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16. Abstract

Mirror fields of view (FOV) of 48 men and women were measured in their own pickup trucks, minivans, and sport utility vehicles using methods previously applied to measuring mirror fields of view in passenger cars. A manual pole-sighting method was supplemented by calculations from three-dimensional vehicle data. A coordinate measurement machine was used to record the mirror orientations and driver eye locations.

Mirror aim did not differ significantly by vehicle type or driver gender, except that the vertical FOV in the left mirror was greater in trucks than in SUVs and minivans, due to larger mirrors. The mean horizontal FOV widths were 12.6, 19.6, and 20.2 degrees for the left (driver-side), center, and right mirrors, respectively. On average, drivers could see 12.1 degrees outboard on the left and 17.2 degrees outboard on the right. The FOV in the left mirror did not differ significantly from the FOV measured in a previous study of passenger cars. The center mirror FOV was smaller and included less of the area to the right of the vehicle than in passenger cars. Right-mirror FOV was similar to passenger cars, except that the outer edge of the horizontal FOV averaged 17.2 degrees, compared with 19.8 degrees in passenger cars. The differences in FOV are probably attributable to differences in vehicle and mirror geometry rather than differences in driver aiming behavior.

Drivers were asked to check and, if desired, to reaim their mirrors as they drove over a short road route. The FOV measured on their return did not differ substantially from the initial FOV measurements, although all but fourteen drivers adjusted at least one mirror. Combined with the results of the previous study, the findings demonstrate the distribution of mirror FOV for vehicles in use.

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Introduction

This study builds on an earlier investigation of fields of view (FOV) in passenger car mirrors (Reed et al., 2000). In that study, mirror FOV were measured for 43 men and women as they sat in their own passenger cars. Data were collected using a pole-sighting method supplemented by measurements of driver eye locations, mirror surfaces, and other vehicle geometry. The current study applied identical methods to the measurement of mirror FOV for 48 men and women in pickup trucks, minivans, and sport utility vehicles. The reader is referred to the earlier report for more background information on mirror FOV measurement and application.

Method

Participants

Forty-eight men and women were recruited via newspaper advertisement in six gender/vehicle-type categories. Table 1 shows the sampling by category. All participants were licensed drivers who were tested in the vehicle they normally drive. Participants were paid $24. Table 2 summarizes driver anthropometry and age by group. The women were younger than the men, on average (44 versus 53 years), and drivers of SUVs were younger than minivan and pickup truck drivers. The men who drove SUVs were large relative to the population as a whole (average stature 1810 compared to an average U.S. male stature of 1760 mm). In contrast, the male pickup truck drivers were all below average in stature. None of these group differences in body dimensions is expected to be important, because the previous study found no effect of anthropometry on FOV.

Table 1
Driver and Vehicle Sampling

Gender	Pickup Truck	Minivan	Sport Utility Vehicle (SUV)
Men	8	8	8
Women	8	8	8

Table 2
Driver Anthropometry and Age
(min-mean-max)

Vehicle Category	Gender	Stature (mm)	Weight (kg)	Age (years)
Pickup Truck	Men	1646-1711-1757	61-79-99	23-53-72
Pickup Truck	Women	1525-1625-1704	50-70-84	25-46-70
Minivan	Men	1675-1761-1830	69-88-100	37-60-80
Minivan	Women	1520-1607-1691	53-73-95	33-51-70
SUV	Men	1712-1810-1880	83-102-130	24-46-67
SUV	Women	1603-1667-1720	53-82-132	21-34-52

Experimental Setup

Testing was conducted in a high-bay facility into which the participants could drive. A stall for the vehicle was prepared as shown in Figure 1. Two traffic cones were placed on each side of the stall to mark the desired location of the vehicle. A circular arc with a five-meter radius was marked on the floor with measurement tape. The measurement tape, shown in Figure 2, was marked with millimeter increments.

The three-dimensional locations of points on the driver and vehicle were measured using a FARO Arm coordinate measurement device, shown in Figure 3. The FARO Arm is constructed of three articulating arms with angle sensors at the joints. The arm reports the location of the probe tip when a button is pressed. Coordinate systems for FARO Arm measurements were established on the floor on both sides of the stall near the location of the vehicle front doors. The horizontal axes of these coordinate systems were aligned using manual measurements, and the offsets between the origins were measured. In each case, X is positive rearward relative to the vehicle, Y is positive to the right, and Z is positive upward.

Prior to measurement with the FARO Arm, the platform supporting the arm was placed under the edge of the vehicle and jacked up slightly to wedge the platform between the floor and the vehicle. The data collection coordinate system was then aligned with the adjacent floor-mounted coordinates by digitizing three points defining the origin and the X and Y axes. The origin location was verified several times during each measurement period to confirm that the FARO Arm had not inadvertently shifted.

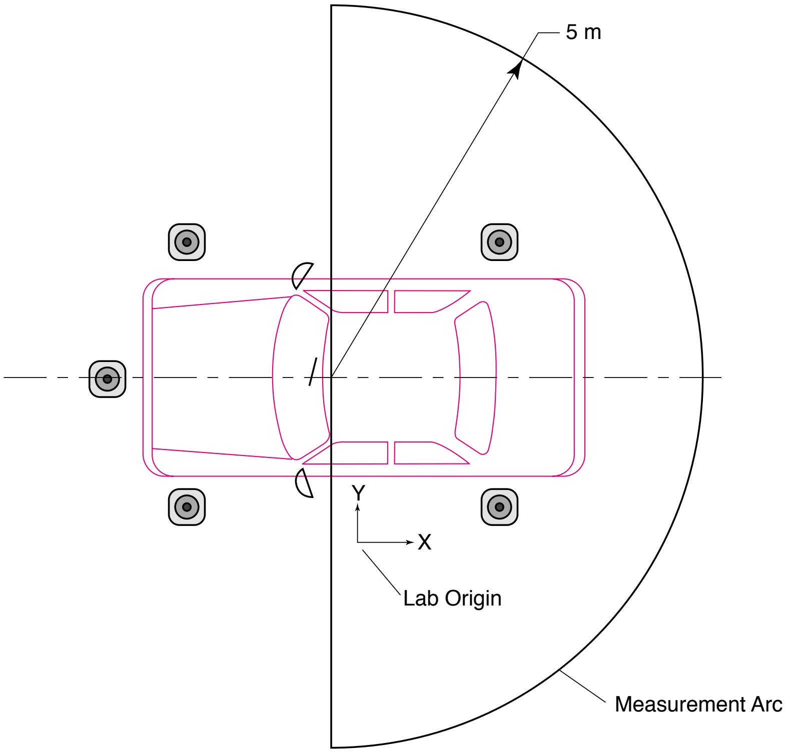


Figure 1. Schematic of measurement stall (top view).

