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16. Abstract

This study examined the relationship between the size of the driver-side outside mirror and the frequency of lane-change crashes. To control for other vehicle and driver differences that might be associated with mirror size, the frequency of going-straight-ahead crashes was used for comparison. The analysis used 1991-2005 North Carolina crash data. The sample consisted of 77 vehicles, including 37 passenger cars, 14 minivans, 14 SUVs, and 12 pickup trucks. The physical dimensions of the vehicles' mirrors were measured with respect to a three-dimensional coordinate system that was relative to fixed points on the ground, when the driver was sitting in his/her normal driving position and looking at the mirror. Eye locations measured while drivers looked in the mirror were used to calculate the nominal field of view provided by the mirror. The effective field of view, limited by the body structure of the vehicle, was obtained using a manual pole-sighting technique.

The main finding is that the relative likelihood of lane-change crashes was not related to the width, the height, or the area of the driver-side mirror. The most likely reason for this finding is that the effective field of view was not related to mirror size (although the nominal field of view was). That, in turn, is partly a consequence of two trends: larger mirrors being associated with larger eye-to-mirror distances, and drivers aiming their mirrors in ways that do not take full advantage of larger mirror sizes.

17. Key Words

rearview mirrors, mirror size, mirror aim, mirror distance, lane-change crashes, field of view

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INTRODUCTION

One of the primary uses of rearview mirrors occurs prior to lane-change maneuvers. This is the case because the mirrors provide information about other vehicles to the rear and side that might pose a conflict. The driver-side outside mirror is of particular importance in such situations.

The current U.S. federal requirements do not specify the minimum size of driver-side outside mirrors for passenger vehicles. Instead, the requirements call for a minimum size of the field of view as follows:

> *S5.2.1 Field of view. Each passenger car shall have an outside mirror of unit magnification. The mirror shall provide the driver a view of a level road surface extending to the horizon from a line, perpendicular to a longitudinal plane tangent to the driver's side of the vehicle at the widest point, extending 2.4 m out from the tangent plane 10.7 m behind the driver's eyes, with the seat in the rearmost position. The line of sight may be partially obscured by rear body or fender contours. The location of the driver's eye reference points shall be those established in Motor Vehicle Safety Standard No. 104 (Sec.571.104) or a nominal location appropriate for any 95th percentile male driver.* (FMVSS, 2007)

For unit magnification rearview mirrors, the effective field of view (FOV) is determined by three variables: the physical size of the reflective part of the mirror (a larger size results in a larger FOV), the distance to the mirror (a shorter distance yields a larger FOV), and the aim of the mirror (the more the driver is able to see the body of his/her own vehicle, the smaller the effective FOV is). As a result of typical driver distances to and aiming of mirrors, the minimum FOV requirements do not fully eliminate blind areas to the rear and side of the vehicle.

Consequently, it is of interest to examine whether the physical dimensions of driver-side outside mirrors have an effect on the likelihood of lane-change crashes. As was indicated above, with everything else equal, the larger the mirror the smaller the blind area, and that should lead to fewer lane-change crashes. However, everything else is rarely equal. For example, it could be that vehicle manufacturers tend to install larger mirrors on vehicles that typically have larger eye-to-mirror distances, thus maintaining approximately the same effective FOV. Another possibility is that drivers might systematically aim larger mirrors more inboard, thus reducing their effective FOV.

In this study, we examined the effect of the size of the outside rearview mirrors on the likelihood of lane-change crashes. We also examined the relationships between mirror size and effective FOV, and between mirror size and both mirror aim and eye-to-mirror distance. These latter analyses were performed to see whether understanding of these relationships would help with the interpretation of the effect of mirror size on lane-change crashes.

A simple comparison of the size of the mirror and the likelihood of lane-change crashes would be potentially confounded by possible driver and vehicle differences associated with the size of the mirrors. Such driver differences would, in turn, influence the amount and type of driving exposure. Consequently, we used the involvement in crashes that involve going straight ahead as a control because this type of crash should not be affected by visibility to the side and rear.

