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16. Abstract

This laboratory study evaluated the effect of three types of driver-side, exterior mirrors on drivers' response times for detection of cars at near distances in the left adjacent lane. The mirrors were a flat mirror, a convex mirror, and a multiradius mirror. All mirrors were of the same size and reflectivity. The drivers' visual field in the mirrors extended diagonally to the left about 20° for the flat mirror, 28° for the convex mirror, and 40° for the multiradius mirror. Consequently, there was a large blind spot using the flat mirror, a smaller blind spot using the convex mirror, but no blind spot using the multiradius mirror.

The primary task was to respond as quickly as possible to the presence or absence of a car in a photograph projected on a large screen behind the subject. (A secondary, loading task involved compensatory tracking.) The subjects responded by pushing one of two response buttons, depending on the presence or absence of the car. Time was measured from the onset of the photograph's appearance to the subject's response.

The main result is that the response times were shortest when using the multiradius mirror and longest when using the flat mirror. This was the case for younger and older subjects, as well as for American and Swedish subjects.

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CONTENTS

INTRODUCTION

Currently, all cars are equipped with an interior flat mirror supplemented by a left and often also a right exterior mirror. In order to collect information from the rear field of view, a driver looks in the interior mirror to see what is going on straight behind the car, and in the exterior mirrors to see the adjacent lanes. The visual fields of the interior and the exterior mirrors overlap partially so the driver should have no problem in seeing the distant rear field of view (provided that the driver selects the correct mirror to get the information). However, if the exterior mirrors are flat, there are blind spots diagonally to the right and left close to the observer's car. Consequently, the driver has no access to the information in the blind spots. Thus, exterior flat mirrors do not provide a full view of traffic to the rear.

Drivers should direct their attention as much as possible in the direction of travel. By doing so they maximize the available time for responding to events in front of the car. These events often require more-or-less immediate adaptive actions. Periodically, the driver also has to examine what is going on behind the car. Consequently, the time required to access information about the traffic situation behind the driver should be as short as possible.

When drivers look into their rearview mirrors, they are still able to obtain some information about the direction of travel through peripheral vision. This is the case because both the interior and left exterior mirrors are mounted about 45° from straight ahead. In contrast, when drivers turn their heads to check traffic to the rear, there is no forward view. Consequently, if there is an event in the direction of travel that requires an immediate response, the response is likely to be delayed. Therefore, an ideal set of rearview mirrors would quickly and accurately provide drivers with the information they need from the rear and simultaneously allow them to monitor major events in the direction of travel.

The problems with blind spots in rearview mirrors has been discussed for a long time (see e.g., Gibson and Crooks, 1938). Over the years, technically sophisticated solutions have been proposed but have not been introduced in the marketplace. The rearview mirrors of today are not very different from those of fifty years ago. Since then, the problem of giving the driver easy access to the information about events to the rear has probably become worse because of the general increase in traffic density and because of more frequent driving on multilane highways. The problem remains to be solved.

In the U.S.A., driver-side exterior mirrors are flat, while in Europe and Japan they are convex. There is a trade-off between image size and the size of the visual field. The size of the image of an object is relatively large in flat mirrors. (The image has the same size as seen in direct vision from the observer's virtual point of observation in the mirror.) On the other hand, the field of view is relatively small. The opposite is true for convex mirrors: The image is minified and the visual field is comparatively large.

There are also concerns about perception of distances and relative speeds of cars approaching from behind. The distance to a rear car appears larger in convex mirrors than it does in flat mirrors, but the perceived rate of closure is independent of mirror type (Helmers, 1974). Yet, data are inconclusive about the differential effect of flat and convex mirrors on driver behaviors and decisions. Walraven and Michon (1969) and Bowles (1969) carried out experiments in full-scale driving situations in which the subjects watched the rearview mirror when a (stimulus) car approaching from behind met a certain distance-speed combination. The subject's task was to decide whether to make a passing maneuver or not. Their results showed only small differences between flat and convex mirrors. Mortimer (1971) carried out a similar full-scale field simulation, but the subjects' task was different. They were continuously exposed to the mirror so they could see the approaching car and were instructed to make the passing maneuver at the last safe moment. The results showed large differences between flat and convex mirrors, although, these differences disappeared when the subject had a supplementary flat interior mirror.

Information to the driver about presence of cars at very close distances is of major importance for evaluation of mirrors regardless of whether or not there is a difference in perception of distance and speed. The rationale for this is that if a car is driving at very close distances (e.g., in the adjacent lane diagonally behind the driver) any lane-changing maneuver should be avoided. This logic is the basis for the present investigation of drivers' detection of cars at visual angles diagonal to the rear that are not covered by conventional mirrors.

An innovative exterior mirror, which has no lateral blind spot, was introduced on the Swedish market by Volvo in 1979 (Pilhall, 1981). This mirror has a multiradius surface composed of two areas: a spherical convex main area that fulfills the ECE regulation for rearview mirrors, and an adjoining peripheral area that has an accelerated curvature toward its far edge. The continuity of the entire specular surface is good, including the transition zone between the two areas. This mirror yields continuous images of objects over an exceptionally wide field of view. Today, this type of mirror is mounted on the driver's side of all Volvo and Saab cars made for the European market. The main area of the mirror has a relatively large spherical radius (about 2100 mm), and the transition between the two areas is marked with a dotted line (Volvo) or a solid line (Saab). However, we are not aware of any published evaluations of the effects of multiradius mirrors on human performance.

One of the most difficult and demanding driving tasks is to shift attention from the forward field of view to check for cars traveling at short distances in the nearest adjacent lanes to the right and left. Drivers collect information from these areas by looking into their exterior rearview mirrors and by making large head and eye movements for a direct view diagonally to the left and right. Before changing lanes, drivers should make such an examination. If they fail to detect a vehicle that is located diagonally behind in the lane they are about to enter, accident risk is substantially increased.

The present study was designed to evaluate the potential benefits of convex and multiradius driver-side mirrors compared with the benefit of flat mirrors. The experimental setup involved a laboratory simulation of a typical driving situation. Response times were measured for checking the presence or absence of a car behind at short distances in the adjacent left lane. In a real-life situation, the driver has to make a decision whether to change lanes depending on additional information, such as the absolute distance and the relative speed of the car behind. These more quantitative aspects of information provided by mirrors were not examined in this study.