Figure 2. Measurement tape and sighting pole.

Figure 3. FARO Arm coordinate measurement machine used to record vehicle geometry and driver eye locations.

Procedure

The participants were recruited for a “Driver Vision Study” using ads that did not mention mirrors. Participants were instructed to report for testing in vehicles they normally drove. When the participants arrived, they were directed to pull their vehicles into the test area, but they were not told that the measurements would involve their mirrors until after they had parked in the test stall and exited the vehicle. At that time, the test procedures were explained and written informed consent was obtained. The anthropometric dimensions listed in Table 3 were measured on each driver. Descriptive information concerning the driver’s vehicle and mirrors was also recorded. Instructions to the participants during testing were scripted to ensure uniformity.

Table 3
Anthropometric Measurements

Stature (without shoes)
Weight (without shoes)
Erect Seated Eye Height
Erect Sitting Height
Corner Eye Breadth
Interpupillary Distance

While the driver was out of the vehicle, the investigator digitized the vehicle interior geometry. Three reference targets were taped to the outside of the vehicle, two near the top and bottom of the B pillar, and one at the top of the A pillar. The locations of these reference points were recorded each time the FARO arm was used to provide a way of aligning the data. Points were recorded defining the locations of the steering wheel, accelerator pedal, brake pedal, instrument panel, and shifter. Four points were recorded on the inside door sill to define the X (longitudinal) axis of the vehicle.

When the driver returned to the vehicle, FOV measurements were taken. Figure 4 shows the investigator with the sighting pole instructing the driver on the measurement procedures. Beginning with the left mirror, the investigator located the approximate center of the FOV by sighting the driver's eyes in the mirror while standing along the measurement arc. The investigator then interacted verbally with the driver to locate the top and bottom of the FOV at that lateral position by sliding visual targets on the measurement pole (see Appendix A for the participant instruction script). Drivers were instructed to use both eyes and to indicate the point at which the target was centered on the edge of the field of view. The vertical positions of the FOV boundary targets were manually recorded.

Figure 4. Measuring field of view in right mirror with sighting pole.

A single target was then located on the pole at the midpoint between the top and bottom FOV boundaries. The investigator determined the left and right edges of the view boundary by moving along the measurement arc with the pole. The drivers reported the boundary condition that defined their FOV, such as the edge of the mirror, edge of the window, or edge of the vehicle. The edge of the FOV was read from the scaled tape on the measurement arc and manually recorded. The FOV for the center and right mirrors were measured using the same techniques.

Following the FOV measurements, the driver's head and eye locations were recorded using the FARO arm. The investigator began by digitizing the locations of the external reference points taped to the vehicle. The locations of these points, recorded with the driver sitting in the vehicle, were used as the target reference point locations. Data collected at other times (such as when the driver was out of the vehicle) were aligned via the reference points to the locations obtained with the driver in his or her normal driving position. This procedure accounted for the slight shifts in vehicle attitude that resulted when the driver entered or exited the vehicle.

With the driver in a normal driving position and looking straight ahead, the investigator digitized the glabella, left infraorbitale, left corner of eye, and left tragion landmarks, as shown in Figure 5. The driver looked in the left, center, and right mirrors in turn, each time prompted by the investigator to look in the mirrors as he or she had during the FOV data collection. The same four landmark locations were recorded. The driver then turned his or her head maximally to the left, so that the investigator could record the right tragion, right corner of eye, and right infraorbitale, in addition to the other four points. These data provide the necessary description of where both eyes were located with respect to the landmarks on the left side of the head.

The driver then exited the vehicle while the mirror geometry was measured. The investigator recorded approximately thirty points around the perimeter of the center and left mirrors, each time recording the three external reference points as well. The investigator then moved to the right side of the vehicle, and recorded the perimeter of the right mirror and points on the right door sill with respect to the floor-based coordinate system established on the right side of the vehicle. Using the measured relationship between the two coordinate systems, the data from the right side were combined with those from the left. Following the FARO Arm measurements, the driver was invited to reaim the mirrors to his or her preferred orientations. The resulting FOV in each mirror was measured as before.

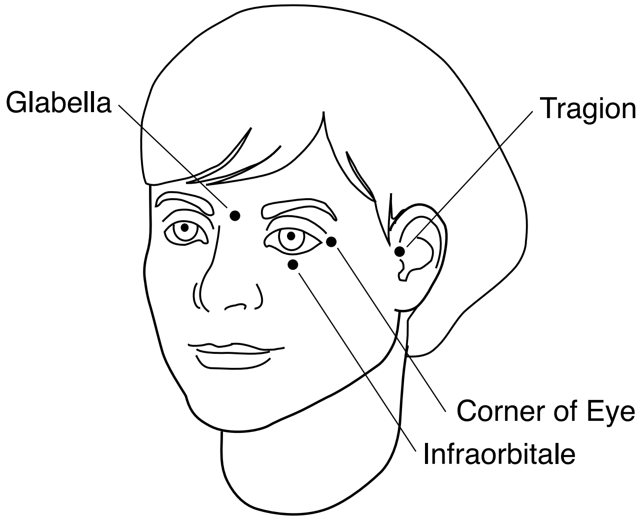


Figure 5. Head landmarks.

FOV Analysis

FOV boundaries measured using the pole-sighting technique were converted to laboratory coordinates using the geometry depicted in Figure 1. For analysis purposes, all data, including driver head locations and vehicle interior geometry, were expressed relative to an origin at the left side of the vehicle. In-vehicle data, such as mirror perimeters, were adjusted to the vehicle attitude measured with the driver in his or her normal driving position using the taped-on reference points.

Driver eye locations were calculated beginning with the landmark data collected with the driver's head turned to the left. An origin was established at the midpoint between the tragion landmarks, with the intertragion vector defining the Y axis, the Z axis defined vertically, and the X axis defined forward through the head. The eye points were then calculated using the X (fore-aft) and Y (lateral) coordinate of the infraorbitale landmark and the Z (vertical) coordinate of the corner-eye landmark. These eye points lie approximately at the center of the orbit, i.e., the approximate pivot center for the eyeball. The relationship between the two eye points and the glabella, left infraorbitale, and left tragion landmarks was stored, so that the locations of the latter three points could be used to calculate the eye locations with the landmark data recorded while the driver looked straight ahead and into each of the mirrors. Eye points for views in each of the three mirrors were calculated by this method for use in FOV calculations.