METHOD

Vehicles

The sample consisted of 77 vehicles, including 37 passenger cars, 14 minivans, 14 SUVs, and 12 pickup trucks. The data for these vehicles were collected during prior studies conducted at UMTRI (Reed, Lehto, and Flannagan, 2000; Reed, Ebert, and Flannagan, 2001). The vehicles belonged to subjects who had been recruited via newspaper advertisements for a comprehensive geometric measurement of their vehicles. Each subject brought his/her vehicle to UMTRI and the vehicle was measured in its existing state (including the subject's choice of seating position, mirror aim, etc.). Mirror dimensions and locations were collected, as was a variety of information about the FOV of the drivers, and the location of their eyes and head when they were seated in the driver's seat. The year, make, and model for each vehicle were recorded during this process, and more detailed information about the vehicles was later obtained using the vehicle identification number (VIN) and the VINDICATOR program (IIHS, 2007). A complete list of the vehicles is in the Appendix.

Mirror dimensions

The physical dimensions of the vehicles' mirrors were measured with respect to a three-dimensional coordinate system that was relative to fixed points on the ground. A FaroArm was used to digitize approximately 30 points around the perimeter of each mirror, and to measure the driver's head and eye locations when the driver was sitting in his/her normal driving position and looking at each mirror in turn. Calculations were then made to determine the location of the mirrors (centroid of the mirror perimeter points), both relative to the driver's eyes and to the ground, and the height and width of the mirrors.

Field of view

The FOV for each subject was established using two different methods. The first method involved making calculations based on a projection of the driver's cyclopean eye point (average location between the right and left eye) behind the plane of the mirror. The rays from this eye point through the perimeter of the mirror defined the angles of the

FOV (see Reed, Lehto, and Flannagan, 2000). This represents the *nominal* FOV provided by the mirror, regardless of any obstructions in the FOV. It therefore does not necessarily capture how far outboard the driver can see in a particular setup with a particular mirror aim.

The second method of establishing the FOV involved a manual pole-sighting technique in which the driver was asked to use both eyes to gaze at the mirror and to indicate at what point a physical target was no longer visible. An investigator established the horizontal and vertical FOV by moving the target along predetermined measurement arcs and verbally interacting with the subject. This type of FOV is referred to as the effective FOV throughout this report, as it defines the boundaries of what the driver can actually see given the aim of the mirror and the location of his/her eyes relative to the mirror. The inside edge of the effective FOV on outside mirrors is often defined by the vehicle itself because many drivers aim their outside mirrors in such a way that a part of the vehicle is visible to them. In the analyses that follow, the *effective* FOV is expressed in terms of the outside edge of the field (in degrees relative to the edge of the vehicle), because this defines how far outboard the driver can see. For example, a left outside edge of -15° means that the driver can see up to 15° outboard to the left, based on the particular head position of the driver at the time of measurement, the mirror dimensions, the mirror location relative to the driver, and the mirror aim. (The effective FOV was determined for 75 of the 77 vehicles.)

Crash database

We used 1991-2005 North Carolina crash data to compile crash frequencies for each vehicle type. This database includes all reportable North Carolina traffic crashes (fatal, injury, and property damage). Crash frequencies were tabulated for each vehicle type across the range of years in which data were available. For vehicle model years 1991 and earlier, the analysis included crash data from 1991 (the first available year of data) to 2005 (the last available year of data). For vehicle model years after 1991, the crash statistics included the year prior to the nominal model year (because models are usually released before their nominal year) to 2005.

Crash frequencies were tabulated for the following crash-related vehicle maneuvers (variable 149): “changing lanes or merging” (vehicle maneuver code 05) and “going straight ahead” (vehicle maneuver code 04). Different body styles or trim levels within a given make, model, and year of vehicle were not distinguished in the analysis.

Variables and analysis

The dependent variable was the ratio of the frequencies of lane-change crashes to going-straight-ahead crashes, calculated separately for each vehicle. The predictor variables were the width, height, and area of the driver-side outside mirror. In addition, the curb weight of the vehicle was treated as a covariate. This covariate controls for the possibility that heavier vehicles, which tend to also have larger mirrors, may have different levels of crash involvement than lighter vehicles for reasons other than mirror size.

Three backward multiple-regression analyses were used to determine whether significant relationships existed between the physical dimensions of the mirror and the vehicle’s involvement in lane-change crashes. Additional analyses examined the relationships of mirror size to the two measures of FOV, mirror distance, and mirror aim. These latter analyses were conducted to assist in the interpretation of the results of the regressions of lane-change crashes on mirror size.

