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THE EFFECTIVENESS OF ELECTRONIC STABILITY CONTROL ON MOTOR VEHICLE CRASH PREVENTION

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16. Abstract

This study investigates the effects of electronic stability control (ESC) on percentage reductions in the odds of certain crashes generally associated with loss of control. A case-control (induced exposure) study design was implemented using data from the Fatality Analysis Reporting System (FARS) and the General Estimates System (GES).

Using FARS data, vehicles with similar makes and models, but different model years, were analyzed. A 30.5% reduction in the odds of a single-vehicle crash was estimated for passenger cars equipped with ESC, and a 49.5% reduction was estimated for sport utility vehicles (SUVs). The estimated percentage reductions in the odds of rollover for passenger cars and SUVs equipped with ESC were 39.7% and 72.9%, respectively. No significant effects were found on roads that were not dry.

Using the accident type variable in the GES database, cases were defined as vehicles in crashes that ran off the roadway, and controls were defined as vehicles involved in rear-end struck crashes. Overall, estimated percentage reductions for passenger cars and SUVs were 54.5% and 70.3%, respectively. Models that adjust for age and gender effects were fit. No significant differences due to ESC were found between males and females, but middle-aged drivers of passenger cars and older drivers of SUVs tended to benefit most from the presence of ESC. Unlike the FARS data analysis, percentage reductions in the odds of loss of control were significantly greater on roads that were not dry for both passenger cars and SUVs equipped with ESC.

In an analysis using GES data of vehicles with different makes and models, but similar model years, estimated percentage reductions in the odds of loss of control crashes were 40.3% for passenger cars and 71.5% for SUVs.

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The Effectiveness of Electronic Stability Control on Motor Vehicle Crash Prevention

1. Introduction

Electronic stability control (ESC) is an active safety technology designed to reduce loss of control by improving vehicle stability. It has the potential to provide benefits in various driving conditions, but is designed to be particularly useful in cases of oversteering and understeering. Oversteering occurs when a driver makes an abrupt steering maneuver in an attempt to maintain control of the vehicle during a critical driving situation. The critical driving situation could involve steering to avoid hitting a fixed object or negotiating a sharp curve in order to stay on the road. As a driver begins to over steer, the vehicle's rear wheels begin to lose traction, and the vehicle has a tendency to spin out of control. In that case, the ESC system automatically applies the outside front brake, countering the unintended spinning movement that could eventually lead to loss of control. On the other hand, understeering occurs, for example, when a driver miscalculates the curvature of the intended path and the front of the vehicle slides to the outside of the road. In that case, the ESC system automatically applies the inside rear brake in an attempt to bring the vehicle back in line with its original intended direction. ESC is also designed to provide safety benefits in bad weather conditions such as those encountered on wet, snowy, or icy roads. In those situations, ESC has the potential to reduce vehicle rollover by preventing vehicles from skidding or sliding on road surfaces with less friction.

ESC is comprised of various components operating simultaneously in an integrated system under the control of a central processor. The ESC system consists of an electronic control unit (microcomputer), a yaw sensor, a hydraulic unit, wheel speed sensors, and a steering angle sensor. The microcomputer uses information provided by the sensors to compare the vehicle's intended movement with the actual movement. If it is determined that the vehicle is leaving the intended path of travel, appropriate commands are transmitted to the braking system to apply the brake at the appropriate wheel. In some cases, the system may also reduce the engine torque.

By now, the results from various studies, which demonstrate the effects of ESC on reducing the likelihood of certain kinds of crashes, have been published. In an analysis of data collected from five states, Dang (2004) estimated that the odds of a single-vehicle crash were reduced by 35% for passenger cars equipped with ESC. For sport utility vehicles equipped with ESC, the estimated reduction was 67%. In the same study, an analysis of the Fatality Analysis Reporting System (FARS) data led to estimated reductions of 30% for passenger cars and 63% for sport utility vehicles.

In another study using data from seven states, Farmer (2004) found that vehicles equipped with ESC had reduced single-vehicle crash involvement risk by approximately 41% and reduced single-vehicle injury risk by the same amount. In that study, results for passenger cars and sport utility vehicles were combined.