Using a least-squares approach, planes were fit to the perimeter points on the left and center mirrors recorded with the FARO Arm. Calculations for center prism mirrors assumed that the front surface was angled 3.58 degrees relative to the back surface (mirror thicker at the top edge) and the center thickness was 5 mm. Ray reflection/refraction algorithms written for use with the prism mirrors assumed that the index of refraction for transition between air and glass was 1.514. Projected (effective) eye points for the left and center mirrors were calculated by reflecting the measured eye locations behind the plane of the mirror. Figure 6 shows the effective eye points schematically for the left mirror. The effective eye point can be viewed as the perceived location of the eye relative to the indirect visual field. For planar mirrors, rays from the eye points through the perimeter of the mirror define the FOV in the mirror. For calculations with spherical right mirrors, a calculation program was written to reflect rays from the eye points in the mirrors, with the mirrors defined using the measured perimeter points and radius (see Results).

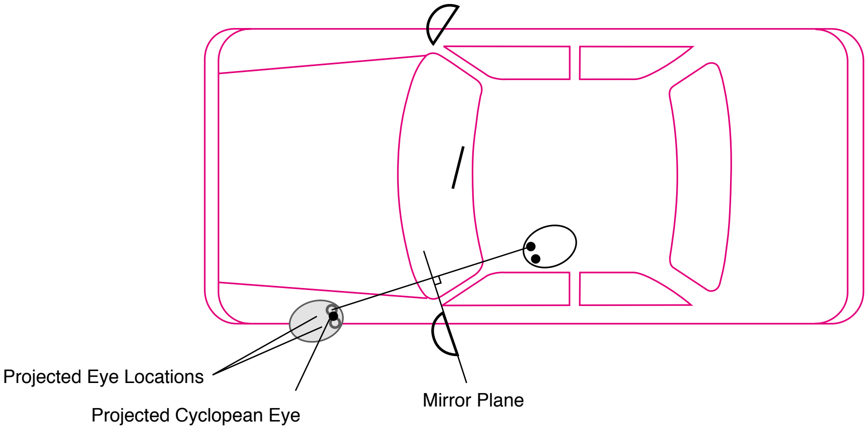


Figure 6. Method for calculating projected (effective) eye points. Cyclopean eye point is the midpoint between the two eye points.

Results

Vehicle and Mirror Descriptions

Table 4 lists the subjects' vehicles by manufacturer. Vehicles manufactured by Ford were most common (23), followed by General Motors and DaimlerChrysler (11 each). The pickup-truck category was dominated by Ford vehicles. Seven were Ranger pickups and three were F150 pickups. Table 5 shows the model year ranges for each vehicle category. The oldest vehicle was a 1985 model year minivan, and the overall median model year was 1997.

Of the forty-eight vehicles, only one (a minivan) did not have a right-side mirror (broken off). One right-side mirror was planar (1995 minivan); all other right-side mirrors were spherical. All left-side mirrors were planar. Forty of the interior (center) mirrors were conventional day/night prism mirrors. Seven of the SUVs had electronic (adaptive) anti-glare center mirrors. One pickup truck had a planar, non-prism center mirror, and one minivan was equipped with an aftermarket, clip-on convex mirror that covered the entire surface of the original equipment mirror. One minivan had a 76x57-mm short-radius convex mirror clipped to the lower right corner of the center mirror, reportedly for monitoring child passengers rather than exterior viewing. Three pickup trucks and one SUV had 50-mm-diameter, short-radius button mirrors at the lower left corner of the left mirror. Two pickup trucks and one SUV had similar button mirrors on the right mirror. Fourteen of the pickup trucks and one SUV had manual adjustments for the exterior mirrors. All other vehicles had motorized adjusters.

Table 4
Vehicles by Manufacturer and Category

Manufacturer	Pickup Truck	Minivan	SUV	Total
Ford	10	8	5	23
General Motors	3	1	7	11
DaimlerChrysler	1	7	3	11
Toyota	1	0	1	2
Nissan	1	0	0	1
Total	16	16	16	48

Table 5
Vehicle Model Year by Category

Category	Oldest	Median	Youngest
Pickup Truck	1988	1995	2000
Minivan	1985	1997	2000
SUV	1988	1998	2000

Table 6 shows the distribution of mirror dimensions, measured in the plane of the mirror perimeter. Separate tables are provided for each vehicle type and for all vehicles combined. The locations of the mirrors (centroid of the mirror perimeter points) with respect to the driver's cyclopean eye point when looking straight ahead are also listed, as are the mirror heights with respect to the ground plane. The average driver eye height above the ground when looking straight ahead was 1380 mm (standard deviation 80 mm) in the minivans, 1408 (51) mm in the SUVs, and 1396 (76) mm in the trucks. The right mirror radii were measured on forty-seven vehicles. One right mirror was apparently flat. The mean radius of the spherical right mirrors was 1381 mm (minimum 992, maximum 1764). For comparison, the right-mirror radii measured on passenger cars in the previous study averaged 1098 mm (minimum 972, maximum 1504).

Table 6a
Mirror Dimensions and Locations (mm)
ALL VEHICLES (N=48)

Dimension	Mean	S.D.	Median	10th %ile	90th %ile
Left Mirror					
Width†	187	25	186	158	223
Height†	125	15	125	109	149
Fore-aft Position re Eye	-595	105	-611	-721	-480
Lateral Position re Eye	-573	39	-570	-635	-528
Vertical Position re Eye	-212	45	-216	-267	-157
Height Above Ground	1183	69	1165	1108	1283
Center Mirror					
Width	241	18	232	228	260
Height	57	11	55	51	61
Fore-aft Position re Eye	-505	70	-502	-591	-424
Lateral Position re Eye	378	44	366	327	439
Vertical Position re Eye	83	38	75	42	136
Height Above Ground	1477	68	1458	1410	1594
Right Mirror *					
Lateral Position re Eye	1355	112	1332	1233	1505

* Except for the lateral position, the values for the right mirror are nominally identical to those measured for the left mirror (assuming symmetrical positioning of the left and right mirrors on the vehicle), except that one vehicle did not have a right mirror.

Table 6b
Mirror Dimensions and Locations (mm)
MINIVANS (N=16)

Dimension	Mean	S.D.	Median	10th %ile	90th %ile
Left Mirror					
Width	184	19	181	163	207
Height	116	10	120	99	127
Fore-aft Position re Eye	-648	76	-635	-750	-562
Lateral Position re Eye	-580	34	-586	-623	-537
Vertical Position re Eye	-234	48	-233	-293	-184
Height Above Ground	1146	67	1114	1102	1275
Center Mirror					
Width	239	19	230	228	251
Height	62	18	58	52	67
Fore-aft Position re Eye	-483	47	-490	-538	-427
Lateral Position re Eye	395	34	390	360	439
Vertical Position re Eye	93	41	85	51	149
Height Above Ground	1473	63	1445	1419	1570
Right Mirror *					
Lateral Position re Eye	1402	49	1420	1336	1458

* Except for the lateral position, the values for the right mirror are nominally identical to those measured for the left mirror (assuming symmetrical positioning of the left and right mirrors on the vehicle), except that one vehicle did not have a right mirror.