RESULTS

Descriptive statistics

The analyses were based on 6,541 lane-change crashes and 142,017 going-straight-ahead crashes. The number of years of crash data included for any given vehicle ranged from a minimum of 5 years to a maximum of 14 years (with a mean of 9.8 years). Table 1 shows the means and standard deviations of the crash ratio and the predictor variables. The distributions were generally normal with some positive skew.

Table 1
Means and standard deviations of the crash ratio and the predictor variables.

Variable	Mean	Standard deviation
Crash ratio	0.048	0.011
Mirror width (cm)	18.1	2.2
Mirror height (cm)	11.0	1.9
Nominal FOV (degrees)	16.3	1.7
Outboard edge of effective FOV (degrees)	-13.1	6.5
Vehicle curb weight (kg)	1,522	282

Table 2 shows a pair-wise correlation matrix for the same six variables. The ratio of lane-change to going-straight-ahead crashes was not highly correlated with any of the other variables. The highest correlation observed was, not surprisingly, between the width and height of the mirror. Consistent with our assumption regarding vehicle weight and mirror size, there were moderate positive correlations between the curb weight of the vehicle and both the height and width of the mirror. Also as expected, there was a moderate positive correlation between the nominal FOV and the width of the mirror.

Table 2

Pearson product-moment correlations among the crash ratio and the predictor variables.

	Crash ratio	Mirror width	Mirror height	Nominal FOV	Effective FOV edge	Curb weight
Crash ratio	1	0.09	< 0.01	-0.02	-0.04	0.09
Mirror width	0.09	1	0.70*	0.42*	0.04	0.61*
Mirror height	< 0.01	0.70*	1	0.21	0.05	0.65*
Nominal FOV	-0.02	0.42*	0.21	1	-0.02	0.02
Effective FOV edge	-0.04	0.04	0.05	-0.02	1	-0.07
Curb weight	0.09	0.61*	0.65*	0.02	-0.07	1

* Correlation is significant at the 0.01 level.

Mirror size vs. ratio of lane-change to going-straight-ahead crashes

Because of the high correlation between the height and width of the mirror, we ran three backward multiple regressions using as predictors, in turn, the mirror width, the mirror height, and the product of the mirror height and width (a surrogate for mirror area). The other independent variable in each regression was the vehicle curb weight. The results indicate that none of the regression analyses produced a significant model, and there were no significant relationships between mirror width, mirror height, or mirror area and crash ratio.

Mirror width vs. field of view

In these analyses, we examined the relationship between the physical dimensions of the mirrors and the FOV that they provided. We specifically focused on mirror width because the lateral dimension is most relevant for detecting adjacent vehicles. Figures 1 and 2 show scatter plots of the two versions of FOV in relation to mirror width. Figure 1 is for the nominal FOV, while Figure 2 is for the left outboard edge of the effective FOV.