Using vehicles in rear-end struck crashes as the control group, Bahouth (2005) estimated an 11.8% reduction in the odds of a multiple-vehicle frontal crash for vehicles equipped with ESC, and a 52.6% reduction in the odds of a single-vehicle crash. As in the Farmer study, results for passenger cars and sport utility vehicles were combined. The study by Bahouth also accounted for vehicle age on the likelihood of involvement in certain crash types.

Two Swedish studies were conducted that used rear-end crashes as the control groups and presented findings on roads that were either wet or covered with ice and snow. In the first study (Lie et al., 2004), an estimated reduction of 31.5% was reported on wet roads, while an estimated reduction of 38.2% was reported on roads covered with ice and snow. In the second study (Lie et al., 2005), results were additionally broken down by injury severity. For serious and fatal loss-of-control type crashes on wet roads, the estimated reduction was 56.2%, and on roads that were covered with ice and snow, the estimated reduction was 49.2%. The results presented in these two studies were for passenger cars only.

In a study analyzing Toyota passenger cars, Aga and Okada (2003) estimated that the accident rate (accidents per vehicles in use per year) for vehicles equipped with ESC had a 35% reduction in single-vehicle crashes and a 30% reduction in head-on collisions with other vehicles. For more severe crashes, the reductions were 50% and 40%, respectively.

In an experimental design using a driving simulator, Papelis et al. (2004) found an 88% reduction in loss of control with the presence of an ESC system. A total of 120 participants from three age groups balanced by gender were selected for inclusion in the study. Participants were compared in loss-of-control driving situations with and without an ESC system. Overall reductions in loss of control were observed for all age groups and both genders.

Thus, a number of studies have been completed suggesting that ESC is an active safety technology with the potential to reduce crashes resulting from loss of control. The studies have been conducted in several countries, with data collected from various sources. In the United States, effectiveness of ESC systems has been reported based on analyses of state as well as national databases. Furthermore, studies conducted in Europe and Japan reported beneficial effects derived from ESC technology using data collected from those two regions. Although the strengths of associations have varied somewhat across studies, results presented thus far have consistently shown the effectiveness of ESC technology on reducing certain types of crashes.

This study is an investigation into the effectiveness of ESC on motor vehicle crash prevention. Publicly available transportation-related databases are analyzed to determine if vehicles equipped with ESC were less likely to be involved in crashes generally associated with loss of control. The goal is to quantify the effects of ESC on reducing the odds of certain types of crashes using appropriate measures of association and tests of hypotheses.

2. Study Design

The design for this study is based on methodology used in case-control studies (see, for example, Breslow, 1996; Breslow and Day, 1980; or Schlesselman, 1982). In a case-control study, subjects with a particular condition (the cases) are selected for comparison with subjects without the condition (the controls). Cases and controls are compared with respect to attributes believed to be relevant to the condition under investigation. For example, in this study, cases can be defined as those vehicles involved in single-vehicle crashes, while controls can be restricted to vehicles involved in multiple-vehicle crashes. Cases and controls can then be compared with respect to the presence or absence of ESC. The idea behind this strategy is that ESC is designed to assist drivers in loss-of-control situations, and loss-of-control situations can potentially lead to single-vehicle crashes. Therefore, the hypothesis of interest is whether the odds of a single-vehicle crash were reduced for vehicles equipped with ESC. Other definitions of cases and controls are possible and are used in this study. For example, cases can be defined as vehicles that ran off the roadway, either due to loss of control or to avoid hitting a fixed object. Controls can be defined as vehicles involved in rear-end crashes in which the control vehicle was struck from behind. This separates vehicles that could potentially benefit from ESC technology in an impending loss-of-control situation (cases) from those vehicles that would most likely not benefit from ESC technology (controls).

For the examples described above, some researchers prefer to use the term *induced exposure* to describe this study design since it does not follow the exact definition reserved in the medical and epidemiology literature for a case-control study. Nevertheless, methods of data analysis for calculating odds ratios and conducting tests of hypotheses proceed in a straightforward manner, as in standard case-control studies.

3. Description of Data

Two sources of data are used in this study: the Fatality Analysis Reporting System (FARS) data, and the General Estimates System (GES) data. Both of these are publicly available transportation-related databases. FARS is designed to be a census file of all fatal involvements, while GES is a sample of mostly nonfatal involvements and a relatively small percentage of fatal involvements.

