additional delineation for guidance. However, it should be noted that the increase in speed at night for the after condition increases the accident potential, since even the nighttime speeds before installation exceed those required for a safe stopping distance.

Safe Stopping Distance

For all conditions investigated (before and after), the actual sight distances were less than the safe stopping distances, a finding that indicates that drivers tend to go too fast for sight distances in fog. It is noted above that the increase in nighttime speeds since the installation of the lights raises the accident potential as a result of the increased stopping distances required. However, the low traffic volume encountered on this rural section of Interstate highway, especially at night, leads to a decrease in vehicle interaction that lessens the significance associated with the safe stopping distance. Also, the improved delineation is thought to help prevent vehicle stoppages along the roadway.

Headways

A review of the headway data showed little difference in headways between the before and after conditions during the hours of daylight. However, available data showed a decrease in nighttime headways (below 3 s) after the inset lights were installed. This finding, coupled with results that showed less vehicle queuing in the after condition, indicates that motorists were using the inset lights for guidance rather than relying on car following.

Queuing

There was a decrease in daytime vehicle queuing for the sight distance of 33.5-45.7 m (110-150 ft) but little difference within the range of 45.7-61.0 m (150-200 ft). At night, for both sight distances considered, there was a decrease in vehicle queuing. There was little difference in the numbers of vehicles in the queues. The increase in headways and decrease in vehicle queuing at night might indicate a reduction in the potential for accidents under the lighting system. However, it should be noted that, for severely restricted sight distances before the system was installed, vehicles tended to form queues for the purpose of being led through the fog, which may be thought of as being safer than having no one to follow.

Lateral Placement

During daylight, the lateral placement of automobiles was farther from the right edge line after the lights were installed. Also, the placement was farther from the edge line during fog for both the before and after periods than it was during clear weather conditions. Both automobiles and tractor-trailers were positioned farther from the edge line for nighttime fog conditions than for clear conditions.

Accidents

It would be difficult to surmise what, if any, increase in accident potential would result from the differences noted in traffic flow parameters. There has been only one accident during fog conditions since the system of lights was installed. Also, in a recent subjective evaluation of the system, more than 95 percent of the motorists interviewed indicated that they were aided by the system and 90 percent reported that the lights reduced their anxiety while driving in fog (1).

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Driver Performance with Right-Side Convex Mirrors

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The mirror-use behavior of drivers was investigated as they gathered information from rearview mirrors in order to execute freeway lane changes and merges. Nine drivers (three novice, three experienced, and three mature) drove a 1973 Buick LeSabre with and without a right-side fender-mounted convex mirror along a 22.5-km (14-mile) freeway route. The total time to obtain information per maneuver was the same for both cases. In a subsequent study, the mirror-use behavior of five subjects who drove a 1976 Nova without a right-side convex mirror was compared with that of 12 subjects who drove the same vehicle with a right-side door-mounted convex mirror. Again there were no differences in total time to obtain rear-vision information. Experienced drivers (mean age = 24) took less time to obtain information when a right-side convex mirror was available than when it was not; older drivers (mean age = 61) took more time. Also, experienced drivers required about 10 h of driving experience to become efficient users of a right-side convex mirror, while older drivers required considerably more driving experience. Finally, a comparison of right-side door- and fender-mounted convex mirrors indicated that the drivers' total time to obtain information was the same for each mounting location, but drivers who had the fender-mounted mirror made a greater number of direct looks to the rear.

Some drivers may find it difficult to obtain the proper information necessary to execute lane changes and merges to the right. Factors that contribute to this difficulty include the following: (a) plane mirrors located on the right door do not always provide an adequate field of view, (b) sail panels located at the right rear of the vehicle can obstruct vision, (c) high head restraints can restrict the vision of short drivers, and (d) physical afflictions and old age can restrict turning one's head to

Table 1. Subjects' ages and distances driven, by groups.

	Group 1		Group 2		Group 3		Group 4	
Subject	Age (years)	Distance Driven (km 000s)	Age (years)	Distance Driven (km 000s)	Age (years)	Distance Driven (km 000s)	Age (years)	Distance Driven (km 000s)
1	16	4.0	20	120	17	55	21	39
2	21	0.8	23	80	18	40	21	320
3	26	5.6	24	240	20	24	22	97
4	23	113	47	480	20	48	23	48
5	24	130	69	480	21	48	23	97
6	25	72			21	320	54	80
7	42	320			43	390	55	160
8	46	400			44	160	58	72
9	51	560			49	48	60	80
10					54	80	61	140
11					60	80	62	160
12					63	800		

Note: 1 km = 0.6 mile.

make direct looks to the rear.

One way to improve right-rear vision is to mount a convex mirror on the right side of the vehicle. A convex mirror of relatively small size [13.3 cm (5.25 in) wide] and moderate radius of curvature [102 cm (40 in)] will provide an adequate field of view (19-20°) for detecting vehicles located at the right rear of the vehicle. For calculation of field-of-view requirements, see Sugiura and Kimura (1).

Since the radius of curvature of a convex mirror is less than infinity, objects appear smaller than they would in a plane mirror. The viewing of these minified objects may result in erroneous distance judgments; that is, drivers may judge vehicles to be located further to the rear than they actually are. Several investigators have studied this problem (2-4) and have found that drivers can misjudge distances when they use convex mirrors. Walraven and Michon (4) reported that experienced drivers would accept smaller traffic gaps than inexperienced drivers, suggesting that judgment would improve with training. Also, Mortimer (5) found that, when drivers use the inside mirror in conjunction with an outside convex mirror, misjudgments in distance do not occur.

Furthermore, when a convex mirror is used as a "go or no-go" device (6), distance judgments are irrelevant. In a "go or no-go" situation, a driver simply uses the convex mirror to detect a vehicle's presence. If no vehicle is present, the driver proceeds with the maneuver. If a vehicle is present, the driver checks its actual location by using the inside mirror or by a direct look to the rear.