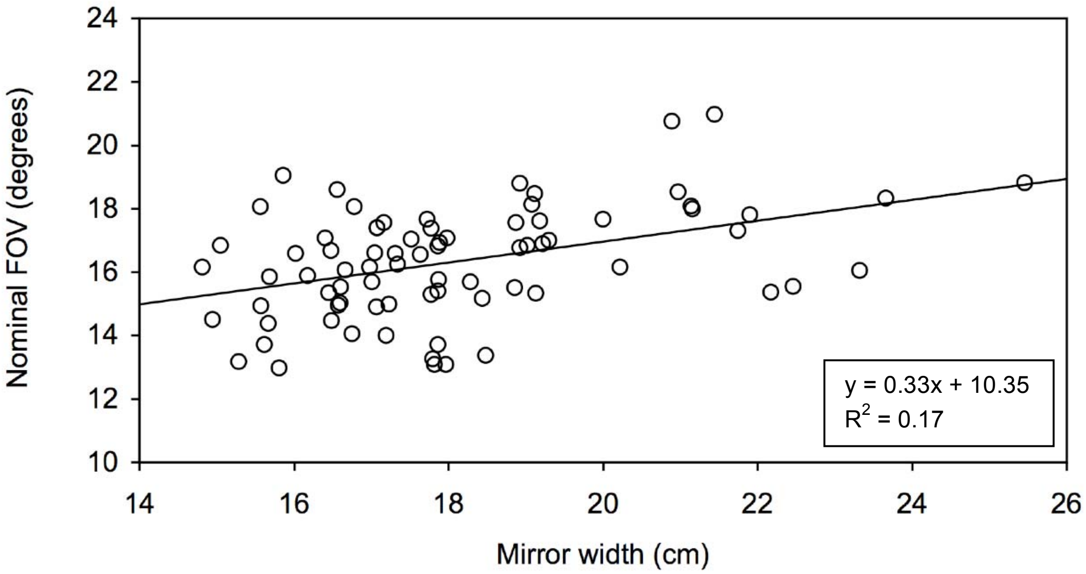

Figure 1. Scatter plot of the nominal FOV as a function of mirror width. The relationship was statistically significant.

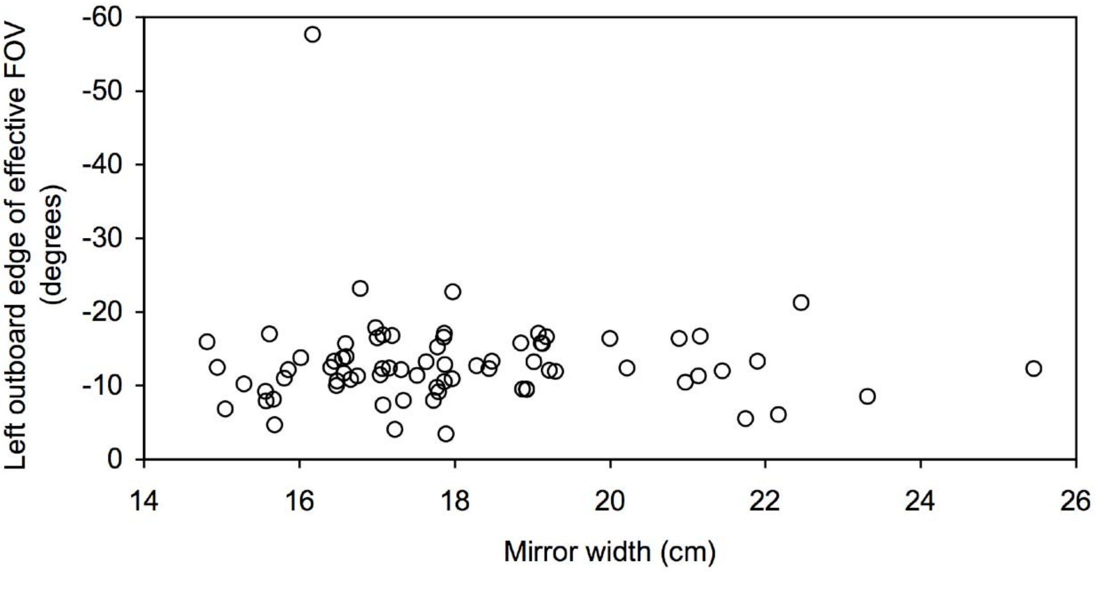

Figure 2. Scatter plot of the outboard edge of the effective FOV as a function of mirror width. The relationship was not statistically significant (whether or not the outlier point was included).

As expected, there was a moderate positive relationship between mirror width and the nominal FOV (see Figure 1), and this relationship was statistically significant, $r(75) = .42, p < .001$. However, there was no relationship between mirror width and the effective FOV (see Figure 2), $r(73) = .04, p > .1$.

Figure 3 plots the relationship between the nominal FOV and the effective FOV. This relationship was not statistically significant, $r(73) = -.02, p > .1$.