METHOD

Tasks

Subjects performed two concurrent tasks in a laboratory simulation of a driving situation (see Figure 1). The primary task was to determine the presence or absence of a car in the subject's left rear field of view, and to respond to this information as quickly as possible by pushing either of two push buttons. One push button was to be used to signal the presence of a car, and the other to signal the absence of a car. The rearward traffic situation was simulated by projection of a slide of a road scene on a large screen behind the subject. The slide was presented simultaneously with a visual and an auditory signal which indicated that the subject should look for a car by using the left rearview mirror and, if necessary, by turning his or her head for a direct look. The subject's response by pressing the YES or NO button turned off the slide projection. In the event of an incorrect response, there was a second auditory signal giving feedback to the subject. The secondary task was a continuous tracking task designed to control the subject's attention between presentations (see Figure 2). This task was similar to steering a car along a winding road presented on a monitor in front of the subject.

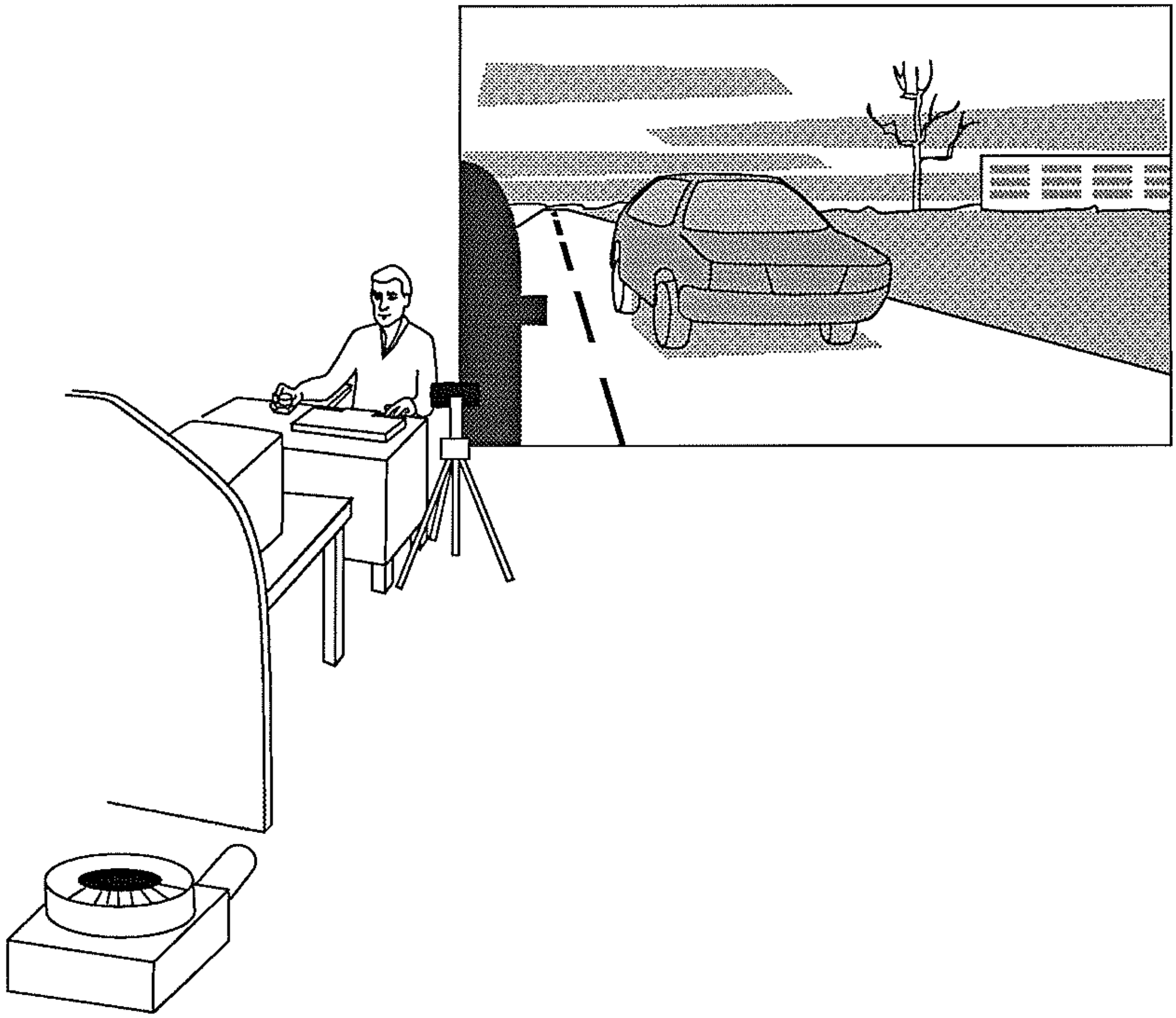

Figure 1. The experimental setup.

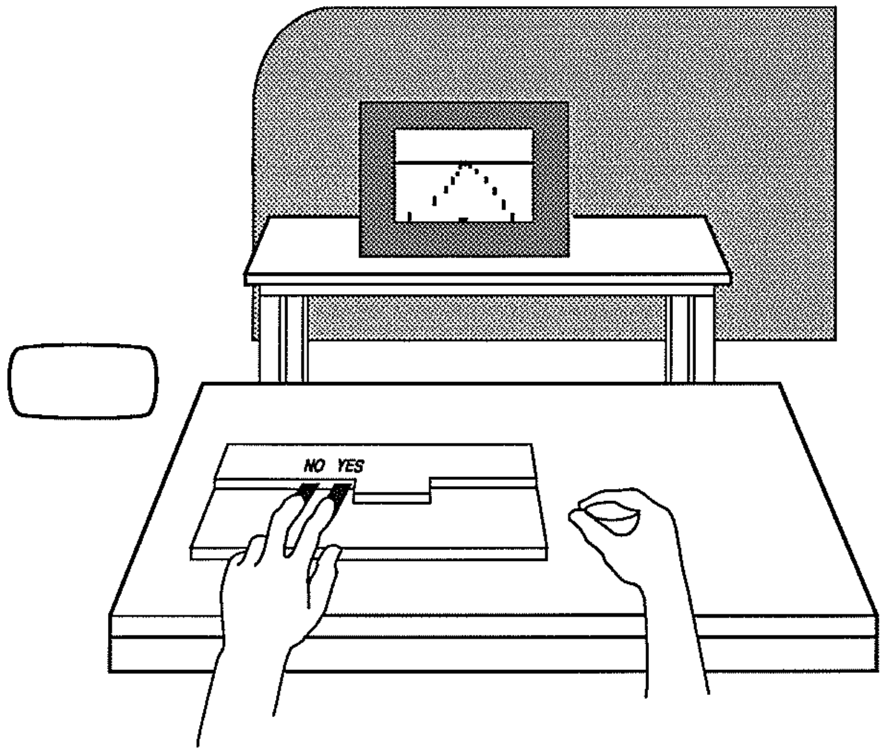

Figure 2. The subject's view with the tracking task monitor straight ahead. The position of the mirror is indicated to the left.