3.1 Fatality Analysis Reporting System (FARS) Files

The Fatality Analysis Reporting System (FARS) is a collection of files documenting all qualifying fatal crashes that occurred within the United States. This database is used in this study to gather information regarding passenger cars and sport utility vehicles that were involved in fatal crashes. To be included in this census of crashes, a crash had to involve a motor vehicle traveling on a traffic way customarily open to the public, and must have result in the death of a person (driver, passenger, or non-motorist) within 30 days of the crash. This database consists of several separate files including a vehicle file, a person file, and an accident file, along with several other files that have been added to the collection over the years. The FARS crash data are collected by the National Center for Statistics and Analysis under the authority of the National Highway Traffic Safety Administration (NHTSA).

3.2 General Estimates System (GES) Files

The GES database is a nationally representative probability sample of crashes, and contains detailed information concerning accident involvement and operating environment. This sample is a complex sample survey with clustering, stratification, and weighting that allows calculation of national estimates. The sample is selected by data collectors from a list of police-reported crashes that occur annually. Because the data are representative of all crashes, the file contains records for vehicles in mostly nonfatal crashes; however, the file also contains a small amount of data for vehicles involved in fatal crashes. Collection of GES data is directed by the National Center for Statistics and Analysis under the authority of NHTSA.

4. Analysis of ESC for Passenger Cars and Sport Utility Vehicles (FARS Data)

The FARS data are analyzed in a case-control design to assess the effects of ESC on certain types of crashes. The types of crashes investigated include single-vehicle crashes (SVC), ran-off-road type crashes, rollover crashes, and crashes on roads that were not dry (this includes wet roads, roads with snow, icy roads, and roads with sand, dirt, or oil). These crash types were chosen based on the belief that they are associated with loss of control, and outcomes for vehicles in these crashes without ESC could have been different had ESC technology been present.

Each presentation begins with an analysis for passenger cars, followed by the equivalent analysis for sport utility vehicles (SUVs). This allows for direct comparison between the two vehicle types. The most common measure of association used in case-control studies is the odds ratio. Methods for calculating odds ratios and confidence intervals are readily available. Therefore, in this study, the effects of ESC are reported according to the percentage reduction in the odds of certain crash types for vehicles equipped with ESC as standard equipment. All results are based on the information contained in 2x2 contingency tables, except for the results obtained using statistical models that assess the effects of ESC while controlling for age and gender.

4.1 Effects of ESC on Single-Vehicle Crashes

FARS data for crash years 1995 through 2003 were analyzed to investigate the effects of the presence of electronic stability control (ESC) on single-vehicle crashes. Passenger cars with model years between 2000 and 2003 were identified with ESC available as standard equipment. In addition, passenger cars of similar makes and models in model years between 1995 and 1999 were identified in which ESC was not available. Table 1 shows the number of passenger cars identified with and without ESC by model year. Appendix A shows the number of passenger cars with and without ESC in greater detail by make and model.

Table 1 Numbers of Passenger Cars Identified with and without ESC by Model Year (FARS 1995-2003)

ESC Not Available						ESC Standard Equipment				
1995	1996	1997	1998	1999	Total	2000	2001	2002	2003	Total
374	213	223	159	131	1,100	120	115	74	37	346

To investigate the effects of ESC on single-vehicle crashes, passenger cars are cross-classified into a 2x2 contingency table. The two cross-classifying factors of interest are the presence or absence of ESC, and whether the vehicle was involved in a single-vehicle crash (SVC) or a multiple-vehicle crash (MVC). Table 2 shows the contingency table and the number of passenger cars falling into each category.

Table 2 Cross-Classification of Passenger Cars by ESC and Accident Type (FARS 1995-2003)

Accident Type		SVC	MVC	Total
ESC	No	490	610	1,100
	Yes	124	222	346
	Total	614	832	1,446

30.5% reduction in odds of SVC for passenger cars equipped with ESC. 95% CI (13.1%, 47.8%)

Based on the data in Table 2, the odds of a single-vehicle crash for passenger cars that were not equipped with ESC were 490/610=0.8033. The odds of a single-vehicle crash for passenger cars equipped with ESC as standard equipment were 124/222=0.5586. Therefore, the percentage reduction in the odds of a single-vehicle crash for passenger cars equipped with ESC is estimated to be 1 - (0.5586/0.8033) = 30.5%. The 95% confidence interval for this percentage is (13.1%, 47.8%). The procedure used for calculating confidence intervals is described in Appendix D.