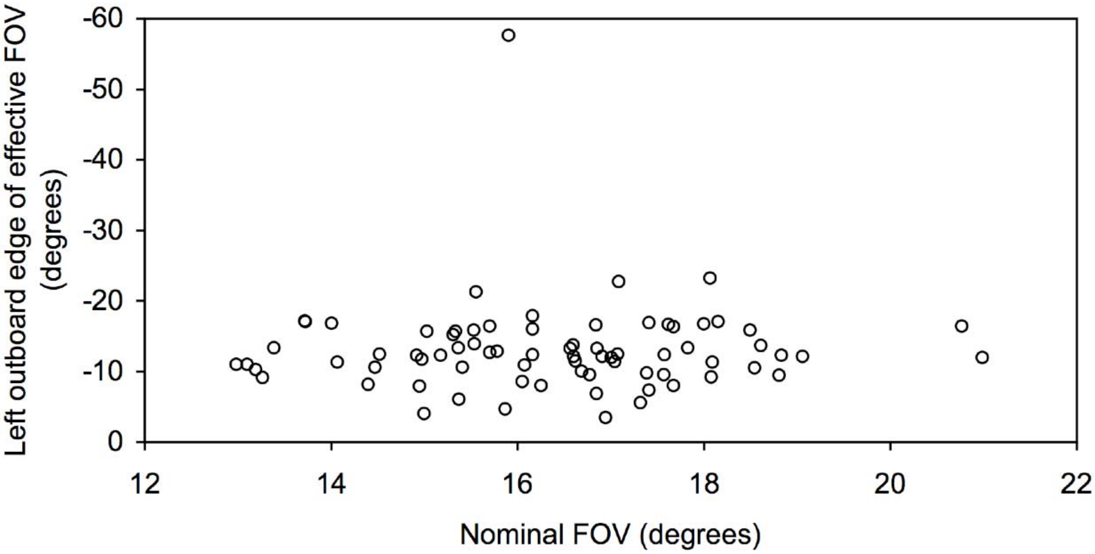

Figure 3. Scatter plot of the outboard edge of the effective FOV as a function of the nominal FOV. The relationship was not statistically significant (whether or not the outlier point was included).

Mirror size vs. mirror distance and mirror aim

In these analyses, we examined whether larger mirror width was associated with larger mirror distance (Figure 4) and more inboard mirror aim (Figure 5). The mirror distance was quantified as the eye-to-mirror distance, and the mirror aim as the center between the outboard and inboard edges of the nominal FOV. The relationship between mirror width and mirror distance was statistically significant, $r(75) = .35, p < .002$, with larger mirrors tending to be associated with larger mirror distances. The relationship between mirror width and mirror aim was not statistically significant, $r(75) = .16, p > .1$. This latter finding implies that drivers with larger mirrors tend to see more of their own vehicles in their mirrors, and thus do not fully use the potential benefits of larger mirrors.

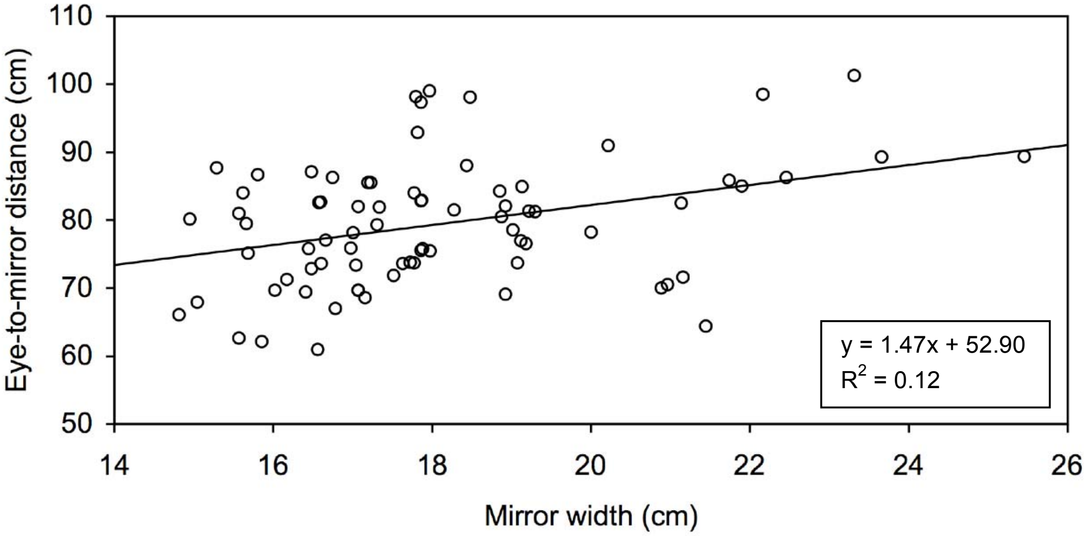

Figure 4. Scatter plot of mirror distance as a function of mirror width. The relationship was statistically significant.