Table 6c
Mirror Dimensions and Locations (mm)
SUV (N=16)

Dimension	Mean	S.D.	Median	10th %ile	90th %ile
Left Mirror					
Width	189	26	187	156	221
Height	125	16	124	108	144
Fore-aft Position re Eye	-605	81	-600	-714	-522
Lateral Position re Eye	-571	31	-565	-609	-544
Vertical Position re Eye	-220	36	-220	-264	-177
Height Above Ground	1188	44	1189	1138	1240
Center Mirror					
Width	242	12	248	228	250
Height	54	3	54	50	56
Fore-aft Position re Eye	-511	66	-503	-593	-432
Lateral Position re Eye	358	46	350	312	415
Vertical Position re Eye	66	31	69	33	102
Height Above Ground	1474	62	1476	1408	1562
Right Mirror *					
Lateral Position re Eye	1314	119	1281	1215	1506

* Except for the lateral position, the values for the right mirror are nominally identical to those measured for the left mirror (assuming symmetrical positioning of the left and right mirrors on the vehicle).

Table 6d
Mirror Dimensions and Locations (mm)
TRUCK (N=16)

Dimension	Mean	S.D.	Median	10th %ile	90th %ile
Left Mirror					
Width	189	32	186	155	228
Height	133	15	130	118	156
Fore-aft Position re Eye	-532	123	-579	-656	-346
Lateral Position re Eye	-569	50	-545	-650	-527
Vertical Position re Eye	-183	34	-187	-217	-154
Height Above Ground	1214	78	1190	1126	1323
Center Mirror					
Width	243	22	229	226	276
Height	55	3	55	51	59
Fore-aft Position re Eye	-521	88	-530	-604	-431
Lateral Position re Eye	380	44	365	336	446
Vertical Position re Eye	89	37	89	51	132
Height Above Ground	1485	81	1458	1403	1600
Right Mirror *					
Lateral Position re Eye	1353	134	1276	1232	1546

* Except for the lateral position, the values for the right mirror are nominally identical to those measured for the left mirror (assuming symmetrical positioning of the left and right mirrors on the vehicle).

Mirror Fields of View

The coordinates of the pole locations defining the FOV for each mirror were expressed in the same coordinate system used to calculate the effective eye points (see Figures 1 and 6). The FOV angles were then calculated relative to the average (cyclopean) eye location obtained while the driver was looking at the corresponding mirror. The angles were adjusted to account for any deviation between the vehicle X-axis, as defined by the longitudinal orientation of the door sill, and the laboratory coordinate system. These adjustments were typically less than two degrees.

Tables 7, 8, and 9 list summary values for FOV measurements. Left mirror measurements for one subject were excluded because the mirror was not in the driver's preferred adjustment and because the measures were outlying, e.g., left mirror edge angle –57 degrees. The variables listed in the tables are defined in Table 10 and illustrated in Figure 7. The horizontal angle measures are relative to the vehicle longitudinal axis. A vertical angle of zero refers to a horizontal sight line, and a lateral angle of zero refers to a sight line parallel to the vehicle longitudinal axis. Outward lateral angles (to the left of the vehicle) are negative, and angles downward from the horizontal are negative.

There are few important differences in FOV variables across vehicle types, and all are attributable to differences in mirror and vehicle geometry. Relative to the ground, mirrors are slightly lower ground on minivans than on SUVs, and mirrors on trucks are slightly higher (Table 6). The mirror widths are similar, but mirrors are taller on SUVs and trucks than on minivans. The mirror height difference results in larger vertical FOV in SUVs and trucks than in minivans. Average left-mirror vertical FOV (calculated) is 7.8, 9.1, and 9.9 degrees for minivans, SUVs, and trucks, respectively. However, the average horizontal FOV does not differ across vehicle types. No significant effects of gender were noted. The right mirror on trucks is angled more inboard than on other vehicle types due to greater vehicle width, but the mirror aim (visual center of the FOV) does not differ.

Figure 8 shows plots of the cumulative left, right, top, and bottom edges for the initial FOV measurements for the left mirror. Figures 9 and 10 show similar plots for the center and right mirrors. The plots include revised normal approximations to the data and comparison data from Reed et al. (2000). The revised normal approximations were obtained using means and standard deviations calculated after deleting the four most extreme values on either end, leaving the central forty-four values (forty-three for the right mirror). Removing these points from the calculation improved the fit of the normal approximation to the remaining data. Table 11 lists the means and standard deviations calculated by this method for both the current study and the previous study on passenger cars. Comparisons between the mean values for the two studies indicates that the average left-mirror FOV measures do not differ significantly between passenger cars and the vehicles in the current study. For the right mirror, only the outer edge angle is different, with the passenger car value larger by about four degrees. All of the center mirror edge angles vary significantly between the passenger cars and the vehicles in the current study.

Table 7
Summary of FOV in LEFT Mirror (all vehicles)
(angles in degrees with respect to the horizontal, longitudinal, rearward-directed vehicle axis)

Dimension	Mean	S.D.	Median	10th %ile	90th %ile
Outside (Left) Edge	-12.1	3.3	-12.0	-16.1	-8.4
Inside Edge	0.5	3.2	0.2	-1.4	2.4
Top Edge	4.2	2.0	4.2	1.5	6.5
Bottom Edge	-4.7	2.2	-4.4	-8.0	-2.3
Horizontal Field	12.6	3.5	11.9	9.7	15.6
Vertical Field	8.9	1.5	8.6	7.0	10.8
Horiz. Field (Calculated)	16.3	1.9	16.4	13.3	18.5
Vert. Field (Calculated)	8.9	1.6	8.7	7.0	10.8
Horizontal Angle	19.4	3.4	18.6	16.4	21.9
Vertical Angle	8.2	1.9	8.2	6.2	10.3
Horizontal Aim	-2.5	3.4	-2.8	-6.3	1.9
Vertical Aim	0.2	2.0	0.4	-2.4	2.9

Table 8
Summary of FOV in CENTER Mirror (all vehicles)
(angles in degrees with respect to the horizontal, longitudinal,
rearward-directed vehicle axis)