Subjects

Twenty-four paid subjects participated in the main study. There were six subjects in each of the following groups: younger males, younger females, older males, and older females. The ages of the younger subjects ranged from 18 to 35, with a mean age of 28 years. The older subjects ranged in age from 62 to 73, with a mean of 68 years.

The experiment was repeated for a smaller group of six Swedish subjects (four males and two females; age range 19 - 50 years; mean age 38 years), who were visitors to the U.S. The rationale for using this sample was to investigate whether there were any important differences in the pattern of results which could be related to prior experiences with convex and multiradius mirrors by the Swedish subjects. Three subjects had their recent experiences mostly with a multiradius exterior driver-side mirror. The remaining three subjects had recent experiences with a convex mirror, but had now and then driven cars with a multiradius mirror.

The American sample with its four subsamples allowed between-subject comparisons for age and sex. However, analogous comparisons were not made for the Swedish sample because of its small size and because the subjects were not selected according to age and sex.

Apparatus

A schematic diagram of the experimental setup is shown in Figure 3. The subject sat in a comfortable car seat behind a table. Directly in front of the subject, at a distance of 1.80 m, there was a television monitor for the tracking task. The subject controlled the tracking task by turning a knob placed on the table, using his or her right hand. The subject used the index and middle fingers of the left hand to press two buttons on a response pad placed on the table.

A driver-side rearview mirror was mounted in a normal position in relation to the subject's head (the lateral angle was 45°; the distance between the subject's eye position and the mirror was 0.70 m; the mirror mounting height was 0.23 m below the subject's eye position).

Color slides of a two-lane road were obtained by photographing backwards from the position of the left exterior mirror of a car. These slides were projected on a large screen. The size of the projected photographs was 3.4 m x 2.0 m (width x height). The distance between the screen and the rearview mirror was 3.0 m.

Two computers were used, one to present the tracking task, and the other to (1) randomly choose 3-, 4-, 5-, 6-, 7-, or 8-second intervals (without replacement) between slide presentations, (2) measure and record the time between the onset of each slide and the subject's YES/NO response, (3) emit an auditory stimulus after an incorrect response, and (4) record incorrect responses.

A dim shielded lamp was directed towards the ceiling to maintain a constant level of dark adaptation. The illuminance on the table in front of the subjects was 1 lux.

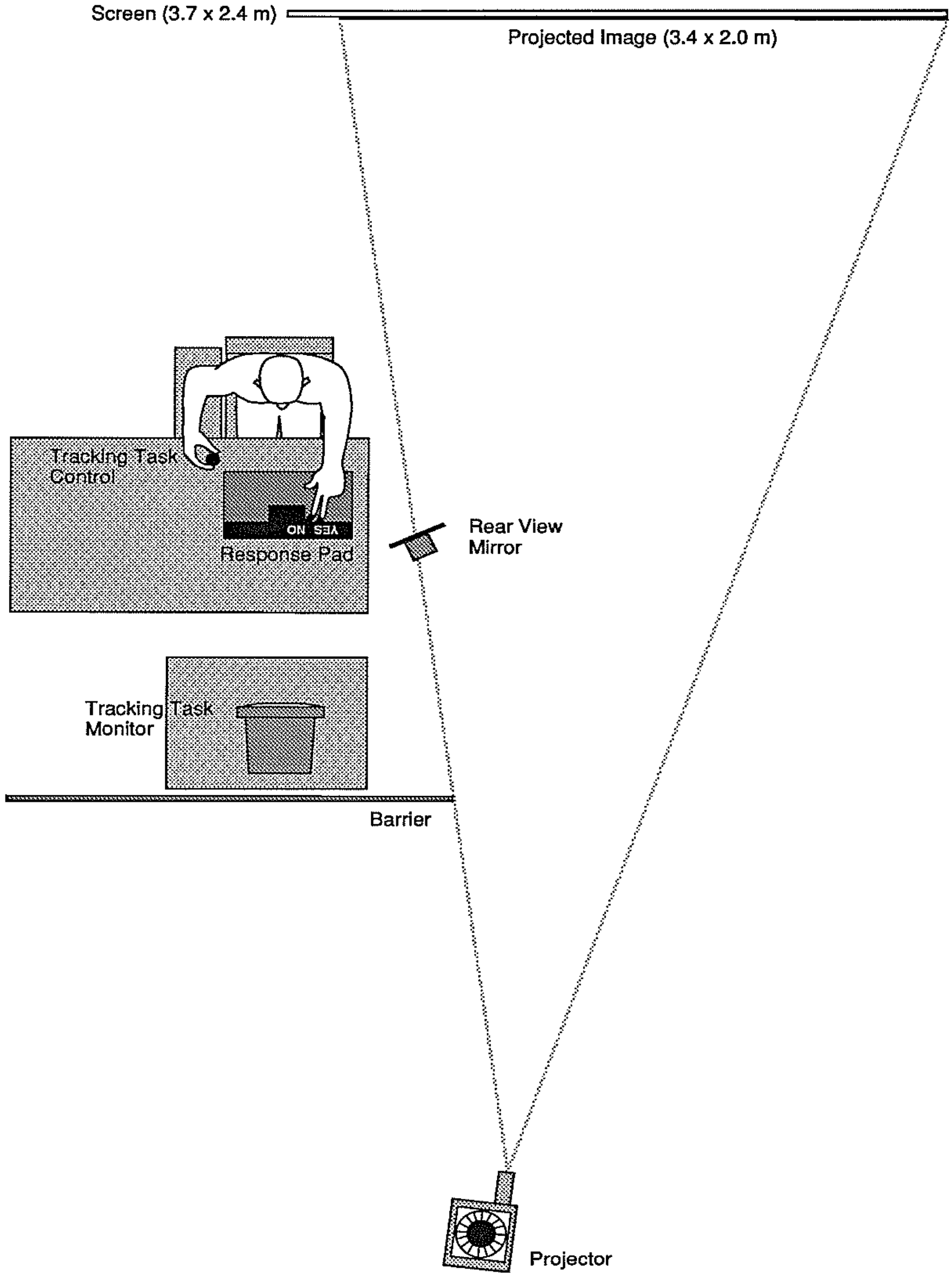

Figure 3. A schematic diagram of the experimental setup seen from above.

Exterior Rearview Mirrors

Three types of driver-side exterior mirrors were tested: standard flat, convex, and multiradius. The convex mirror had a spherical radius of 2100 mm. The multiradius mirror had a spherically convex main area (radius 2100 mm). At the far end of this area, which was marked by a dotted vertical line, there was an additional area, which had a horizontally accelerated convexity toward its left edge. All three mirrors were standard Volvo mirrors with identical overall dimensions (for fitting the same mirror frame). The form of the mirror surface was approximately rectangular with rounded corners (width 17 cm, height 9.5 cm). The reflectivity of all mirrors was 55%.