Burger and others (7) have collected data on drivers' glance behavior with convex mirror systems while the drivers executed left and right maneuvers in freeway and city traffic. They found that when a right-side fender-mounted convex mirror was available drivers made fewer direct looks to the side or rear of the vehicle than when it was not available.

Questions to be answered by means of the present research include the following:

1. How does the information-gathering behavior of drivers change when a right-side convex mirror is available? Will drivers use the convex mirror in actual traffic situations, and will they take more or less time to obtain information? A survey by Kaehn (8) found that drivers of government vehicles who used right-hand convex mirrors were impressed by the improved field of view.

2. Does convex-mirror-use behavior differ according to the age of the driver? As Mourant and Rockwell (9) reported, young novice drivers make very little use of the left-side mirror and hence are likely to make little use of the right-side convex mirror. Older, mature drivers have ingrained information-gathering habits and therefore will probably take a longer time to become accustomed to the convex mirror. Even though older drivers, in general, have poorer vision than younger drivers, the location of the convex mirror on the right side of the vehicle places it far enough away from the driver so as to eliminate the necessity for large changes in eye accommodation (as well as reducing the need for a head turn to the rear). Thus, as noted by Seeser (10), older drivers will not need corrective lenses to view it.

3. How long does it take drivers to learn to use convex mirrors? Since little is currently known about how drivers use a right-side convex mirror as a detection device, especially how it is used in conjunction with inside mirror glances, it may be difficult to tell when drivers have become highly skilled convex-mirror users. However, since skill learning improves rapidly during the early part of training, it will be possible to detect when a learning plateau has been reached.

4. Does the location of the right-side convex mirror (door or fender mounted) affect the method and duration of information gathering? A door-mounted convex mirror requires a greater head turn from straight ahead, and it permits the use of peripheral vision to obtain more information. A fender-mounted mirror, on the other hand, requires only slight eye movement from straight ahead. If the fender- and door-mounted mirrors are of the same size and convexity, their fields of view will be about equal.

5. Does information obtained prior to the decision to execute a lane change affect subsequent information-gathering strategy? Realization that a vehicle is moving through a constantly changing environment suggests that the "memory effect" of information obtained prior to making a decision would be fairly short. This question was addressed mainly for methodological considerations. If there is no memory effect, different mirror systems may be compared by having drivers sample their mirrors whenever desired (the natural driving method). However, if there is a memory effect, then mirrors should be sampled only after the decision to make a lane change has been reached.

METHOD

Drivers

Table 1 shows the ages and distances driven for the four subject groups. All drivers had valid Michigan licenses and at least 20/40 visual acuity.

Design

The subjects performed in four groups:

Group	Condition
1	Exploratory
2	Training
3	Door-mounted mirror
4	Fender-mounted mirror

Group 1 subjects drove a 1973 Buick LeSabre first with conventional mirrors and then with a 102-cm (40-in) convex mirror mounted on the right front fender. The conventional mirror system consisted of the inside and left outside mirrors supplied by the manufacturer. Subjects practiced using the convex mirror for about 200 km (125 miles) before data collection. In this exploratory study, subjects 1-3 were novice drivers, subjects 4-6 were experienced drivers, and subjects 7-9 were mature drivers.

Group 2 subjects drove a 1976 Nova Concours twice with conventional mirrors, six times with a door-mounted 102-cm convex mirror, and finally twice again with conventional mirrors. Before each convex-mirror run, subjects practiced using the convex mirror for about about 4 h or 320 km (200 miles). Thus, every subject had more than 1600 km (1000 miles) of driving experience with the convex mirror before the start of the sixth convex-mirror run. Subjects 1-3 were experienced drivers, subject 4 was mature driver, and subject 5 was an older driver.

Subjects in groups 3 and 4 also drove the 1976 Nova Concours. For group 3 the 102-cm convex mirror was door mounted, and for group 4 it was fender mounted. Both mirrors provided about the same field of view (20° horizontal) as measured by Society of Automotive Engineers (SAE) recommended practice J1050. After each subject had driven the Nova for about 12 h or 970 km (600 miles), four data-collection runs were made. Group 3 subjects 1-6 were experienced drivers, subjects 7-9 were mature drivers, and subjects 10-12 were older drivers. Group 4 subjects 1-5 were experienced drivers and subjects 6-11 were older drivers.

Procedure

Data were collected as subjects executed lane changes on a 22.5-km (14-mile) freeway route that had moderate to heavy traffic. Data collection for each maneuver was initiated 15 s prior to the execution of the maneuver. Execution of the maneuver occurred when the leading edge of the test vehicle crossed the lane marking.

Drivers were instructed to align both left and right outside mirrors so that a small portion of the vehicle was visible in the inboard edge of the mirror. Drivers were told to use the right-side convex mirror as a "go or no-go" device. If a vehicle was present in the convex mirror, the driver was to check its location by a glance to the inside mirror or a direct look. All subjects drove the test vehicle for at least 30 min before data were collected, so that they could become familiar with the route and vehicle-handling characteristics.

Before the start of data collection, subjects were read the following instructions:

> You are to execute either left or right lane changes upon command of the experimenter. However, please check for possible traffic in the adjacent lane before proceeding to make the lane change. Please use the convex mirror as a "go or no-go" device. That is, if a vehicle is present, check its location by a glance to the inside mirror or a direct look to the rear. If no vehicle is present in the convex mirror, you may want to proceed with the maneuver. Do you have any questions?

Data Collection Equipment

A closed-circuit television system consisting of four television cameras, special-effects electronics, an electronic counter, a video monitor, and a videotape recorder was installed in the rear passenger compartment of the test car. Power was supplied from an inverter connected to the vehicle's battery.