In a case-control study, the vehicles of interest should be as similar as possible, except for the presence or absence of ESC, so that any measured effects can most likely be attributed to the presence of ESC. However, many of the passenger cars without ESC were older than passenger cars with ESC at the time of the crash. In fact, according to Table 1, the majority of vehicles without ESC technology had 1995 model years. For example, a 1995 model car involved in a fatal crash in 2003 was eight years old at the time of the crash. The earliest model year for any car equipped with ESC included in this study was 2000. Therefore, the maximum age of a passenger car equipped with ESC at the time of the crash was three years old. The reduction in the odds of a single-vehicle crash for passenger cars equipped with ESC could be confounded by an association between single-vehicle crashes and age of the vehicle at the time of the crash.

Table 3 shows the contingency table if the data are restricted to vehicles that were three years old or newer at the time of the crash. This removes any effects of the age of the vehicle. Note that the second row in Table 3 is the same as the second row in Table 2 since all passenger cars in this study equipped with ESC were three years old or newer. From the data in Table 3, the odds of a single-vehicle crash for passenger cars not equipped with ESC were 275/316=0.8703. The percentage reduction in the odds of a single-vehicle crash for passenger cars equipped with ESC is estimated to be 1 - (0.5586/0.8703) = 35.8%. The 95% confidence interval for this percentage is (18.3%, 53.3%). Therefore, the reduction in the odds of a single-vehicle crash for vehicles equipped with ESC is estimated to be greater when older vehicles at the time of the crash are excluded from analysis. It appears that age of the vehicle at the time of the crash does not compromise the significant effect found in Table 2.

Table 3 Cross-Classification of Passenger Cars by ESC and Accident Type Restricted to Vehicles Three Years Old or Newer (FARS 1995-2003)

Accident Type		SVC	MVC	Total
ESC	No	275	316	591
	Yes	124	222	346
	Total	399	538	937

35.8% reduction in odds of SVC for passenger cars equipped with ESC. 95% CI (18.3%, 53.3%)

The effects of ESC on reducing single-vehicle crashes for SUVs are expected to be different than the effects experienced by passenger cars. Table 4 shows the number of SUVs identified in the FARS files with and without ESC by model year. Appendix B shows the number of SUVs with and without ESC in greater detail by make and model.

Table 4 Numbers of Sport Utility Vehicles Identified with and without ESC by Model Year (FARS 1995-2003)

ESC Not Available					ESC Standard Equipment				
1996	1997	1998	1999	Total	2000	2001	2002	2003	Total
9	16	45	201	271	35	82	58	27	202

Table 5 is a contingency table of the number of SUVs involved in fatal crashes, cross-classified by ESC and accident type. According to the data, the odds of a single-vehicle crash for SUVs that were not equipped with ESC were 125/146=0.8562. On the other hand, the odds of a single-vehicle crash for SUVs that had ESC as standard equipment were 61/141=0.4326. Therefore, the percentage reduction in the odds of a single-vehicle crash for an SUV equipped with ESC is estimated to be 1 - (0.4326/0.8562) = 49.5%. The 95% confidence interval for this percentage is (30.1%, 68.9%).

Table 5 Cross-Classification of SUVs by ESC and Accident Type (FARS 1995-2003)

Accident Type		SVC	MVC	Total
ESC	No	125	146	271
	Yes	61	141	202
	Total	186	287	473

49.5% reduction in odds of SVC for SUVs equipped with ESC. 95% CI (30.1%, 68.9%)

In order to eliminate any effects due to age of the SUV at the time of the crash, Table 6 shows the data restricted to vehicles that were three years old or newer at the time of the crash. In this case, the odds of a single-vehicle crash for SUVs without ESC were 97/108=0.8981. The percentage reduction in the odds of a single-vehicle crash for an SUV equipped with ESC is estimated to be 1 - (0.4326/0.8981) = 51.8%. The 95% confidence interval for this percentage is (32.2%, 71.4%). As with passenger cars, the results are not compromised when analysis is restricted to vehicles three years old or newer at the time of the crash.