The subjects' visual fields in each mirror are shown in Figure 4. The visual field diagonally to the left was about 20° for the flat mirror, 28° for the convex mirror, and 40° for the multiradius mirror. The position of the projection screen is also shown in this figure. The screen was placed so that the entire projected photograph was seen in the multiradius mirror.

Stimuli

Six different color slides were used. Five slides showed the same scene with a car at five different distances; the sixth slide showed the same scene, but with no car.

The five positions of the car relative to the visual coverage of each type of mirror are also shown in Figure 4. The area seen in the multiradius mirror, but not in the convex mirror, was not large enough to contain a whole car. Therefore, in the slide representing a car in Position 1, only the rear fender and door of the car were visible on the screen. The rear of the car, including the front door, was visible in Position 2. In Position 3, the whole side of the car up to the right headlight was visible, but the front of the car was not. In Positions 4 and 5, the whole car was visible. In these two positions the car was visible primarily from head-on. The road scene with a car in Position 4 is shown schematically in Figure 1.

Design

The main independent variable was type of mirror (flat, convex, and multiradius). The second independent variable was position of the car at the rear. This variable had six levels; five of these levels had a car at different longitudinal distances behind the subject, and one level had no car. All subjects were exposed to all combinations of mirrors and positions of the car. Each subject was given all trials for one mirror first followed by all trials for second, and then the third mirror. There are six possible orders for three mirrors. These six orders were distributed to the six subjects in each age/sex subsample and no order was repeated. This way, any learning effects were balanced within each subsample.

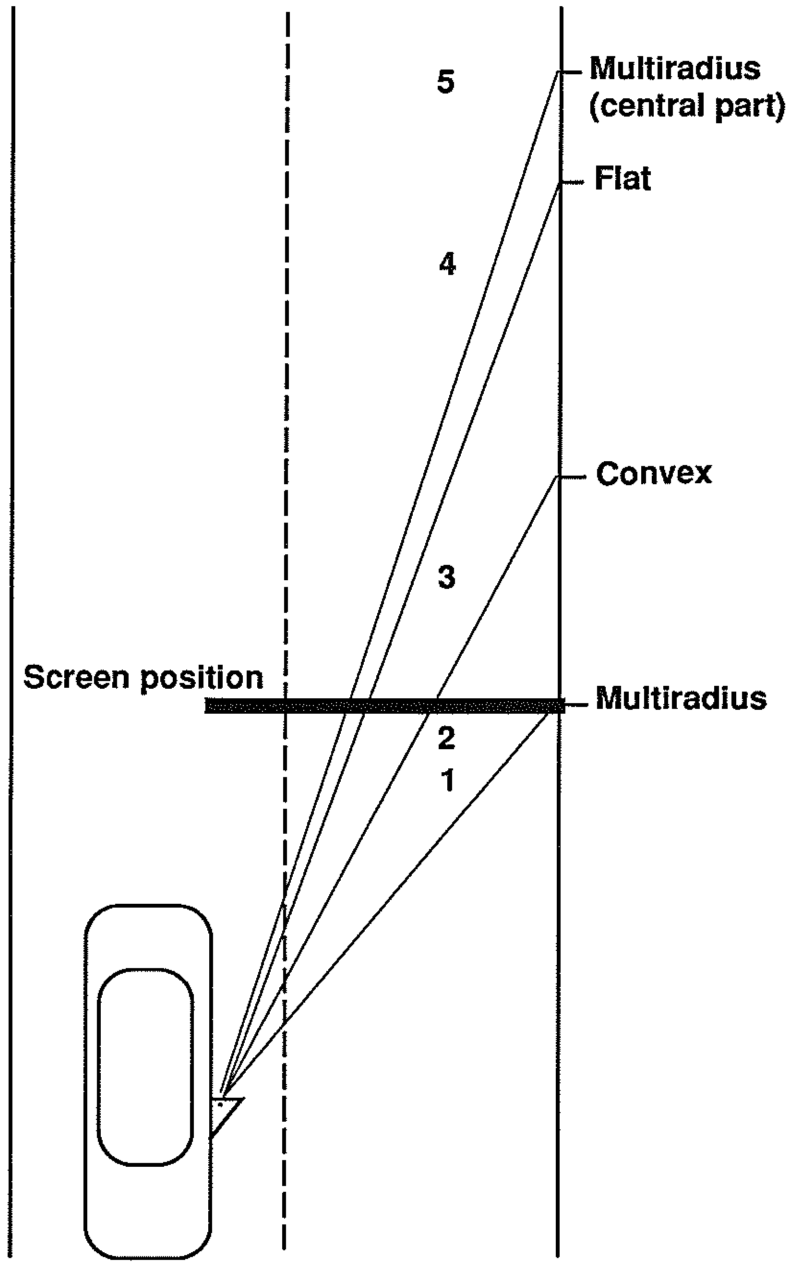

Figure 4. Drivers' visual field for the flat, convex, and multiradius mirrors in relation to a two-lane road. Also shown are the position of the projection screen and the locations of the car in positions 1 through 5.

There were 72 experimental trials with each mirror; half of the trials presented no car. The car was presented 12 times each in positions 1 and 2, and 4 times each in positions 3, 4, and 5. The order of trials was randomized but the same order was used for all subjects.

Procedure

Each subject was tested individually in a one-hour session. The subject received oral instructions. First, the purpose of the experiment was explained, and all the mirrors were presented. The visual field of each mirror was demonstrated by placing three differently colored panels against the screen on which the slides were to be projected. Each panel was located in such a way that it fitted the visual field for each mirror. Subjects were instructed to examine the size of the visual field in each mirror by looking at the screen through the mirror and by looking directly at the screen by turning their heads. The subjects were notified that some mirrors had a blind spot. They were also told that they might turn their heads for a direct view of the blind area to see if a car is present or not. They were also instructed to use the rearview mirror first. (The actual instructions are reproduced in Appendix 1).

The subject's tasks were then described. First, the tracking task was explained; then, the subject received a few minutes of practice on this task. Second, the main task (to search for a car on the screen behind the subject) was explained.

The following procedure was repeated for each mirror: The subject was given instructions and helped to adjust the mirror correctly. This was followed by 18 practice trials and 72 experimental trials. There were short breaks in order to install and adjust the second and the third mirror.