One camera monitored the driver's eyes through a front surface mirror mounted on the instrument panel, and a second camera monitored the road scene ahead of the vehicle. Two additional cameras separately monitored the road scene on the left rear and on the right rear. The video display from each camera appeared simultaneously as one of four separate sections of each television frame. Each frame was also numbered by the electronic counter; these numbers were then used to calculate glance durations. An experimenter seated out of view of the driver in the rear passenger compartment could view the scenes from all four cameras simultaneously on the monitor while the information was being videotaped.

RESULTS

Mirror Use With and Without a Right-Side Convex Mirror

The top part of Figure 1 contains the information-gathering data for nine subjects (group 1) who drove a 1973 Buick LeSabre with and without a 102-cm-radius convex mirror mounted on the right front fender. To obtain the necessary information for a right lane change, drivers averaged 2.65 s/maneuver without the use of a right-side convex mirror and 2.84 s/maneuver with the use of a right-side mirror. The increase in time with the use of a convex mirror was not statistically significant ($t = 0.11$; $df = 8$). Note that the number of glances made to the vehicle's inside mirror decreased when the convex mirror was available. None of the nine subjects had any previous driving experience with convex mirrors, which probably accounts for the approximately equal amount of time spent making direct looks with (0.38 s/maneuver) and without (0.36 s/maneuver) the use of the right-side convex mirror.

The lower part of Figure 1 contains the information-gathering data for 5 subjects (group 2) who drove a 1976 Nova Concours without a right-side mirror and 12 subjects (group 3) who drove the same vehicle with a 102-cm-radius convex mirror mounted on the right door. Group 2 drivers averaged 2.95 s/right lane change and group 3 drivers averaged 2.86 s. The decrease in time with the use of a convex mirror was not statistically significant ($t = 0.46$; $df = 22$). However, drivers' mirror-use behavior when a convex mirror was available was dramatically different from that observed when the vehicle had no right-side convex mirror.

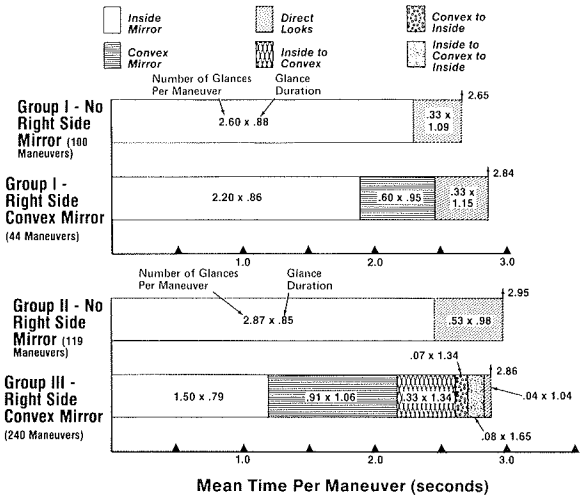
Group 2 drivers averaged 0.52 s/maneuver for direct looks when the vehicle had no right-side convex mirror, and group 3 drivers averaged only 0.04 s/maneuver when the convex mirror was available. Group 3 drivers made "combination looks." That is, they sampled the inside mirror and then moved their eyes directly to the convex mirror before returning to look at the road scene ahead. Other combination looks were from convex mirror to inside mirror and from inside mirror to convex mirror to inside mirror. These combination looks resulted in the inside mirror being sampled 1.98 times/maneuver and the convex mirror being sampled 1.39 times/maneuver.

Mirror Use Behavior as a Function of Age

Figure 2 contains the information-gathering data for experienced, mature, and novice drivers of a 1973 Buick LeSabre. The mature drivers took 3.47 s to obtain information when the convex mirror was available and only 2.55 s when no right-side convex mirror was available. The additional time with the use of the convex mirror was due to the fact that the mature drivers sampled the convex mirror on the average of 0.93 times/maneuver. Both the experienced and novice drivers took less time to obtain information when the convex mirror was available than when it was not. However, the novice drivers averaged sampling the convex mirror every fourth maneuver, while the experienced drivers averaged sampling it every second maneuver.

Figure 3 contains the information-gathering data for experienced, mature, and older drivers of a 1976 Nova Concours. The experienced drivers who had a right-side convex mirror (group 3) averaged less time per maneuver than the experienced drivers who did not have a right-side convex mirror (group 2). However, the mature and older drivers who had a right-side convex mirror (group 3) averaged more time per maneuver than the mature and older drivers who did not have a right-side convex mirror (group 2). These results agreed with those for the Buick drivers. Note also that drivers made very few direct looks when a right-side convex mirror was available.

Figure 1. Information-gathering data for right lane changes with and without a right-side convex mirror.



Training Results

Figure 4 contains the information-gathering data averaged over all group 2 drivers for four control runs (no right-side convex mirror) and six convex-mirror runs. After the first convex-mirror run, the frequency of inside-mirror use alone decreased dramatically. On convex-mirror runs 3, 4, 5, and 6, the average total time per maneuver was very close to that of the control runs. Note also that when the convex mirror was available drivers made very few direct looks to the rear.

As there are in all training experiments, there were large individual differences in behavior. Figure 5 contains the information-gathering data for a 23-year-old male and a 69-year-old male. The younger driver's average time per maneuver on convex-mirror runs 4, 5, and 6 (3.20 s) was considerably longer than the average time on four control runs (2.65 s). Thus, this was an atypical young driver. Yet his behavior was different

Figure 2. Age and information-gathering data for right lane change with and without a right-side convex mirror: 1973 Buick.