Dimension	Mean	S.D.	Median	10th %ile	90th %ile
Left (Driver-Side) Edge	-10.9	2.9	-10.6	-15.6	-7.2
Right Edge	8.7	4.9	8.4	5.2	11.9
Top Edge	1.2	1.5	1.1	0.2	2.5
Bottom Edge	-4.0	1.4	-4.1	-5.4	-2.8
Horizontal Field	19.6	5.6	19.0	14.2	24.1
Vertical Field	5.2	1.1	5.4	4.2	6.4
Horiz. Field (Calculated)	27.4	2.8	27.1	24.0	30.9
Vert. Field (Calculated)	5.3	1.2	5.1	4.4	6.2
Horizontal Angle	-16.0	2.6	-16.0	-19.2	-12.2
Vertical Angle	-9.4	3.3	-9.9	-13.5	-4.3
Horizontal Aim	3.7	3.9	3.5	-1.3	7.9
Vertical Aim	-0.8	3.2	-0.9	-4.5	1.2

Table 9
Summary of FOV in RIGHT Mirror (all vehicles)
(angles in degrees with respect to the horizontal, longitudinal,
rearward-directed vehicle axis)

Dimension	Mean	S.D.	Median	10th %ile	90th %ile
Inside (Left) Edge	-3.0	2.3	-3.1	-5.0	-0.4
Outside Edge	17.2	5.4	16.6	11.8	24.2
Top Edge	6.1	2.7	6.0	3.0	9.7
Bottom Edge†	-9.3	3.2	-9.7	-12.9	-4.6
Horizontal Field	20.2	4.4	20.2	16.0	25.3
Vertical Field	15.4	2.9	14.9	12.7	18.4
Horiz. Field (Calculated)	23.6	4.2	24.0	20.1	28.0
Vert. Field (Calculated)	14.1	2.4	13.5	12.1	17.6
Horizontal Angle	-28.5	3.0	-28.3	-32.6	-24.7
Vertical Angle	4.7	2.0	4.9	1.7	7.0
Horizontal Aim	9.0	4.9	8.3	3.5	16.0
Vertical Aim	-1.1	2.8	-1.1	-4.3	2.0

† The bottom edge angle in the right mirror was sometimes limited by the floor at measuring position. Some drivers could see the floor in the right mirror at distances closer than the measurement arc, and hence had downward FOV boundaries less restrictive than the reported angles.

Table 10
Definition of Variables Describing Field of View

Variable	Definition
Inside (Left / Driver-Side) Edge	Angle of the edge of the field of view with respect to rearward longitudinal axis of the vehicle; calculated using the vector from the projected cyclopean eye point to the FOV boundary on the measurement arc. For the right mirror, the angle is calculated using the vector from the FOV boundary point to the corresponding edge of the mirror.
Outside Edge	Complement to the Inside Edge.
Top Edge	Angle with respect to horizontal of the top edge of the field of view; calculated using the vector from the projected cyclopean eye point to the FOV boundary on the measurement arc. For the right mirror, the angle is calculated using the vector from the FOV boundary point to the top of the mirror. Measurement is made at the center of the lateral FOV.
Bottom Edge	Complement to Top Edge.
Horizontal Field	Angular width of horizontal FOV, based on pole-sighting FOV measurements referenced to projected cyclopean eye; difference between left and right edge angles.
Vertical Field	Angular width of horizontal FOV, based on pole-sighting FOV measurements referenced to projected cyclopean eye; difference between top and bottom edge angles.
Horizontal Field (Calculated)	Angular width of horizontal ambinocular FOV, based on reflections of rays from both eye locations through points on the mirror perimeter. This is the actual FOV given by the mirror; because of interference from vehicle structure, the FOV behind the vehicle, described by the pole-sighting measurements, is generally smaller. The difference between Horiz. Field (Calc.) and Horizontal Field is a measure of the amount of how much of the vehicle the driver can see in the mirrors.
Vertical Field (Calculated)	Analogous to Horizontal Field (Calculated).
Horizontal Angle	Angle in the horizontal plane of a vector perpendicular to the face of the mirror (left and center mirrors) or perpendicular to a plane fit to the perimeter points (right mirror); a measure of the orientation of the mirror.
Vertical Angle	Analogous to Horizontal Angle.
Horizontal Aim	Center of the calculated cyclopean horizontal FOV, obtained by reflecting rays from the cyclopean eye point through the perimeter points on the mirror. This angle can be interpreted as the visual aim of the mirror, i.e., the vector angle that lies in the center of the mirror FOV.
Vertical Aim	Analogous to Horizontal Aim.

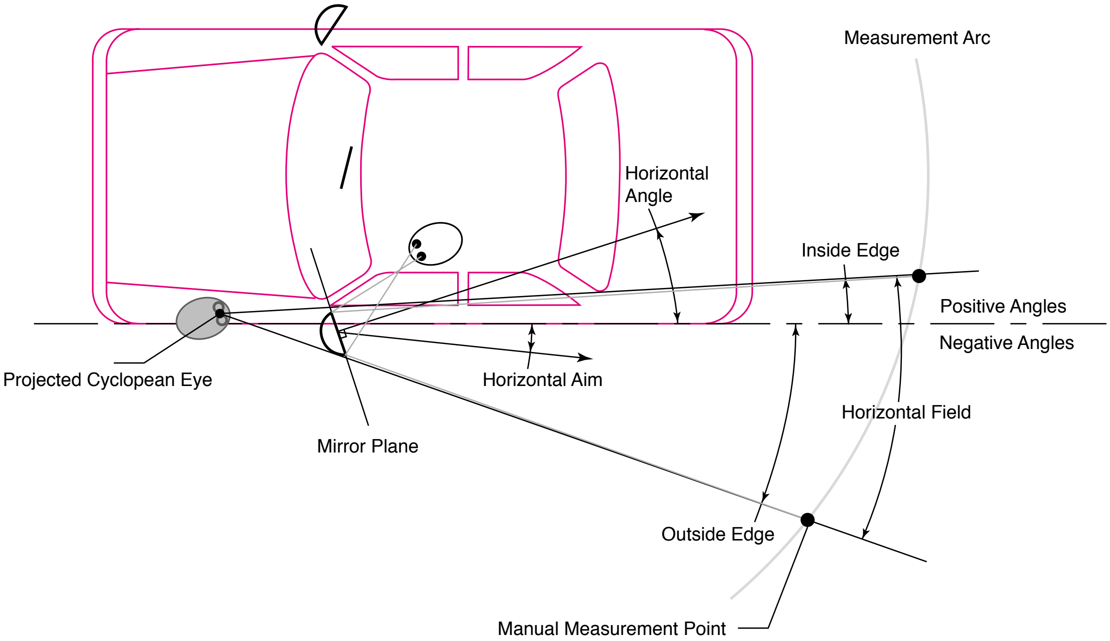


Figure 7. FOV measurement definitions. Vectors from the projected cyclopean eye point to the pole-sighting FOV measurement points do not necessarily pass through the perimeter of the mirror, but the angles measured in this way are very similar to the true FOV angles (shown with light gray lines).