The subject's task was rather complex. Between trials he or she had to concentrate attention on the continuous tracking task straight ahead. A trial started by simultaneous visual and auditory signals indicating that there was a picture projected on the screen. The subject was now to search for a car on the screen, by first looking in the mirror, and, if necessary, by a direct look. The subject was instructed to press, as quickly as possible, the YES button if there was a car projected on the screen, and the NO button if there was no car present. After pressing the button, the picture was immediately turned off, and the subject resumed the tracking task until the next trial was presented after 3 to 8 seconds.

Two experimenters carried out the experiment. One gave the instructions, demonstrated the tasks to the subject, and made sure that the subjects followed the instructions. The other operated the computer that controlled the presentations of the slides and collected the response times.

RESULTS

The response times for correct responses for the (American) sample were submitted to an analysis of variance. This analysis had two within-subject variables: mirror type (flat, convex, and multiradius) and position of the car at the rear. The six levels of the position variable were grouped in the following four mirror-related categories: no car presented on the screen, a car seen only in the multiradius mirror, a car seen in the multiradius and convex mirrors, and a car seen in all mirrors. The reason for this grouping is that our interest is not in positions per se, but in positions that differentiate among the mirrors. Two between-subjects variables were also incorporated in the analysis: age and sex.

The main effect of each of the independent variables, with the exception of sex, was statistically significant[1]: (1) Mirror type $F(2, 40) = 19.2, p < .0001$, with the longest response times for the flat mirror (1676 msec), followed by the convex mirror (1473 msec), and the multiradius mirror (1316 msec). (2) Position $F(3, 60) = 98.4, p < .0001$, with the longest response times for the condition with no car (1762 msec), followed by the positions seen only in the multiradius mirror (1656 msec), the positions seen only in the multiradius and convex mirrors (1418 msec), and finally the positions seen in all mirrors (1117 msec). (3) Age $F(1, 20) = 27.2, p < .0001$, with longer response times for the older subjects (1715 msec vs. 1262 msec). The effect of mirror type and position are shown in Figures 5 and 6. The interaction between mirror types and positions was also significant: (4) Mirror type x Position $F(6, 120) = 5.96, p = .0005$. The presence of this interaction indicates that the curves in Figure 7 are not parallel. Specifically, it was relatively more difficult to detect a car in situations for which large head movements were required.

The two-way interactions involving age (Age x Mirror type and Age x Position) were not statistically significant (Figures 8 and 9). These results indicate that the small deviations from parallel curves in Figures 8 and 9 can be explained by randomness in the data. This finding suggests that no mirror type or position was especially difficult to master for the older compared with the younger subjects.

A separate analysis of variance was carried out on the data from the small Swedish sample with the same two within-subject variables, mirror type and position. The findings for this group were analogous to the findings for the American subjects. Statistically significant effects were found for mirror type $F(2, 10) = 7.94, p = .03$, position $F(3, 15) = 26.5, p = .0008$, as well as for the interaction between mirror type and position $F(6, 30) = 4.90, p = .04$.

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[1]The degrees of freedom shown for the *F*s are the full numbers of degrees of freedom for the design, but, for main effects and interactions involving a repeated factor, the levels reported for *p* are based on the Greenhouse-Geisser correction for possible violations of homogeneity (e.g. Keppel, 1982, pp. 470-471).

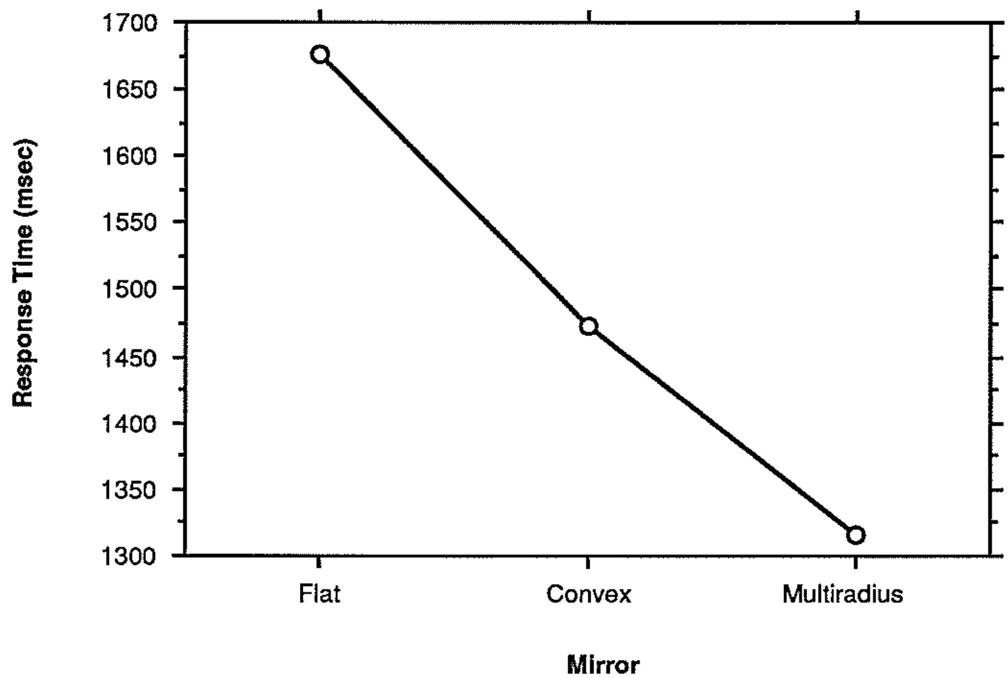

Figure 5. Response times by mirror type.

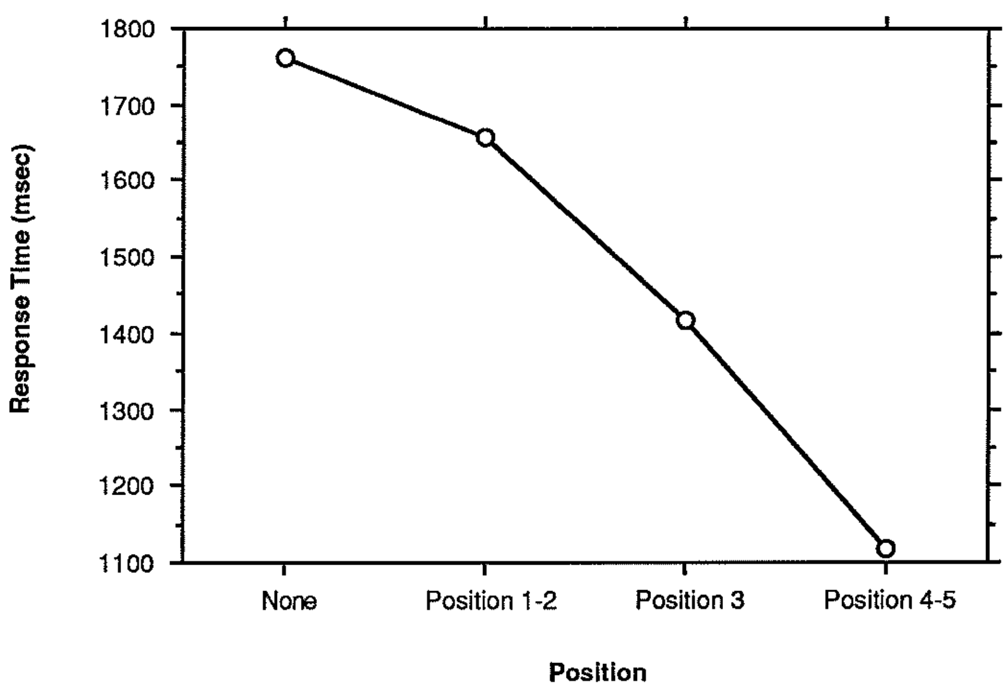

Figure 6. Response times by position of car.