Table 6 Cross-Classification of SUVs by ESC and Accident Type Restricted to Vehicles Three Years Old or Newer (FARS 1995-2003)

Accident Type		SVC	MVC	Total
ESC	No	97	108	205
	Yes	61	141	202
	Total	158	249	407

51.8% reduction in odds of SVC for SUVs equipped with ESC. 95% CI (32.2%, 71.4%)

4.2 Effects of ESC on Single-Vehicle Crashes by Age and Gender

Age and gender could play important roles with respect to benefits derived from reducing single-vehicle crashes for vehicles equipped with ESC. A statistical model can be fit to assess the effects of ESC while controlling for other factors such as age and gender. In addition to controlling for several variables simultaneously, statistical models can also be used to test the significance of these terms, as well as the inclusion of certain interaction terms. A model known as the generalized additive model (GAM; see, for example, Hastie and Tibshirani, 1990) is fit to the FARS data to assess the effects of age, gender, and ESC on single-vehicle crashes. The GAM can fit smooth terms such as smoothing splines to continuous variables. A smooth term will be fit to the age variable since it is measured on a continuous scale.

The results of the fit of a GAM to the FARS data for passenger cars are shown in Table 7. Parameters can be added or removed from the model based on statistical significance. The significance of a parameter is generally determined by the magnitude of the p-value. In practice, a p-value less than 0.05 is the most common criterion used to assess significance, although other values, such as 0.10 or 0.15, can be used. The parameters included in this model are ESC, gender, and two smooth terms for the interaction between age and gender. Significance of the smooth terms is based on a chi-square statistic and estimated degrees of freedom (Edf).

Table 7 Fit of a Generalized Additive Model to the FARS Data for Passenger Cars

Parameter	Estimate	Std. Error	T Ratio	P-Value
Intercept	-0.759	0.114	-6.64	<0.001
ESC	-0.331	0.132	-2.52	0.012
Gender	0.686	0.128	5.34	<0.001

Approximate Significance of Smooth Terms:

	Edf	Chi-Square	P-Value
s(Age) x Male	3	42.55	<0.001
s(Age) x Female	3	2.84	0.417

The parameters in this model have interpretations on the log odds scale. For example, the negative coefficient attached to ESC indicates that the odds of a single-vehicle crash were reduced for vehicles with ESC as standard equipment. Similarly, the positive coefficient attached to gender indicates that, in general, the odds of a single-vehicle crash were greater for males than for females. However, the model also contains smooth interaction terms between age and gender and these need to be taken into account as age and gender vary. Predicted values from this model can be used to compare the odds of a single-vehicle crash for different values of age, gender, and ESC.

First, since the model contains no interactions involving ESC, the estimated reduction in the odds of a single-vehicle crash for passenger cars equipped with ESC at any fixed age and any fixed gender is