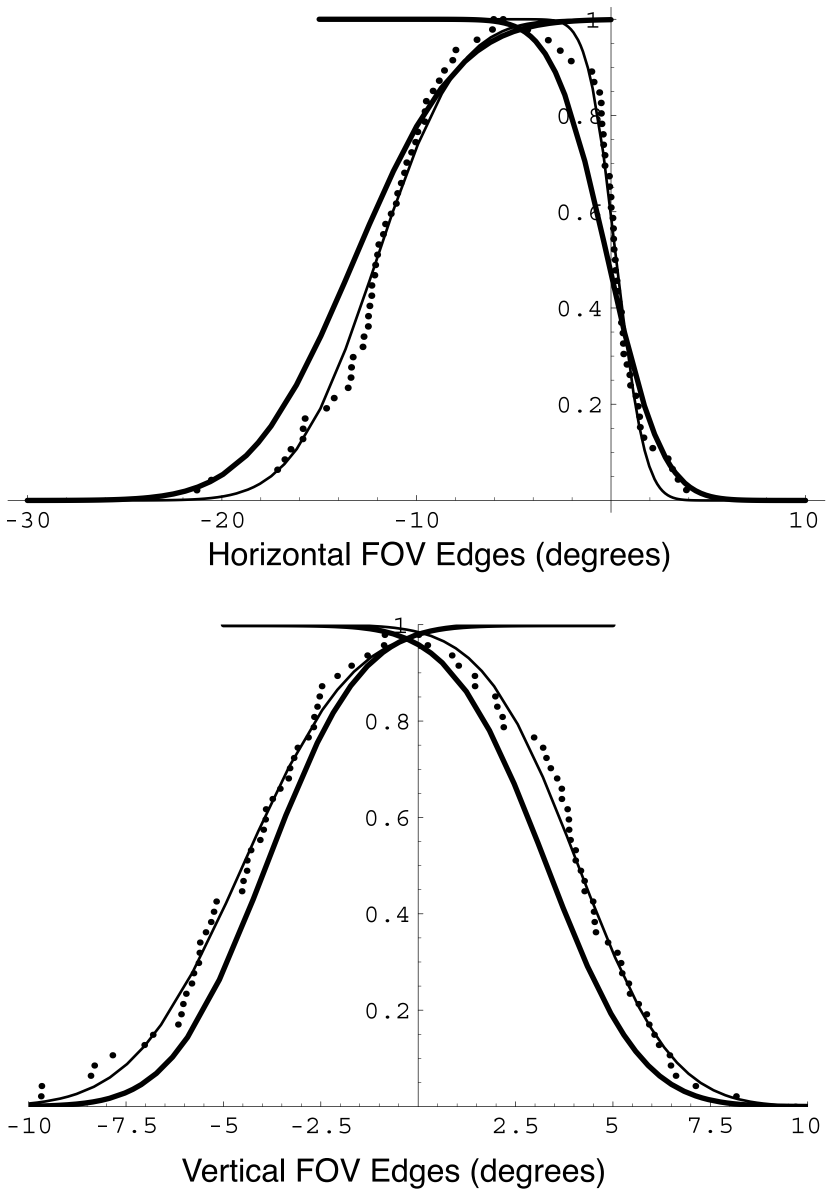


Figure 8a. Cumulative left, right, top, and bottom edges of the FOV in the LEFT mirror (points), normal approximation, revised normal approximation (see text) after deleting the four most extreme values on both ends (thin lines), and revised normal approximations for passenger cars (thick lines) from Reed et al. (2000).

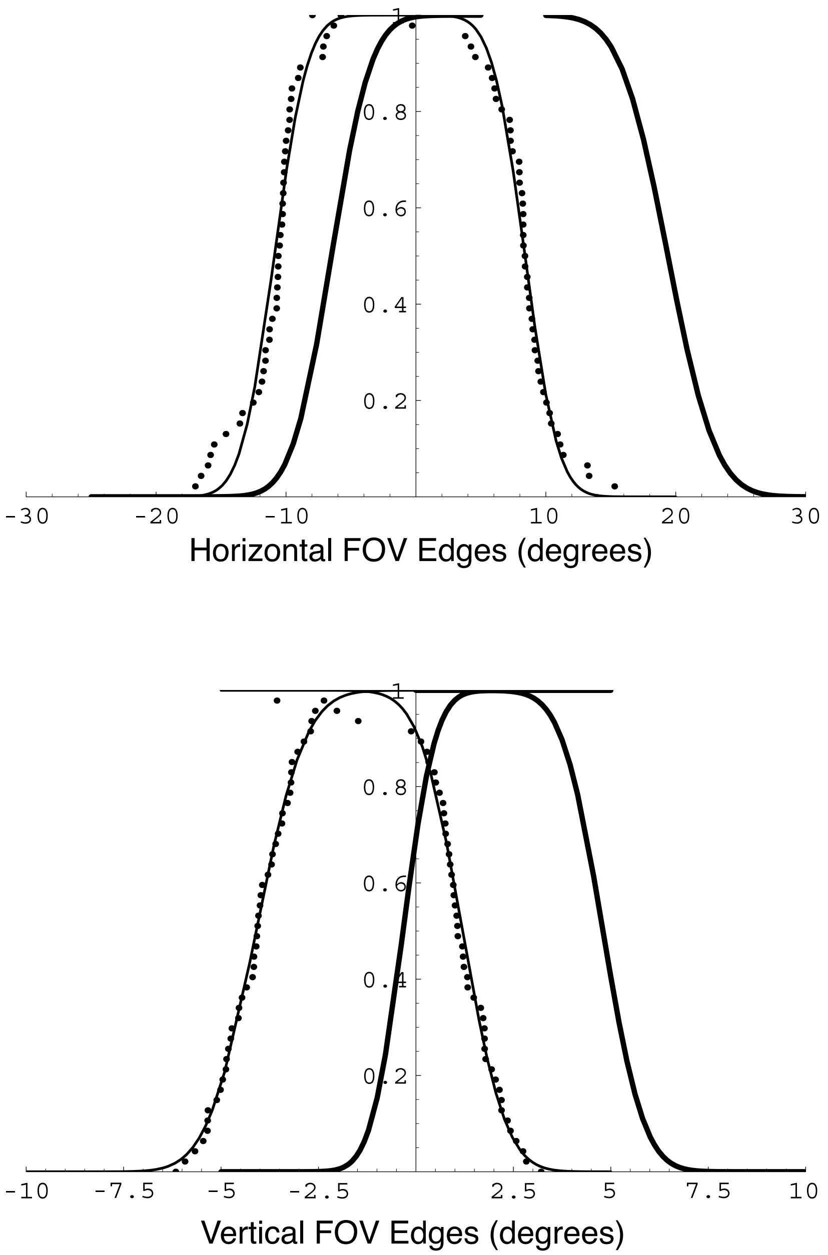
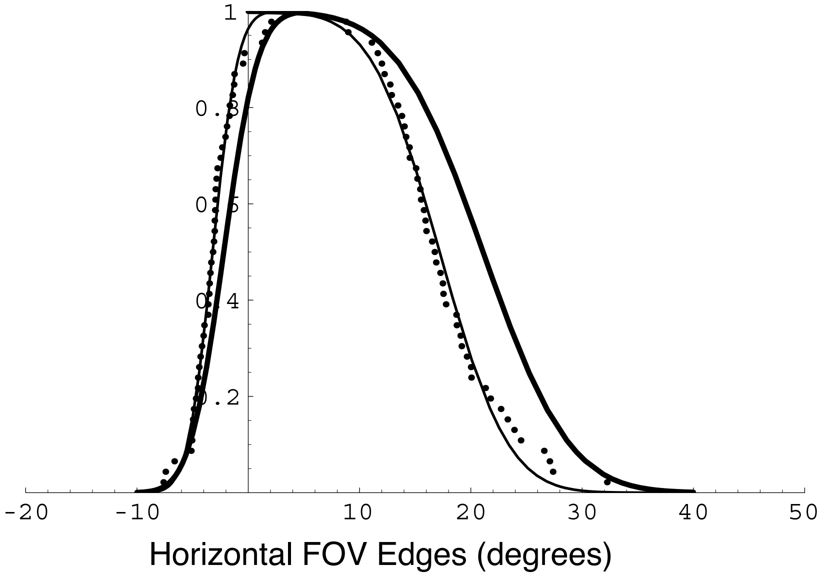