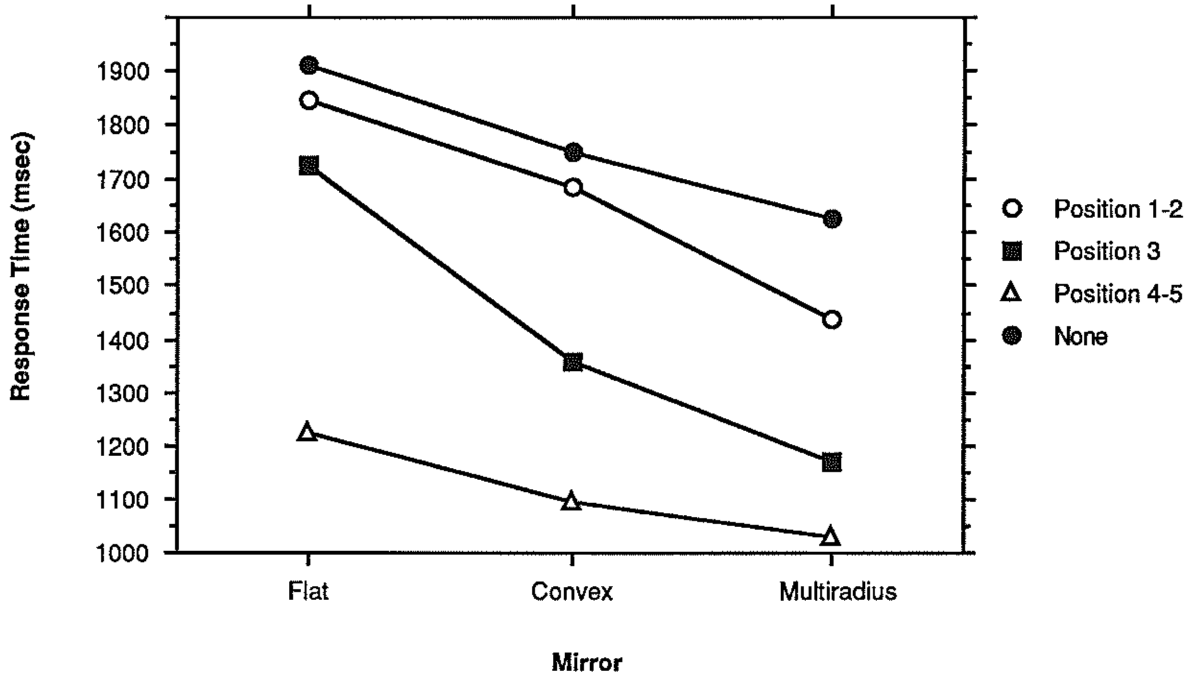

Figure 7. Response times by mirror types and position of the car.

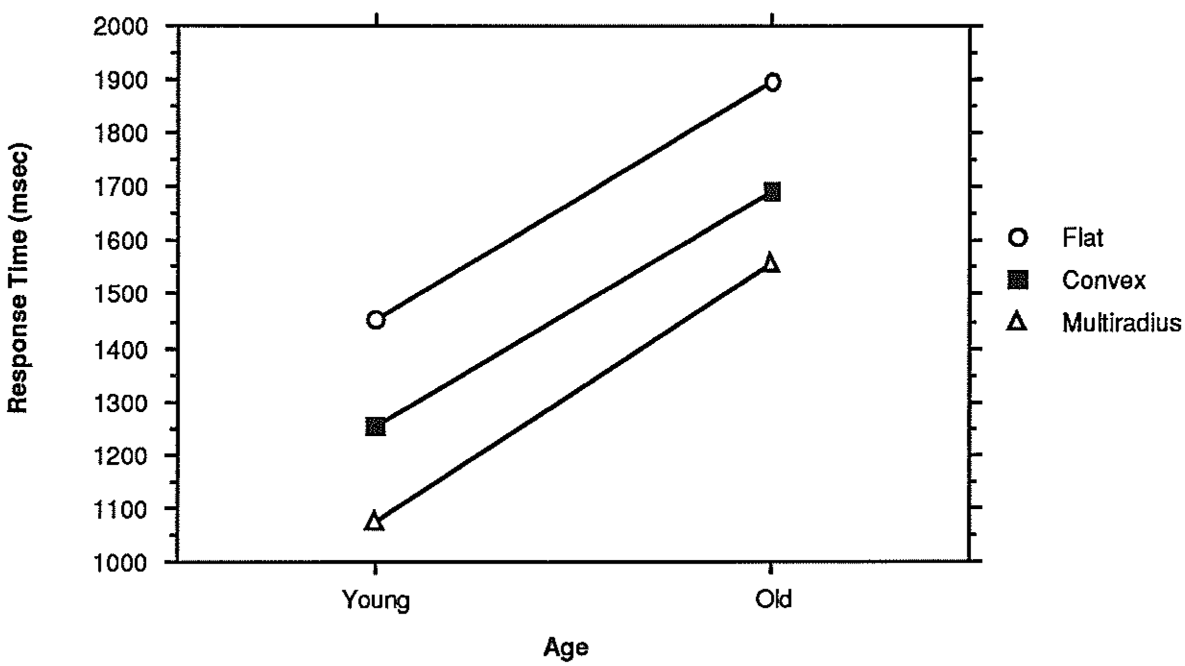

Figure 8. Response times by mirror type and age of subjects.