$$1 - \exp(-0.331) = 28.2\% .$$

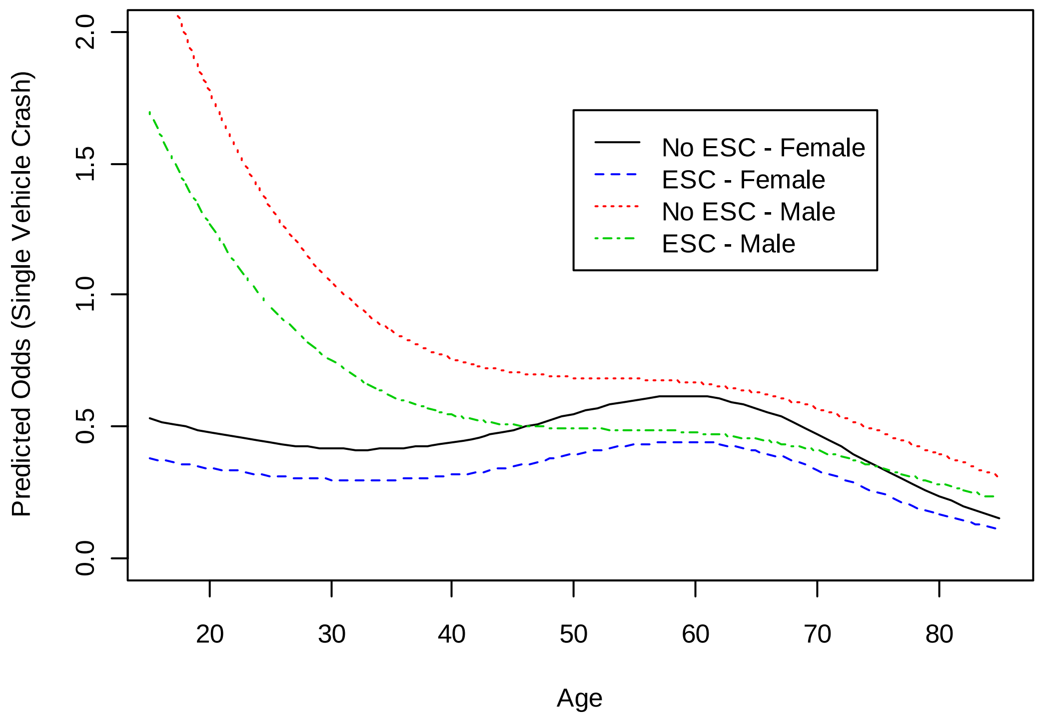
Note that -0.331 is the estimate attached to ESC in Table 7. Following the procedure outlined in Appendix D for calculating confidence intervals, the 95% confidence interval is

$$0.282 \pm 1.96\ (0.132)\ (0.718)$$

or (9.6%, 46.8%). Note that 0.132 is the estimated standard error of ESC in Table 7. These estimates are fairly close to the ones given in Table 2, which are not adjusted for age and gender. Due to interactions and other terms in the model, a figure can be used to display the predicted odds of a single-vehicle crash by age, gender, and ESC. Figure 1 shows output generated from the generalized additive model. The vertical axis is the predicted odds of a single-vehicle crash, while the horizontal axis shows driver age.

The plot clearly shows that young males were most likely to be involved in single-vehicle crashes. The plot also shows a decrease in odds for men as their age increases. For example, the predicted odds of a single-vehicle crash for a twenty-year-old male without ESC were 1.77, while the odds for a fifty-year-old male without ESC were 0.69. On the other hand, for females the plot does not show a large effect due to age. The lines for females are fairly constant with respect to age, except for a slight increase between the ages of, say, fifty and seventy, and slight decreases thereafter. Note that the line for males without ESC is uniformly higher than any other line. On the other hand, the line for females with ESC is uniformly lower than any other line. The line for males with ESC and the line for females without ESC intersect at the approximate ages of 47 and 75. This suggests that males with ESC in this age range had reduced odds of a single-vehicle crash relative to females without ESC.

Figure 1 Effects of Age, Gender and ESC on the Odds of a Single-Vehicle Crash for Passenger Cars (FARS 1995-2003)



The reduction in odds at any age can be estimated by dividing the odds between any two lines in Figure 1. For example, for a thirty-year-old male with ESC, the estimated odds of a single-vehicle crash were 0.7512. For a thirty-year-old male without ESC, the estimated odds were 1.046. Therefore, the estimated reduction in the odds of a single-vehicle crash for a vehicle equipped with ESC was $1-0.7512/1.046=28.2\%$, which coincides with the estimate calculated from Table 7 above. This estimate is constant, regardless of age and gender since the model does not contain interaction terms involving ESC. Calculation of the confidence interval, which is shown above, requires the model output generated from statistical software.

For SUVs, the fit of a generalized additive model can also be used to assess the effects of age, gender, and ESC on single-vehicle crashes. Table 8 shows the fit of a GAM to the FARS data for SUVs. In this model, no interaction terms were significant. Among the three variables, only main effects for ESC, gender, and a smooth term for age were significant. Since there are no interaction terms in this model, the estimated effects of ESC were the same for any fixed age and gender. From the model output, the estimated percentage reduction in the odds of a single-vehicle crash for an SUV equipped with ESC was

$$1 - \exp(-0.663) = 48.5\% .$$

The 95% confidence interval is

$$0.485 \pm 1.96\ (0.202)\ (0.515)$$

or (28.1%, 68.9%). These model-based results are very similar to the results provided in Table 5 in which adjustments were not made for age and gender.