Figure 8b. Cumulative left, right, top, and bottom edges of the FOV in the CENTER mirror (points), normal approximation, revised normal approximation (see text) after deleting the four most extreme values on both ends (thin lines), and revised normal approximations for passenger cars (thick lines) from Reed et al. (2000).



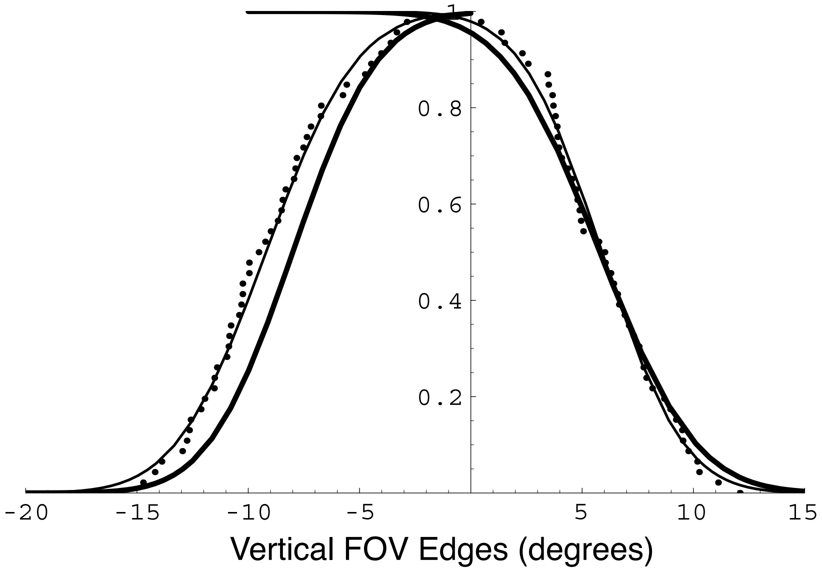


Figure 8c. Cumulative left, right, top, and bottom edges of the FOV in the RIGHT mirror (points), normal approximation, revised normal approximation (see text) after deleting the four most extreme values on both ends (thin lines), and revised normal approximations for passenger cars (thick lines) from Reed et al. (2000).

Table 11
Means and Standard Deviations (degrees) Used for
Revised Normal Approximations in Figures 8, 9, and 10

Mirror	Edge	Passenger Cars (Reed et al. 2000)		Minivans, SUVs, and Pickup Trucks	
		Mean	S.D.	Mean	S.D.
Left					
	Outside	-13.2	4.2	-12.0	2.9
	Inside	-0.2	2.2	0.3	1.1
	Top	3.3	1.9	4.1	1.9
	Bottom	-3.9†	1.9	-4.5	2.2
Center					
	Left**	-6.5	2.4	-10.9	2.0
	Right**	19.4	2.9	8.4	2.0
	Top**	4.8	0.8	1.2	0.9
	Bottom**	-0.3	0.7	-4.1	1.0
Right					
	Outside**	21.1	6.1	17.2	4.8
	Inside	-2.2	2.4	-3.2	1.8
	Top	5.8	3.4	5.9	2.9
	Bottom	-8.0	3.0	-9.2	3.2

† This value erroneously reported as 3.9 in Reed et al. (2000).
** Difference between passenger cars and vehicles in current study is significant with $p \leq 0.01$ using a two-tailed *t*-test.

Results from Reaim Tests

After the initial FOV measurement, the driver took his or her vehicle on a short drive to check the mirror aim. Drivers were told to adjust the mirrors to their preferred aim. On returning, the FOV was measured, using the pole-sighting technique, only for mirrors that the driver reported adjusting. Seven drivers adjusted the left mirror, eight drivers adjusted the center mirror, and eight drivers adjusted the right mirror. Fourteen drivers did not adjust any mirror. Table 12 summarizes FOV measures after the drive. If the mirror was not readjusted, data from the original measurement were used. FOV measures obtained after the drivers were provided an opportunity to reaim the mirrors did not differ substantially from the initial measurements, indicating that the average in-use values obtained in the initial measurements are also a good representation of the preferred mirror adjustments for these drivers.