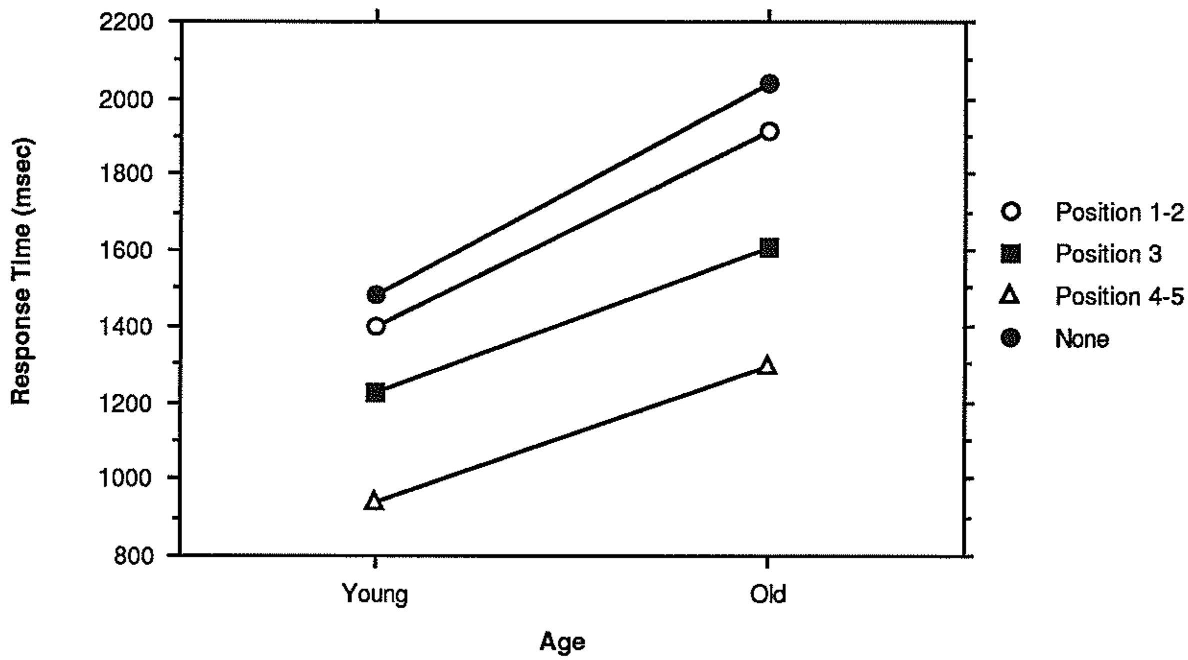

Figure 9. Response times by age of subjects and position of the car.

The effects of mirror type and position for the two samples are shown in Figures 10 and 11. For both samples the rank orders of response times are the same across mirror types and across positions. The absolute levels of response times for the two samples should not be directly compared. One reason for this is that the two samples are not selected in the same way. The Swedish subjects were selected regardless of age, while the American sample was selected to include equal numbers of young as well as old subjects. The interaction between mirror type and position also had the same general pattern for the two samples, except that the Swedish subjects tended to have relatively longer response times for Position 3 when using the convex mirror than did the American sample. The reason for this difference is not known.

Error responses were also recorded. The overall proportion of errors relative to the total number of responses was small and approximately equal for the two samples (1.9 % for the American, and 1.8 % for the Swedish sample). The error patterns were also similar for the two samples. About 25 % of all errors were made in the flat mirror, 25 % in the multiradius mirror and the remaining 50 % were made in the convex mirror. Furthermore, subjects often spontaneously commented on their incorrect responses by saying that their errors were errors of response (pushing the wrong button) rather than errors of perception.

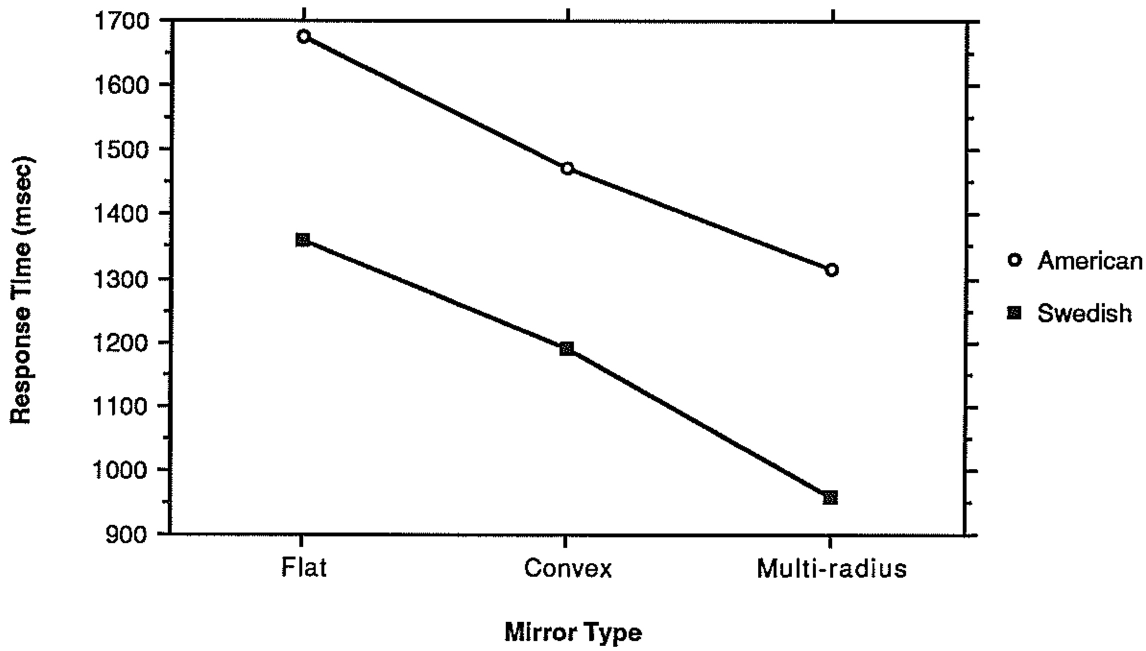

Figure 10. Response times by mirror type and nationality of the subjects.