Table 8 Fit of a Generalized Additive Model to the FARS Data for SUVs

Parameter	Estimate	Std. Error	T Ratio	P-Value
Intercept	-0.552	0.180	-3.07	0.002
ESC	-0.663	0.202	-3.29	0.001
Gender	0.610	0.205	2.98	0.003

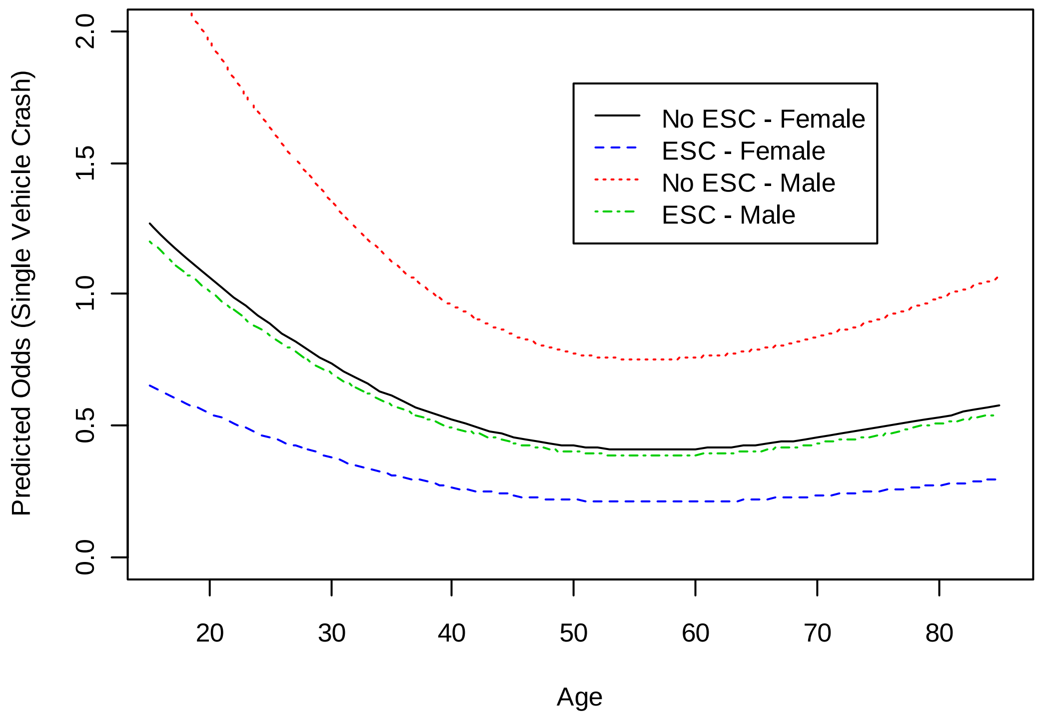
Approximate Significance of Smooth Terms:

	Edf	Chi-Square	P-Value
s(Age)	2.12	22.5	0.008

According to the model results shown in Table 8, Figure 2 shows a plot of the predicted odds of a single-vehicle crash by age, gender, and ESC for SUVs. It is a consequence of no interaction terms that none of the lines intersect. As in the previous plot for passenger cars, young males had the highest predicted odds of a single-vehicle crash. Overall, the odds of a single-vehicle crash were greatest for young drivers, declined for middle-aged drivers, and then increased for older drivers. Examination of the plot provides evidence for the beneficial effects of ESC on reducing single-vehicle crashes. The line for males without ESC is uniformly higher than any other line. On the other hand, the line for females with ESC is uniformly lower than any other line. Therefore, at any age, females with ESC had the lowest predicted odds of a single-vehicle crash. Note that the odds of a single-vehicle crash for males with ESC were almost identical to the odds for females without ESC, as shown by the two lines which almost overlap.

