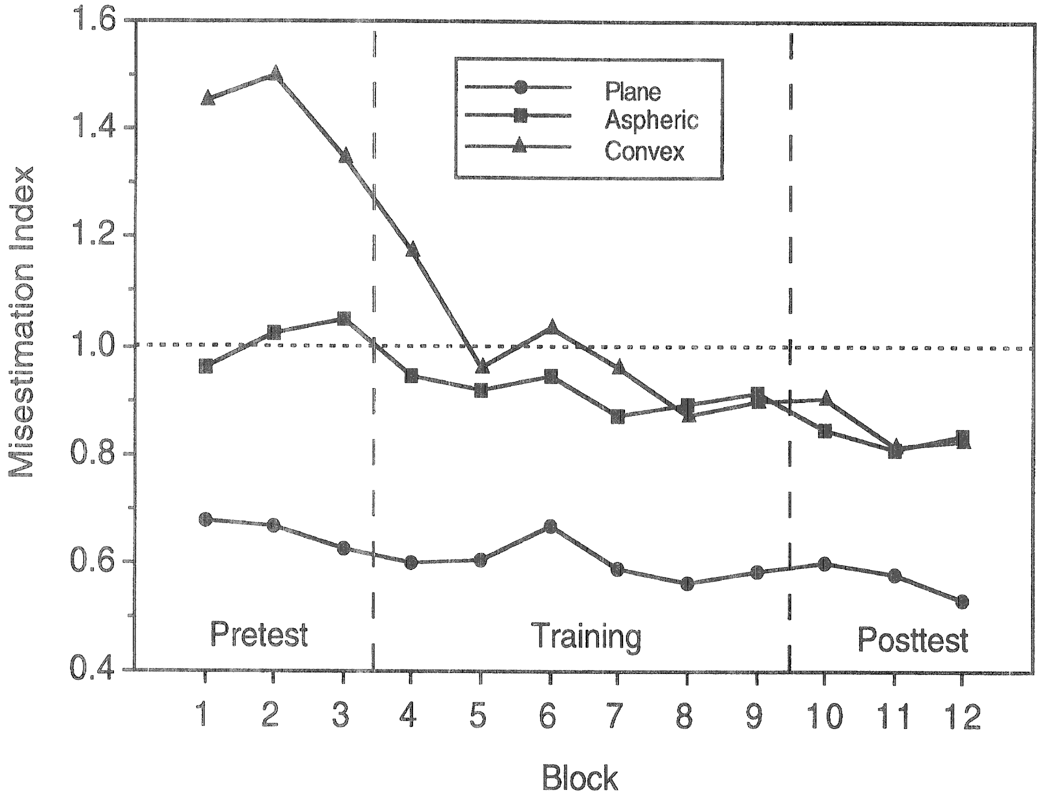

Figure 5. The misestimation index for each mirror type as a function of blocks. These data are combined over all five actual distances. Blocks 1 to 3 were prior to training, blocks 4 to 9 were during training, and blocks 10 to 12 were after training.

In order to highlight how estimates were made during the pretest and posttest phases, we selected the data from just those phases and combined them over the five distances and the three blocks within each of the two phases. That combined index is shown, for each mirror type in the two phases, in Figure 6. An analysis of variance for those data, using mirror type, age, and phase as variables, indicated a significant main effect of mirror type, $F(2,18) = 12.58$, $p = .0004$, as well as a significant interaction of mirror type and phase, $F(2,18) = 4.30$, $p = .030$. Newman-Keuls post hoc tests indicated that all pairwise differences were significant in the pretest phase, and that, in the posttest phase, performance with the plane mirror was different from each of the other two, which did not differ from each other.