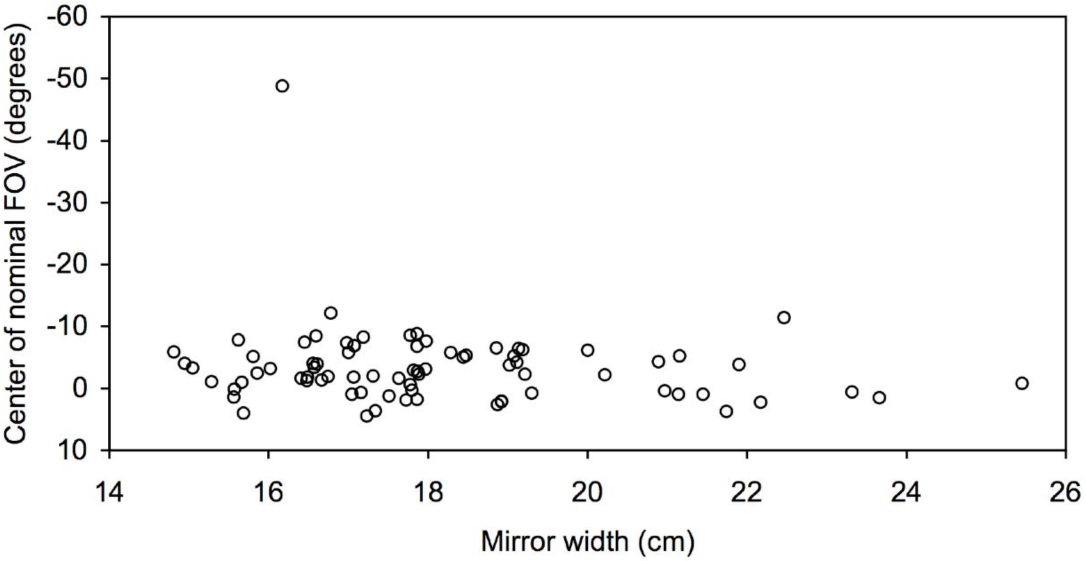

Figure 5. Scatter plot of mirror aim as a function of mirror width. The relationship was not statistically significant (whether or not the outlier point was included).

DISCUSSION

The main finding of this study is that the likelihood of lane-change crashes was not related to the size of the driver-side outside mirror. This was the case for the mirror width, height, and area.

This may be surprising, given the existence of blind areas to the side and rear of vehicles. Is it not the case that wider mirrors provide larger FOVs, smaller blind areas, and consequently, better vision? That would appear to be true when everything else is equal. However, the present data indicate that vehicle manufacturers tend to install larger mirrors on vehicles that typically have larger driver-to-mirror distances, thus reducing the FOV of larger mirrors.

A wide mirror could be aimed more outboard than a narrow mirror and still maintain the same amount of one’s own vehicle that is visible in the mirror for reference. However, we found that mirror aim was not related to mirror size. Consequently, the drivers did not take full advantage of wider mirrors.

The net effect of the actual combinations of mirror size, mirror distance, and mirror aim is that, although there was a moderate positive relationship between mirror width and the nominal horizontal FOV, there was no significant relationship between mirror width and the effective FOV. Similarly, there was no significant relationship between the nominal and effective FOVs.

The present results indicate that larger mirrors did not provide larger effective horizontal FOVs given the eye locations and aiming behavior for the specific drivers that we measured. Therefore, even though larger mirrors can potentially provide larger fields of view, they would not necessarily be expected to result in fewer lane-change crashes, given the likely real-world combinations of vehicles, eye-to-mirror distances, and mirror aims.

CONCLUSIONS

The main finding of this study is that the relative likelihood of lane-change crashes was not related to the width, the height, or the area of the driver-side mirror. The most likely reason for this finding is that the effective FOV was not related to mirror size (although the nominal FOV was). That, in turn, is partly a consequence of two trends: larger mirrors being associated with larger eye-to-mirror distances, and drivers aiming their mirrors in ways that do not take full advantage of larger mirror sizes.

REFERENCES

FMVSS [Federal Motor Vehicle Standard]. (2007). *Standard No. 111: Rearview mirrors.* Washington, D.C.: U.S. Government Printing Office.