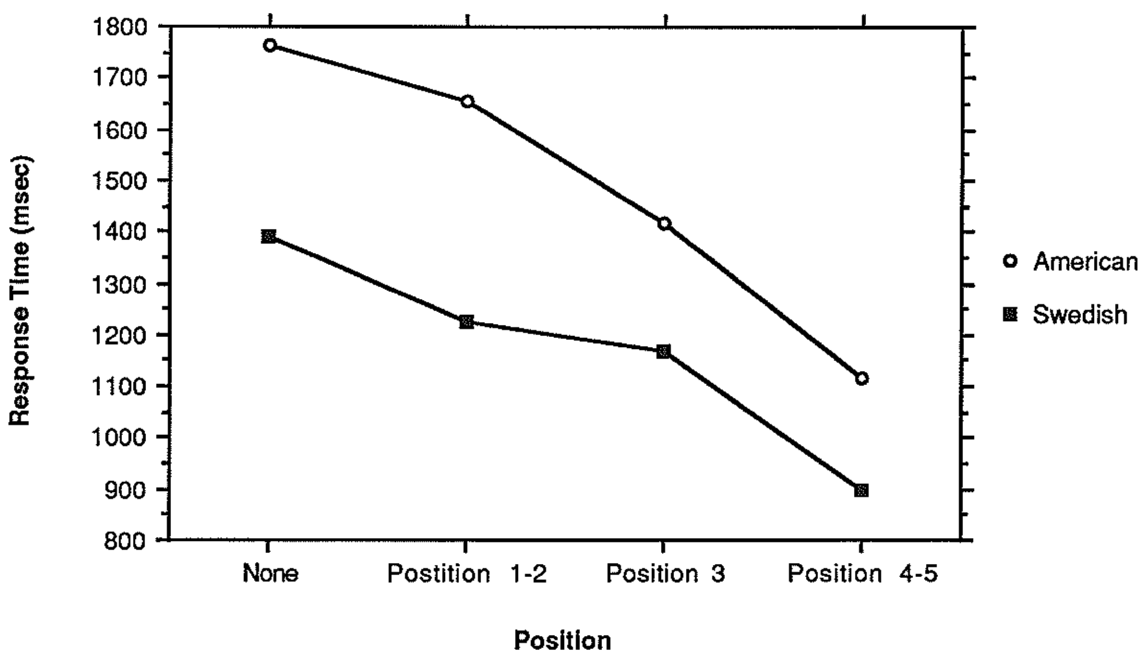

Figure 11. Response times by position of the car and nationality of the subjects.

DISCUSSION

The results are relatively straightforward and easy to interpret. The subjects' response times for obtaining information about the presence of cars in the adjacent left lane are shortest when using the multiradius mirror, followed by the convex mirror, and longest for the flat mirror. This result applies to all tested positions of the rear car, as well as for young and old subjects.

The shortest response times were for the multiradius mirror, which had no blind spot and, consequently, did not require any supplemental large head movements for collection of information. On the other hand, the longest response times were obtained with the flat mirror, which required large head movements in a large proportion of trials. The convex mirror had response times shorter than the flat mirror and longer than the multiradius mirror, and required less frequent large head movements than the flat mirror. On the other hand, large head movements for a direct look diagonally to the rear left cannot explain all of the differences in response times for the mirrors. Even when the rear car was in positions 4 and 5 and, consequently, was seen in all mirrors, the multiradius mirror had the shortest response times, followed by the convex, and the flat mirror had the longest. The explanation of these differences is not known.

The number of incorrect responses was small overall (less than 2 %), but it was twice as high for the convex mirror compared with those of the flat and the multiradius mirror. This result should be interpreted with great care, because the position variable for the rear car was varied in five fixed steps and not continuously, as is the case in traffic. Consequently, there is a possibility that the chosen fixed positions by chance have been more unfavorable for this mirror than for the other two mirrors.

Drivers need qualitative as well as quantitative information about the traffic situation behind the car. The qualitative information is of a yes or no character. This information answers simple questions about presence, as for example, "Is there a car at my rear?" In case there is a car, further information of a more quantitative character may be needed to answer questions necessary for further guidance of driver behavior. Examples of such quantitative questions are, "Does the distance to the car behind prevent a safe and comfortable lane change?" or, "Does the relative speed of an approaching car from behind (in combination with the distance to the car) interfere with the maneuver I am intending to make?" If the answer to these questions is yes, the maneuver should be postponed. In this study, only the more qualitative aspects of information acquisition from driver-side exterior rearview mirrors were studied. Therefore, the more quantitative aspects of information to the driver in rearview mirrors remain to be examined.

This study was carried out in a simulated driving situation. Subjects and other observers, after being exposed to the experimental situation (either as subjects or guests) have remarked that they find the situation very realistic. Furthermore, this laboratory simulation was very efficient for data collection. However, the results from this (as from any other laboratory study) should be validated by carrying out experiments in real traffic.

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APPENDIX

SUBJECT INSTRUCTIONS

The purpose of the study in which you have been asked to participate is to evaluate three different types of (exterior left) rearview mirrors. The first mirror has a limited coverage of the visual field, however there is no distortion of the image in this mirror. Consequently, there is a large blind area in which a car at near distance in the adjacent lane to the left can hide. The second mirror has a somewhat minified image and smaller blind area. The third mirror is a special mirror. At the far edge of the mirror there is a surface with a greater minification. Thus, the left visual area covered by this mirror is larger. There is no blind spot if the mirror is correctly adjusted. The evaluation will be carried out by measuring the time it takes you to check if there is a car in slides shown at the screen behind you. (Demonstrate visual sector of each mirror with colored panels).

You will be performing two tasks simultaneously. The first of the two tasks will be a driving simulation task. You will be operating the driving simulator continuously throughout the duration of the study. The road of the driving simulator will appear on the monitor in front of you. It is controlled by turning the black controller knob to your right. We would like you to use your right hand to control the driving simulator. I will now show you how to control the simulator. (Show subject how to operate simulator).

Your second, and more important task, will be to look through a rearview mirror to determine whether or not you can see a car in a projected image on the screen behind you. There will be 3 sets of 72 trials total with 18 practice trials proceeding each set. We will be using a different type of mirror for each set of trials. At the conclusion of a set of trials there will be a short pause in the study so we can change mirrors and have you adjust the new mirror. One of 6 different images will be projected on the screen behind you. Five of the images have a car in them at various distances. One image will have no car but will have the same scene as the other five. (Show subject the six slides).

A trial will go as follows: While operating the driving simulator we would like you to pay close attention to the small green light bulb on the television monitor which is currently turned off. When the green light and an auditory signal comes on, that will indicate that the image is now present on the screen behind you. At this time you should respond to the light by immediately turning your head to look in the rearview mirror so you can see if a car is present or not. Using your two index fingers on your left hand, respond as quickly as possible by pressing one of the two white buttons in front of you. The left button is for yes, which signifies that indeed there is a car present. The right button is for no, which signifies no car is present. (Show correct finger placement).

Once your response is made, the image will go away and you should direct your attention back to the driving simulation task and await the next trial. Although we would like you to respond as quickly as possible, it is important that you choose correctly with the least amount of errors possible. If an incorrect response is made there will be an auditory signal directly after your response.

With some mirrors it will be easy to identify a car on the screen in the rearview mirror, while with others there will be a blind area that will make it impossible. When there is a blind area you may turn your head and view the blind area directly to see if a car is present or not before responding. But please remember to always use the rearview mirror first before turning to look with direct vision.

Are there any questions??