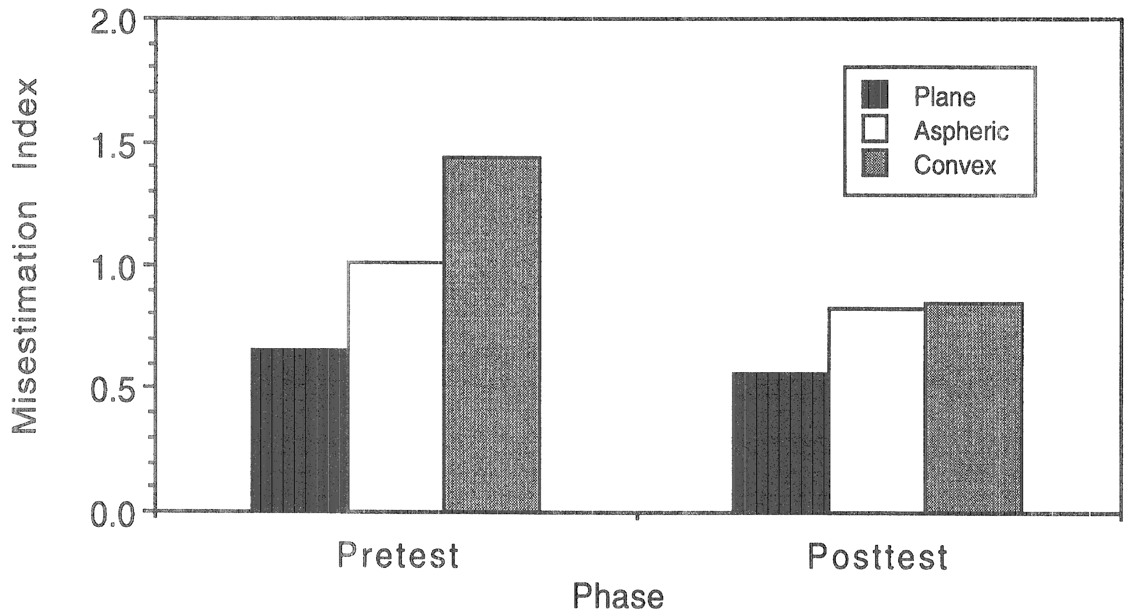

Figure 6. The misestimation index for each mirror type, before and after training.

Summary

In the pretest phase there was clear evidence that both the aspheric and convex mirrors led to longer distance judgments than the plane mirror. Furthermore, the convex mirror (which had the shortest radius at 1000 mm, and therefore the most minification of images) led to longer distance judgments than the aspheric mirror.

In terms of the standard that was presented to subjects (a stimulus at 20 m was assigned a value of 100 on the scale to be used for distance estimates) the plane mirror led to substantial underestimation of distance, and the aspheric mirror produced highly accurate estimates in the pretest phase. However, if performance with the plane mirror is designated the criterion for correct performance, then both of the nonplanar mirrors led to overestimation.

In the case of the convex mirror, there is clear evidence for a rapid, but incomplete, form of adaptation. The degree of overestimation drops quickly as soon as subjects are given feedback about the direct appearance of the distances to the rearward stimulus car, with most of the adaptation taking place during the fourth block of five trials (the first block of the training phase). There is some evidence for a slower, continuing reduction in estimates with both of the nonplanar mirrors. However, this evidence is weak, especially considering that a reduction that is almost as big occurs with the plane mirror. Because all of the subjects were very familiar with plane mirrors in left exterior position it seems reasonable not to assign much importance to the downward drift in the plane mirror performance.

By the posttest phase, performance on the two nonplanar mirrors is nearly identical, and both continue to show significant overestimation relative to the plane mirror. It should not necessarily be concluded that performance with the two nonplanar mirrors is in fact the same. Proving equality is never possible with variable data, just as proving any null hypothesis is impossible. However, it is clear that both mirrors continue to lead to overestimation of some degree after about one hour (and 60 trials) of experience. It is not clear whether the reduction in overestimation has reached an asymptote by the end of the present experiment, but the rate of adaptation with the convex mirror has certainly decreased.

Conclusions

The present results clearly demonstrate a rapid, but incomplete, form of adaptation to nonplanar rearview mirrors. Whether a slower, more complete form of adaptation may also occur is an open question. The present study examined the effects of only a minimal amount of experience. A reasonable extension of this study might be simply to increase the number of sessions, following essentially the same procedure.