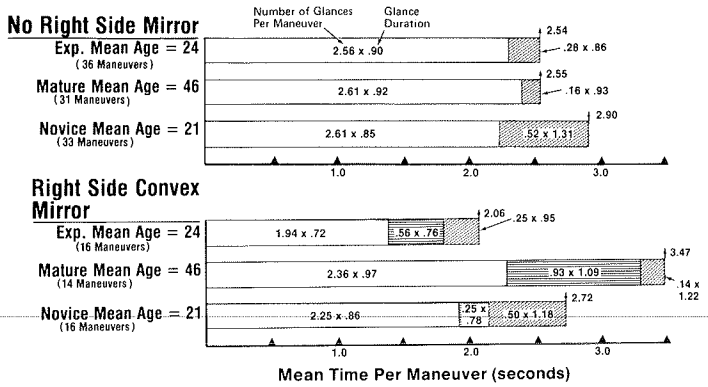


Figure 3. Age and information-gathering data for right lane changes with and without a right-side convex mirror: 1976 Nova Concours.

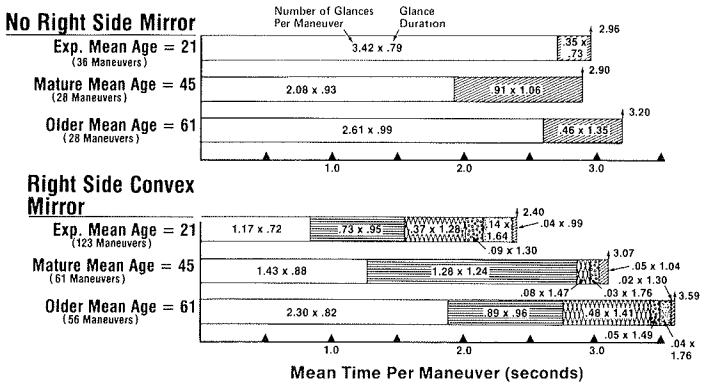


Figure 4. Effect of training on information gathering by group 2 for right lane changes.

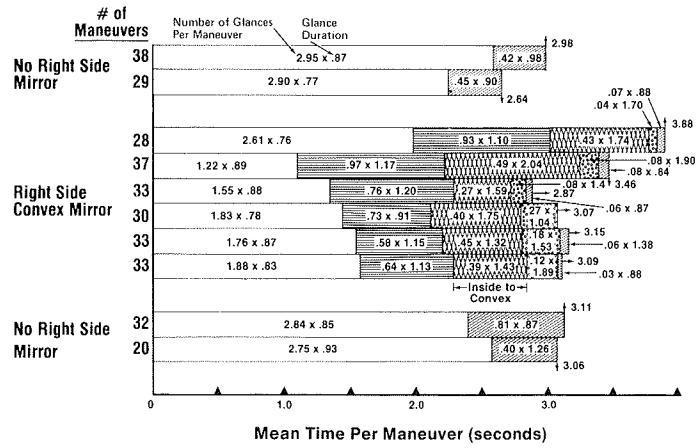


Figure 5. Effect of training for two individual subjects.

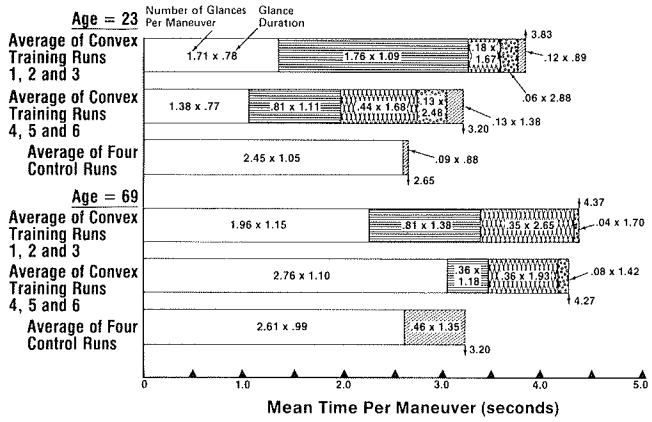
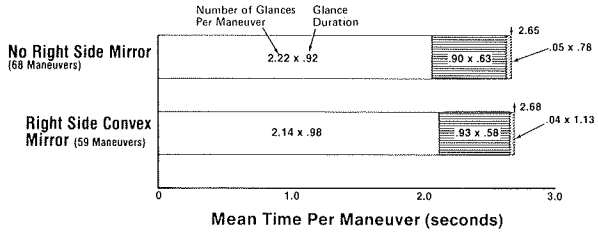


Figure 6. Information-gathering data for left lane change.



from that of the older driver, since his total time on convex-mirror runs 4, 5, and 6 was shorter than that on convex-mirror runs 1, 2, and 3. Apparently older drivers take a much longer time to learn sampling with the convex mirror than do younger drivers.

As an experimental control, driver mirror-use behavior in making left lane changes with the standard left-side mirror was also analyzed. These results are shown in Figure 6. Driver mirror-use behavior on the control runs was the same as that on convex-mirror runs 4, 5, and 6. Thus, such uncontrollable factors as traffic, weather, and driver motivation either had a negligible effect on the control and convex-mirror runs or they were averaged out.

Comparison of Door- and Fender-Mounted Convex Mirrors

Figure 7 contains the information-gathering data for run 4 with the door-mounted convex mirror (group 3) and with the fender-mounted convex mirror (group 4). Subjects who had the door-mounted mirror averaged 2.86 s to obtain information, while subjects who had the fender-mounted mirror averaged 2.89 s. This result might be expected, since the door- and fender-mounted mirrors provided about the same field of view.

However, there were differences between the two groups in their information-gathering behavior. While subjects who had the door-mounted mirror averaged only 4 direct looks/100 maneuvers, subjects who had the fender-mounted mirror averaged 40 direct looks/100 maneuvers. This may be due to the fact that use of the door-mounted convex mirror requires a larger turn of the eye or head from straight ahead and permits the use of peripheral vision on the right side. Use of the fender-mounted convex mirror requires a smaller eye turn from straight ahead but limits peripheral vision to the right side.