IIHS [Insurance Institute for Highway Safety]. (2007). *VINDICATOR software*. Arlington, VA: Highway Loss Data Institute of the Insurance Institute for Highway Safety.

Reed, M.P., Ebert, S.M., and Flannagan, M.J. (2001). *Mirror field of view in light trucks, minivans, and sport utility vehicles* (Technical Report No. UMTRI-2001-1). Ann Arbor: The University of Michigan Transportation Research Institute.

Reed, M.P., Lehto, M.M., and Flannagan, M.J. (2000). *Field of view in passenger car mirrors* (Technical Report No. UMTRI-2000-23). Ann Arbor: The University of Michigan Transportation Research Institute.

APPENDIX

Vehicles included in this study.

Vehicle class	Make and model	Measured model year
Passenger car	Buick Century	1996
Passenger car	Buick Century	1999
Passenger car	Buick Park Avenue	1991
Passenger car	Buick Regal	1990
Passenger car	Chevrolet Beretta	1989
Passenger car	Chevrolet Caprice	1987
Passenger car	Chevrolet Cavalier	1994
Passenger car	Chevrolet Cavalier	1996
Passenger car	Chevrolet Cavalier	1998
Passenger car	Dodge Spirit	1992
Passenger car	Ford Crown Victoria	1992
Passenger car	Ford Escort	1998
Passenger car	Honda Accord	1985
Passenger car	Honda Accord	1989
Passenger car	Honda Accord	1991
Passenger car	Honda Civic	1989
Passenger car	Honda Civic	1997
Passenger car	Mercury Marquis	1995
Passenger car	Mercury Sable	1994
Passenger car	Mercury Topaz	1987
Passenger car	Mercury Topaz	1992
Passenger car	Mitsubishi Eclipse Spyder	1999
Passenger car	Nissan Maxima	1998
Passenger car	Oldsmobile Ciera	1987
Passenger car	Oldsmobile Cutlass Ciera	1987
Passenger car	Pontiac Grand Am	1997
Passenger car	Pontiac Grand Prix	1989
Passenger car	Pontiac Grand Prix	1994
Passenger car	Saturn SL	1998
Passenger car	Toyota Camry	1987
Passenger car	Toyota Camry	1992

Vehicle class	Make and model	Measured model year
Passenger car	Toyota Camry	1994
Passenger car	Toyota Camry	1995
Passenger car	Toyota Camry	1997
Passenger car	Toyota Camry	1998
Passenger car	Toyota Corolla	1996
Passenger car	Volkswagen Passat	1999
Minivan	Chevrolet Astro	2000
Minivan	Dodge Caravan	1991
Minivan	Dodge Caravan	1999
Minivan	Ford Aerostar	1992
Minivan	Ford Aerostar	1994
Minivan	Ford Windstar	1995
Minivan	Ford Windstar	1998
Minivan	Mercury Villager	1995
Minivan	Mercury Villager	1997
Minivan	Mercury Villager	1999
Minivan	Plymouth Grand Voyager	1997
Minivan	Plymouth Voyager	1993
Minivan	Plymouth Voyager	1996
Minivan	Plymouth Voyager	2000
SUV	Chevrolet Blazer	1996
SUV	Ford Bronco	1988
SUV	Ford Explorer	1991
SUV	Ford Explorer	1998
SUV	GMC Jimmy	1993
SUV	GMC Jimmy	2000
SUV	GMC Suburban	1998
SUV	GMC Yukon	1999
SUV	Jeep Cherokee	1998
SUV	Jeep Cherokee	2000
SUV	Jeep Wagoneer	1988
SUV	Mercury Mountaineer	1997
SUV	Mercury Mountaineer	1999

Vehicle class	Make and model	Measured model year
SUV	Toyota 4Runner	1998
Pickup truck	Chevrolet Silverado	2000
Pickup truck	Dodge Ram	1994
Pickup truck	Ford F150	1991
Pickup truck	Ford F150	1993
Pickup truck	Ford F150	1995
Pickup truck	Ford Ranger	1990
Pickup truck	Ford Ranger	1993
Pickup truck	Ford Ranger	1997
Pickup truck	Ford Ranger	1998
Pickup truck	Ford Ranger	1999
Pickup truck	Ford Ranger	2000
Pickup truck	GMC Sonoma	2000