Another obvious extension of this research would be to examine what conditions are most conducive to perceptual adaptation. The training program used here was extremely simple, and it did not involve the subject in a task in which accurate information about distance had to be actively used. That kind of involvement is often identified as one of the most crucial factors in promoting perceptual adaptation (e.g., Rock, 1966).

It is possible to imagine a large variety of mechanisms that might contribute to perceptual adaptation to the distortions inherent in nonplanar mirrors. Mechanisms might vary in the speed with which they operate, in the completeness of the adaptation they produce, and in the degree of awareness that a subject has of the mechanism.

It may be significant that even the original degrees of overestimation in this experiment were substantially lower than predictions based only on the subtended angles of the images. Most authors have discussed the effects of nonplanar mirrors on distance perception simply in terms of some form of the subtended-angle model. The fact that subjects do not judge distance in a way that is consistent with that simple model suggests that they are sensitive to other aspects of the visual environment that provide cues to distance, and that some of those cues may provide relatively accurate distance information.

It might be argued that perceptual adaptation to nonplanar mirrors is a secondary issue for the use of such mirrors, because they are not intended to be used for distance and speed judgments in any case. It is often suggested that nonplanar mirrors with large fields of view should be used as "go/no-go" indicators. Mourant and Donohue (1979), for example, made that explicit in instructions to subjects in a study of the use of convex exterior mirrors on the passenger side. However, even if drivers follow a strategy that does not normally involve using nonplanar mirrors for distance judgments, it is possible that they will at times, perhaps under stressful conditions, be influenced by the perceived distance of images in such mirrors. There is not currently strong evidence for such an effect, but it is a difficult argument to dismiss definitively. If a strong form of perceptual adaptation can occur with nonplanar mirrors, their use in reducing or eliminating blind spots would be a much simpler issue.

References

Burger, W. J., Mulholland, M. U., Smith, R. L., & Sharkey, T. J. (1980). *Passenger vehicle, light truck and van convex mirror optimization and evaluation studies: Vol. 1: Convex mirror optimization* (DOT HS 805 695). Washington, D.C.: Department of Transportation, National Highway Traffic Safety Administration.

Burger, W. J., & Ziedman, D. (1987a). *Development and implementation of a rear vision device test protocol: Volume I: Physical characteristics measurement* (DOT HS 807 233). Washington, D.C.: Department of Transportation, National Highway Traffic Safety Administration.

Burger, W. J., & Ziedman, D. (1987b). *Development and implementation of a rear vision device test protocol: Volume II, Simulated-use testing* (DOT HS 807 232). Washington, D.C.: Department of Transportation, National Highway Traffic Safety Administration.

Flannagan, M. J. (1988). *Human performance aspects of rearview mirrors: An applied-literature review* (Report No. UMTRI-88-20). Ann Arbor, Michigan: The University of Michigan Transportation Research Institute.

Flannagan, M. J., & Sivak, M. (1993). Indirect vision systems. In B. Peacock & W. Karwowski (Eds.), *Automotive ergonomics* (pp. 205-217). London: Taylor & Francis.

Marks, L. E. (1974). *Sensory processes: The new psychophysics*. New York: Academic Press.

Mourant, R. R., & Donohue, R. J. (1979). Driver performance with right-side convex mirrors. *Transportation Research Record*, No. 737, 95-104.

Platzer, G. E. (1995). *The geometry of automotive rearview mirrors: Why blind zones exist and strategies to overcome them* (SAE Technical Paper Series No. 950601). Warrendale, Pennsylvania: Society of Automotive Engineers.

Rock, I. (1966). *The nature of perceptual adaptation*. New York: Basic Books.

Seeser, J. (1974). *Automotive convex mirrors: Optical properties* (Technical Report 201). Holland, Michigan: Donnelly Mirrors.

Smith, R. L., Bardales, M. C., & Burger, W. J. (1978). *Perceived importance of zones surrounding a vehicle and learning to use a convex mirror effectively* (DOT HS 803 713). Washington, D.C.: National Highway Traffic Safety Administration.