Memory-Effect Results

Figure 8 contains the information-gathering data for left lane changes of a restricted group of drivers (group 4) and a normal group of drivers (group 3). The restricted group of drivers was not permitted to sample any mirrors between commands to execute left lane changes. This behavior may be considered "memoryless" in that rear-vision information was gathered only after the command to execute a left lane change had been made. The normal group of drivers was permitted to sample all mirrors continuously. Thus, information gathered just prior to a command to execute a left lane change may have been useful in actually completing the lane change.

The restricted group of drivers averaged more time per maneuver to obtain information on runs 1 and 2, but on runs 3 and 4 both groups averaged about the same amount of time per maneuver to obtain information. On all trials, the average glance duration to the left outside mirror was longer for the restricted group of drivers than for the normal group of drivers, which may indicate that a more concentrated effort was being made to detect vehicles by means of the left outside mirror. The restricted group of drivers also made more direct looks to the rear than did the normal group of drivers, perhaps because they were unsure whether other vehicles were present in the area to their left side.

CONCLUSIONS

1. A right-side door-mounted convex mirror is an acceptable visual aid for drivers in obtaining informa-

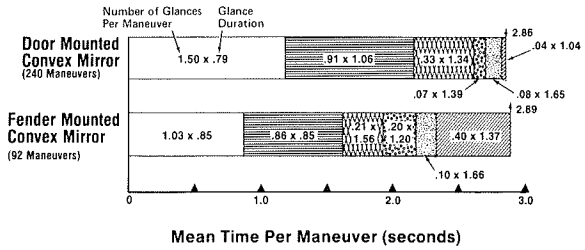


Figure 7. Information-gathering data for right lane changes with door-mounted and fender-mounted convex mirrors.

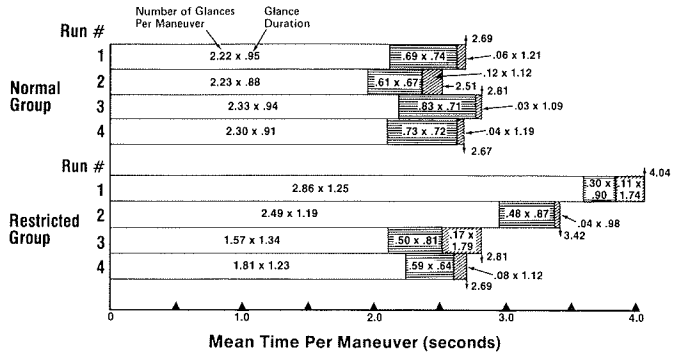


Figure 8. Information-gathering data for left lane changes for the normal and restricted group.

tion for right lane changes. The convex mirror enables drivers to substantially reduce the number of direct looks to the side and rear of the vehicle. Thus, short drivers and drivers who have physical afflictions that prevent head turns can effectively obtain information to execute right lane changes.

2. Older drivers spent more time sampling mirrors (plane and convex). This is supported by Kretovics (11), who found that older drivers turned their heads farther toward the mirror than younger drivers.

3. The use of the right-side convex mirror does not affect the use of the left-side plane mirror. Drivers took the same amount of time and used the same techniques to acquire left lane-change information whether the vehicle was equipped with a right-side convex mirror or not.

4. A fender-mounted convex mirror resulted in more direct looks to the side and rear of the vehicle than did a door-mounted convex mirror. Even though the fields of view for the fender- and door-mounted mirrors were about equal, drivers who used the door-mounted mirror apparently obtained information from their peripheral vision and therefore did not need to make as many direct looks to the right rear.

5. It appears that drivers do not rely on information obtained before a command to make a lane change. Since freeway traffic is so dynamic—i.e., vehicles move at 88 km/h (55 mph) and there are multiple lanes—drivers must obtain information immediately prior to the execution of a lane change. This makes previously obtained information of little value.

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Discussion

Thomas H. Rockwell, Department of Industrial and Systems Engineering, Ohio State University, Columbus

The authors are to be commended for their approach to this problem; indeed, the use of field studies for evaluation purposes is essential, albeit at some sacrifice of experimental control. Several of their experimental findings are consistent with my own work in mirror use. Glance durations are about right, although I would also like to see individual subject means and variances, since aggregation of the rate removes intrasubject and intersubject variation.

The paper is silent about the explicit instructions given to the subject and about the effect of traffic on individual maneuvers. I suspect that the velocity and density of the following traffic in relation to the subject's car would influence glance frequency and duration, as would the headways of automobiles directly ahead of the subject driver. These variables are difficult to measure, let alone control. I would like to have seen a components-of-variance analysis of key dependent measures as they were affected by such independent variables as lead-automobile headway, relative velocity and spacing of traffic following in the right lane, age, sex, and subject strategy.

The lack of sample sizes probably prohibited good estimates of intersubject and intrasubject variation, although both of these give insights into the quality of experimental control and interpretation of results.

The idea of using the left-side mirror sampling as an experimental control was an excellent one, particularly for trip-duration effects and driver attentiveness and less so for traffic effects. The authors' concern that peripheral vision may account for the sharp differences in mirror sampling for the fender- versus door-mounted mirrors is probably valid (40/100 versus 4/100 maneuvers). I understand that the door-mounted position was about 80° from line of sight. Data from an Ohio State University (OSU) study of 48 drivers (using their own cars in freeway lane changes and merges) that involved 7000 mirror samples indicated that head turns cover 50 percent and eye movements 50 percent of the angle between line of sight and the mirror (11). A 40° head turn in this case (to use the door-mounted mirror) might have allowed peripheral detection of target automobiles.

The OSU study also showed that age effects are significant in glance durations and head turns, but we found older drivers making greater head turns than younger drivers. (Older in this case was defined as over 45.) Previous research at OSU indicated larger eye-search patterns among older drivers, perhaps indicating less confidence in peripheral detection. We also found that sex, driver height, and automobile size had little effect on left-side and inside mirror sampling.