Table 12
FOV Measures after Mirror Adjustment

Dimension	Mean	S.D.	Median	10th %ile	90th %ile
Left Mirror					
Left (Outside) Edge	-12.6	3.7	-12.2	-17.7	-8.6
Right Edge	0.4	3.3	0.2	-2.2	2.6
Top Edge	4.1	2.1	4.2	1.3	6.2
Bottom Edge	-4.9	2.1	-4.5	-8.0	-2.6
Horizontal Field	13.0	3.6	12.7	9.9	16.1
Vertical Field	9.0	1.5	8.6	7.3	10.9
Center Mirror					
Left (Driver-Side) Edge	-10.9	2.6	-10.3	-14.9	-8.4
Right Edge	8.7	4.8	8.6	4.6	11.4
Top Edge	1.3	1.3	1.1	0.2	2.5
Bottom Edge	-4.3	2.0	-4.1	-5.4	-3.0
Horizontal Field	19.6	5.7	19.0	14.2	24.2
Vertical Field	5.6	1.6	5.5	4.4	6.4
Right Mirror					
Left (Inside) Edge	-2.7	2.6	-2.9	-5.1	0.0
Right Edge	18.2	5.7	17.3	11.9	26.0
Top Edge	6.1	2.8	6.0	2.8	9.8
Bottom Edge	-9.5	3.1	-10.2	-12.8	-5.5
Horizontal Field	20.9	4.2	21.2	16.4	25.0
Vertical Field	15.6	3.0	15.2	13.0	18.4

Seeing Part of One's Vehicle

As in the previous study with passenger cars, most of the outside mirrors in this study were aimed in such a way that the drivers could see their vehicles. All but 9 of 48 drivers identified the car as the limit for the inside edge of the left-mirror FOV (compared with 7 of 43 in the passenger car study). In the right mirror, the car defined the inside edge of the FOV for all but 11 of 48 drivers (compared with 9 of 41 in the passenger car study).

The calculated FOV (using ray projections) was generally larger than the FOV measured using the pole-sighting technique, with the difference providing an estimate of how much of the mirror FOV was obstructed by the vehicle. On average, the measured horizontal field of view was 3.7 degrees less than the calculated field of view in the left mirror (3.5 in the passenger car study) and 3.4 degrees less in the right mirror (cf. 4.0), although there was considerable variability. Given the average, horizontal, calculated FOV of 16.3 degrees on the left and 23.6 degrees on the right, drivers used an average of 23 percent (left) and 14 percent (right) of the ambinocular mirror FOV to see their vehicles (compared with 21 percent and 15 percent in the previous study).

Comparison of Calculated and Measured FOV

The validity of the calculated FOV method using measured eye and mirror locations was similar to the previous study. FOV angles calculated by ray projection were compared with those obtained by the pole-sighting method. The correlation was 0.90 for the left mirror outside edge and 0.95 for the right mirror outside edge (outside edges are used because the vehicle does not truncate the FOV on the outside edge). These values compare favorably with the correlation coefficients of 0.86 and 0.90 obtained in the previous study. As in the passenger car study, the mean outside edge angle for the left mirror was slightly smaller than the value obtained by the pole-sighting technique (-10.6 vs. -12.1 degrees), a difference that is probably due to small head movements during the pole-sighting measurements.

Range of Adjustment for Left Mirror

After the conclusion of FOV measurement, the locations of points on the corner of the mirror surface were measured with the mirror adjusted to the extremes of its range of motion. A vector normal to the surface was calculated in each position (maximally left, right, up, and down) and used to calculate plan-view and side-view angular adjustment ranges. Many of the vehicles with manually adjusting mirrors could be adjusted through a very large horizontal range, but much of the range would not be useful to a driver. Consequently, the analysis was restricted to 32 vehicles equipped with motorized mirror adjustments for which valid data were available. These included 15 minivans, 13 SUVs, and 4 trucks (most trucks had manually adjusted mirrors).

As shown in Table 13, the mirrors provided an average of about 20 degrees of both vertical and horizontal adjustment. The center of the adjustment range was close to the average left-mirror orientation. The average horizontal angle set by the drivers was 19.4 degrees with respect to the vehicle centerline, compared with the center of the adjustment range at 16.5 degrees. For vertical adjustment, the drivers set their mirrors at 8.2 degrees with respect to horizontal, compared with 6.5 degrees. The standard deviations for all of the measures are fairly small, indicating consistency across vehicles in the layout of the left mirror adjustment range.

Table 13
Orientation of Left Mirror Surface Normal at Maximum Range of Adjustment
(N = 32 vehicles with power-adjust mirrors)
(angles in degrees with respect to the horizontal, longitudinal, rearward-directed vehicle axis)

Dimension	Mean	S.D.	Median	10th %ile	90th %ile
Up	17.1	3.1	17.3	12.8	20.9
Down	-4.0	1.8	-3.8	-5.7	-2.1
Left	6.8	3.2	6.4	3.1	11.8
Right	26.2	3.0	25.7	23.1	30.7
Vertical Range	21.1	2.5	21.3	18.6	23.1
Horizontal Range	19.4	3.1	19.3	16.2	21.9
Center of Vertical Range	6.5	2.2	6.6	4.0	9.3
Center of Horizontal Range	16.5	2.7	16.2	13.5	20.3

Discussion

This study added FOV data from 48 minivans, SUVs, and pickup trucks to a database of 43 passenger cars measured using identical techniques. No important differences between the two studies in FOV in the outside mirrors were identified. SUVs and pickup trucks have larger mirrors, on average, than minivans and passenger cars, but the difference is mainly in the vertical dimension. The mirrors in SUVs and pickup trucks are also farther from the driver's eyes than in passenger cars, on average, reducing the FOV benefits of the larger mirrors.

Drivers of minivans, SUVs, pickup trucks, and passenger cars apparently aim their mirrors similarly. Most drivers aim the outside mirrors so that they can see their vehicle in 15 to 20 percent of the mirror view. As in the previous study, the opportunity to reaim the mirrors did not result in substantially different mirror FOV, indicating that the drivers were operating with their mirrors aimed approximately as they preferred them.

The coordinate-measurement methods for calculating mirror FOV worked as well in this study as in the previous study. These methods are primarily useful for determining FOV boundaries that are not restricted by the vehicle. Discrepancies between the two methods are most likely due to the fact that changes in a driver's eye locations during the pole-sighting measurements can expand the FOV, especially for the left mirror.

The data from these two studies characterize mirror FOV in U.S. private vehicles fairly completely, although larger light trucks (full-size pickup trucks), larger SUVs, and full-size vans are not well represented. However, the data from this study suggest that mirror aiming strategies are independent of vehicle type, and hence the FOV in the missing vehicles is likely to be similar to those in the database.

As in the previous study, a primary conclusion is that attempts to improve drivers' indirect FOV must contend with the preference of most drivers to see the side of the vehicle in the outside mirrors. Although changes in driver training could improve aiming practices for some drivers (Platzer, 1995), given current aiming behavior the best option for improving left-side visibility may be to use nonplanar mirrors on the driver side (Flannagan, 2000).

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