The issue of memory probably is more important when drivers overtake vehicles and return to the right lane and may account for certain mirror sequence sampling. In that regard, were the differences in certain combinations of mirror sampling found in group 3 (and in group 4) and not in group 1 the result of automobile type or experience?

The authors are encouraged to plot glance frequency against glance duration; i.e., do successive glances produce shorter durations? Finally, we need to probe for the driver's strategy in mirror use; i.e., does the driver depend on the convex mirror for detection, evaluation, and decision information or does he or she use the convex mirror for detection and use other mirrors or direct looks and memory for the evaluation and decision processes?

As to the final judgment on convex mirrors, I believe that this must wait until we ascertain the quality of resultant maneuvers and can be assured of minimal acclimation time. I presume from the paper that the experiments were not conducted in high-density traffic with its attendant stress. This condition might be the ultimate test of convex mirrors as aids to information acquisition in driving.

Robert L. Henderson, National Highway Traffic Safety Administration

My remarks are directed, by request, at providing additional data on the general subject of convex mirrors rather than discussing the authors' paper.

I would like to describe briefly a National Highway Traffic Safety Administration (NHTSA) contract I am managing that will eventually examine a rather large number of rearview mirror systems. It is being conducted for us by Bill Burger at Vector Research. The basic objective of the study is to evaluate driver mirror-use behavior while performing in-traffic maneuvers. The study uses a variety of mirror systems designed to meet the requirements of a proposed new federal motor vehicle safety standard. Measures of mirror and direct glance frequency and duration similar to those reported by Mourant and Donohue will be the major criteria measures. A repeated-measures design will be used in which the same 12 subjects will use all mirror systems.

Data collection on this main portion of the study is now in progress. The data I will present today were collected in the first phase of the study for the express purpose of selecting the radius of curvature for the convex-mirror component of those systems that use convex mirrors.

The literature indicates that a 51-cm (20-in) radius of curvature is probably the maximum usable convexity because of image minification and distortion. At the other extreme, when the radius exceeds about 203 cm (80 in), the limited gain in the field of view over a less expensive plane mirror does not justify the added cost. We have selected four specific values from within this range for this study—51-cm, 102-cm (40-in), 140-cm (55-in), and 203-cm radii of curvature. Unlike some past studies in which mirror size is held constant as convexity varies, we held field of view constant for all convexities by varying the size of the mirrors. The question we wished to answer was whether there is an optimum convexity and, if there is, whether that optimum value varies as a function of the presence of other mirrors in the system.

METHOD

Three vehicles were used; each vehicle had a mirror system designed specifically to meet the requirements of the proposed new mirror standard. The vehicles were a passenger automobile, a light truck, and a van. Two types of mirror systems were employed on the automobile. The first type used two plane mirrors: one inside and the other on the left outside. Each of these mirrors was slightly larger than that found on passenger automobiles today. The second type used a left outside plane mirror somewhat larger than standard, a standard inside plane mirror, and a right outside convex mirror. The convex mirror (radius of curvature of 51, 102, 140, or 203 cm) was systematically varied.

The second type of automobile mirror system was

also used on the van and the pickup. In addition, these two vehicles were tested with a combination plane and convex mirror on each side and with a single convex mirror on each side. The convexity was again varied among the four levels described earlier.

A semidynamic test condition was used to obtain distance, speed, and gap-acceptance judgments. Subjects viewed a target automobile approaching their own static vehicles through the mirror system of interest. Each of 12 subjects was tested by using each of 45 rearview systems properly counterbalanced in a repeated-measures design. These same 12 subjects will be used later in our on-the-road studies. A total of 11 880 trials were run. Each subject has two blocks of eight speed and distance judgments and six lane-change judgments for each mirror system. For all trials, subjects also performed a forward tracking task for perceptual loading.

RESULTS

1. Learning: Significant learning effects were noted for all mirror systems. Because of the counterbalanced order of presentation, no clearcut and consistent learning curves were noted for specific mirror systems. In spite of the relatively large number of trials, it appears that learning is still taking place after approximately 900 trials, indicating that learning to use convex mirrors is a long-term phenomenon.
2. Relative distance error: Examination of the overall relationship between convexity and overestimates or underestimates of distance indicates some trends, but the magnitude of the differences is so slight as to indicate no practical significance.
3. Absolute distance error: There was little difference in average error as a function of mirror convexity. The same is true for the standard deviation. Although some of the differences were statistically significant, the practical differences are trivial.
4. Gap acceptance: We found small but fairly consistent trends toward better gap-acceptance performance from larger-radius mirrors. Best performance at all convexities was found in mirror systems in which a plane mirror was in close proximity to the convex mirror.
5. Subjective ratings: Perhaps the clearest and most consistent trends were found in the subjective ratings. Highly curved mirrors were consistently judged to be more difficult to learn and to produce less confidence than less highly curved mirrors.

These data provide very little guidance for selecting the convex-mirror component of the systems we are using in our on-the-road study. Although certain trends are evident, in most instances the magnitude of the observed differences is so small as to have little practical significance. Consequently, we selected the convex-mirror components after considering the general literature, the trends observed in our data, the extent of the obstruction to direct field of view, and judgments concerning what manufacturers might prefer for aesthetic reasons or for overall standardization. For your information, we are using 140-cm radius of curvature for the right outside mirror for all systems that involve plane mirrors on the inside and left outside. For truck and van systems that use combination plane and convex mirrors on both sides of the vehicle, we are using 51-cm-radius convex mirrors. For the truck and van systems that use a single convex mirror on each side, the 102-cm radius of curvature was selected.

I appreciate the opportunity to describe this project and hope that next year we will be able to report the results of the on-the-road study.

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Historically, U.S. automobiles have been fitted with plane interior and exterior mirrors. The field of view available from a plane mirror is determined by the size of the mirror and its distance from the eyes of the driver. With respect to the exterior left-side mirror, the lateral field of view can be increased by increasing the size of the mirror along its horizontal axis. While there are some limitations on the extent to which the mirror can be extended (due to limitations on the overall width of motor vehicles), it is possible to obtain improvements in the horizontal field of view to the left of the vehicle by improving the design location of the exterior left-side mirror and increasing its width. However, this is not feasible with a plane mirror mounted on the right side of the vehicle, because of its much greater distance from the eyes of the driver.

A simple solution to increasing the field of view from exterior mirrors is to use convex mirrors. Convex mirrors have been used by European and British drivers for years, mounted on the door or fender; a significant precedent therefore exists to suggest that they can be used safely. However, U.S. manufacturers have not felt that American drivers would willingly accept convex mirrors and have been concerned with the effects that such mirrors can have on distance judgments because of the minification of objects.

To this end, a number of studies have been completed during the last decade concerning the ability of drivers to make various kinds of judgments related to the use of rearview mirrors in order to compare performance with plane versus convex exterior mirrors. These studies have used various types of measurements, such as the frequency and duration of glances in interior and exterior mirrors (12), detectability of vehicles in dusk or dawn illumination (3), subjective evaluations of the effects of headlight glare in rearview mirrors (3), distance judgments (13), and gap-acceptance judgments (2-5).

As Mourant and Donohue have pointed out in their paper, the balance of these studies indicated that drivers overestimate the distance of a vehicle seen in a convex mirror, i.e., judge it to be further away than it really is, although, in a normal driving situation, when a driver also has available the plane interior mirror, the judgments made when a convex exterior mirror or a plane exterior mirror were used were the same. Thus, it would appear that drivers can make safe judgments with exterior convex mirrors, though their eye-fixation patterns were somewhat different than when a plane exterior mirror was used.

The present study was concerned with eye-fixation behavior of drivers who used plane and convex exterior mirrors mounted on the right side of the vehicle. Two locations were selected for mounting of the mirror: on the right door and on the right fender. Other variables investigated were the effect of driver experience and age, effects of learning, and the effect of information obtained from rearview mirrors shortly before the decision was made to execute a lane-change maneuver, which the authors termed the memory effect.

The authors used a video recording technique to ascertain the frequency and duration of glances made by drivers in lane-change maneuvers and measured the frequency and duration of glances in each of the rearview mirrors. The emphasis in the study was on the comparison of mirror use with and without a convex mirror on the right side.

It is important to note one aspect of the instructions given to the subjects. The subjects were told to use the

right-side convex mirror as a "go or no-go" device. Furthermore, if a vehicle was noted in the convex mirror, the driver was to check its location by a direct glance to the rear or by use of the inside mirror. Thus, any findings from this study will be limited because of the nature of the instructions given to the subjects about how they should use the convex right-side mirror. Clearly, the instructions were such that subjects were discouraged from using the right-side convex mirror to make estimates of distance or relative velocity of a vehicle seen in the right lane before making a lane change. One effect of this type of instruction would naturally be to increase the proportion of direct glances the drivers would make when using a right-side convex mirror in relation to driving without it. Based on the data presented (for example, in Figures 3 and 4 there were relatively few direct looks to the rear when a convex mirror was used and there were relatively few glances from the convex mirror to the inside mirror), it appears that there were few occasions when there was a vehicle visible in the convex mirror at the time that a decision to make a right lane-change maneuver was made. There is no indication given in the paper as to the proportion of maneuvers in which a vehicle was reasonably close to the subject's vehicle when the command was given to execute the maneuver, either when the right-side mirrors were in use or without them. It would seem that this could have been an important piece of data that should have been available from the video recordings and might have been taken into account in explaining some of the findings.

I was somewhat concerned that there were relatively few subjects used in some of the conditions. For example, the findings in Figure 2 are based on the result of only three subjects in each of the age and experience groups. So few subjects would scarcely be enough to allow reasonable differences to be discovered between categories of this variable.

However, it was refreshing to see the findings in Figure 6, which indicated that, when mirror-use behavior was observed in left lane changing for the five subjects in group 2, the performance in left lane-change maneuvers was very similar when the vehicle was equipped with a right-side convex mirror and on a set of control runs when it was without the right-side mirror. This indicates that the overall procedure appears to have a good degree of reliability, at least when 60 or more maneuvers are involved.

The authors also address the effect of the age of the drivers. In this case, there were substantially more subjects available in the two groups (groups 2 and 3) that were used for this comparison, which showed that experienced drivers required less time to obtain mirror information than mature and older drivers when a right-side convex mirror was available, whereas without the right-side convex mirror all three groups required approximately the same amount of mirror information-gathering time.

A comparison is also shown, in Figure 7, between door- and fender-mounted right-side convex-mirror performance. This figure appeared to be based on the comparison of the performance of the 12 subjects in group 3 and the 11 subjects in group 4 who had a mean time to obtain rear-vision information of 2.86 s and 2.9 s, respectively, for the door-mounted and fender-mounted convex mirror. It appeared to me, however, that this comparison was confounded by differences between these two groups. Group 3 was described as carrying out the experiment in the normal mode of mirror scanning, whereas group 4 was restricted in scanning behavior; i.e., the subjects were not permitted to scan the mirrors until the command had been given by the experimenter to begin a lane-change maneuver. The purpose was to permit evaluation of the memory effect. It seems to me that these two groups should not be used to compare another variable. The effect of fender mounting versus door mounting of the convex mirror could perhaps be obtained from the data obtained on group 1, which carried out the normal task with a fender-mounted convex mirror on the right side, compared with group 3, which performed the task with the convex mirror mounted on the right door. In that comparison, the mean time to obtain information was 2.84 and 2.86 s for the fender- and door-mounted convex mirrors, respectively.

The concept of evaluating the memory effect is certainly an interesting one and shows that the authors were sensitive to many subtle variables that could affect driver behavior with rearview mirrors. This effect was evaluated by comparing a group operating in the normal mode with a group operating in the restricted mode in making left lane-change maneuvers. While the information-gathering time was substantially longer on the first two (out of four) trials in the restricted group, indicating a potential memory effect, there were no differences in the subsequent two trials. While this might indicate that the memory effect had been erased by the third and fourth trials, I feel that this is not likely. Is it possible, for example, that a motivational effect was operating, due to a slightly greater stress imposed on the subjects and the interaction with the experimenter, who called out the command to begin the lane-change maneuver?

Based on the viewing behavior that was measured in this study, it does seem reasonable that convex mirrors could be used on the right side of the vehicle. The total amount of time spent viewing mirrors was not increased significantly by the addition of this third mirror on the right side. Certainly, a convex right-side mirror of adequate size and moderate radius of curvature, such as that used in these studies, would greatly improve the field of view to the right of the vehicle, where the present use of a plane mirror or no mirror at all provides a potentially hazardous blind spot.

Although this study indicated that the fender-mounted convex mirror resulted in more direct looks to the side and rear of the vehicle than did a door-mounted convex mirror, this should not be taken to imply that a fender-mounted location is undesirable. Location on the fender has some additional advantages, such as actually providing a greater field of view to the right. This is particularly valuable in dense traffic when another vehicle is close by on the right side and potentially outside the field of view of a door-mounted mirror but visible in a fender-mounted mirror. Secondly, a fender-mounted mirror requires less divergence of the eyes from the forward field of view, which is the most important location to be scanned by the driver in normal driving situations.

This study has been useful in taking a look at age and maturational factors. Certainly, more data of this type would be valuable.

In this context, the authors have studied the memory effect, which was of considerable interest and requires further study. The memory effect could be particularly important in those emergency situations where there is little time to obtain additional visual information and a rapid decision must be made as to the most appropriate evasive maneuver to make. In such cases, there may be little or no time for adequate mirror scanning to determine the locations of other potential vehicles, and the memory effect could be of critical importance. Eye fixations of experienced drivers indicate that they scan the environment all around the vehicle frequently; it may be premature to suggest that drivers do not retain an

appraisal of the location of other vehicles around them in short-term memory.

Finally, one might legitimately ask what the relevance of obtaining frequency and duration of glance behavior in mirrors is in relationship to accidents in which rear-vision information may have been inadequate? The overall duration of mirror glances would be important in those situations where little time is available to make a decision in an evasive maneuver. On the other hand, the quality of the information that is obtained is also critical. Thus, one might ask whether drivers obtain more accurate information concerning the location, distance, and relative velocity of other vehicles with a right-side convex mirror than with no mirror on the right side and how safe the resulting lane-change maneuvers are. The latter question was not addressed in this study. This raises the issue of the relevance of performance criteria in rear-visibility studies. Perhaps such criteria cannot be structured properly until more information becomes available as to the underlying causes of crashes that involve inadequacies in visibility to the rear.

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Authors' Closure

Both Mortimer and Rockwell had positive comments on the use of left lane-change data for experimental control purposes. These left lane-change data indicated that the effects of traffic, weather, and driver motivation were averaged out when computed over 60 left lane-change maneuvers. These data may also serve as a standard reference when considering driver search behavior with reference to left lane changes. In this regard, the data show that drivers made only six direct looks to the rear while executing 127 left lane-change maneuvers. However, drivers did rely heavily on their left outside mirrors; they looked at them more than twice per maneuver.

Concerns were voiced about the small number of subjects in the study of age effects. We agree that more data should be collected on this very important variable. The data could be used to develop aids and countermeasures for the older driver. Perhaps older drivers will find convex mirrors useful, in that they will partially eliminate the need for head turns to the right rear.

It should be noted that all data were collected while driving on freeways in the city of Detroit in moderate to heavy traffic. We considered this to be a very demanding task for most drivers. Thus, instructions to the subjects probably had very little effect on driver performance. Many times, when the experimenter gave the command to execute a lane change, other traffic in adjacent lanes prevented the subject from immediately executing the maneuver. Thus drivers had to search by using their mirrors or by making direct looks to determine when to proceed with the lane change. Because the traffic flow on the freeways was always moderate to heavy, it had little effect on comparisons between door- and fender-mounted mirrors.

Since the data in this study have shown that the use of a door-mounted convex mirror has reduced the frequency of direct looks per 100 maneuvers from 40 (with no right-side mirror) to 4, we believe that automobile drivers will have no problem in using a right-side convex mirror.

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Human Factors Considerations for In-Vehicle Route Guidance

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This paper considers the development and maintenance of credibility in the design, implementation, and operation of a route guidance system. Because drivers will have positive attitudes about a system that provides them with relevant, reliable, and accurate information, all precautions must be taken to ensure that these driver expectations are met. Messages must be presented clearly and must allow ample time for the driver to respond to a given situation. Factors that affect reading time of displays include driver work load, message load, message length, message familiarity, and display format. In order to maintain driver credibility, surveillance must be an integral part of a route guidance system. Such surveillance must be able to detect adverse conditions, validate the adverse conditions, and determine the nature and scope of the problem. Electronic sensor surveillance, however, has some limitations. Because it is a blind system, (a) some form of visual validation and assessment of incidents to ensure the accuracy of displayed messages and (b) some guarantee of adequate system maintenance are necessary. A "forgiving" system—one that alerts the driver and provides instructions about how to return to a scheduled route after a diversion—must also be considered.

An important consideration in a successful route guidance system for the United States (where success is measured by achieving desirable driver response) is to develop and maintain credibility, that is, driver faith in the system. The quickest way to fail is to lose driver confidence. The most elaborate and costliest system can