The reduction in odds can be estimated from the plot by dividing the predicted odds for two lines at any fixed age and gender. For example, for a fifty-year-old female with ESC, the predicted odds of a single-vehicle crash were 0.2179. For a fifty-year-old female without ESC, the odds were 0.4227. Therefore, the estimated reduction in the odds of a single-vehicle crash for an SUV with ESC was $1-(0.2179/0.4227)=48.5\%$, which coincides with the model-based estimate derived from Table 8.

Figure 2 Effects of Age, Gender and ESC on the Odds of a Single-Vehicle Crash for Sport Utility Vehicles (FARS 1995-2003)



4.3 Effects of ESC on Ran-Off-Road Crashes

Electronic stability control is designed to provide assistance to a driver when it is determined that the driver is about to lose control. The strategy for assessing the effectiveness of ESC, in this study and in other published studies, has been based on the idea that single-vehicle crashes were more likely to have been associated with loss of control than multiple-vehicle crashes. It is well recognized that other factors such as fatigue, impaired vision, and drug or alcohol use could contribute to the likelihood of a single-vehicle crash. Furthermore, it is also possible that other technologies, in addition to ESC, that were introduced concurrently with ESC, could have beneficial effects in reducing single-vehicle crashes. Therefore, it is likely that not all vehicles involved in single-vehicle crashes could have benefited from ESC technology. On the other hand, it is plausible that ESC technology could have beneficial effects in at least some proportion of multiple-vehicle crashes (see, for example, Bahouth, 2005 or Aga and Okada, 2003).

In the FARS database, other variables are available for defining cases and controls that suggest a vehicle may have been involved in a loss-of-control type crash. For example, the variable relation to roadway can be categorized to describe vehicles that either went off the roadway or remained on the roadway. It is understood that no definition of cases and controls is perfect since it is likely that other factors, such as the ones mentioned above, could contribute to the likelihood of these types of crashes. Nevertheless, other definitions of cases and controls help to confirm, or at least substantiate and provide a basis for comparison of, results presented thus far.

Table 9 is a cross-classification of the FARS data for passenger cars by ESC and relation to roadway. Using the method of comparing the odds of running off the road for passenger cars with ESC to the odds of running off the road for passenger cars without ESC, the estimated percentage reduction in the odds of running off the road for a passenger car equipped with ESC was 34.8%. The estimated 95% confidence interval is (17.7%, 51.8%). The results are fairly consistent with, and slightly stronger than, those for single-vehicle crashes shown in Table 2.

Table 9 Cross-Classification of Passenger Cars by ESC and Relation to Roadway (FARS 1995-2003)

Relation to Road		Off Road	On Road	Total
ESC	No	426	674	1,100
	Yes	101	245	346
	Total	527	919	1,446

34.8% reduction in odds of Off Road for passenger cars equipped with ESC. 95% CI (17.7%, 51.8%)

The same approach is applied to the analysis of SUVs, as shown in Table 10. The estimated percentage reduction in the odds of running off the road for SUVs with ESC was 56.4%, with a 95% confidence interval of (37.3%, 75.4%). These results are fairly consistent with those shown in Tables 5 and 6. Overall, the estimated benefits of ESC based on the definition of cases and controls using relation to roadway agree with, and in some sense are stronger than, the results based on single and multiple-vehicle crashes.

Table 10 Cross-Classification of SUVs by ESC and Relation to Roadway (FARS 1995-2003)

Relation to Road		Off Road	On Road	Total
ESC	No	92	179	271
	Yes	37	165	202
	Total	129	344	473

56.4% reduction in odds of Off Road for SUVs equipped with ESC. 95% CI (37.3%, 75.4%)

4.4 Effects of ESC on Rollover Crashes

Another benefit derived from ESC technology would be a reduction in the odds of vehicle rollover. In this regard, particular attention is given to SUVs since many studies have established the link between a higher likelihood of rollover in sport utility vehicles (see, for example, Blower et al., 2005 and the references therein). Table 11 and Table 12 show cross-tabulations of ESC and rollover occurrence for passenger cars and SUVs. The estimated percentage reductions in the odds of rollover for vehicles equipped with ESC were 39.7% (19.0%, 60.4%) and 72.9% (60.7%, 85.0%), respectively*.

Table 11 Cross-Classification of Passenger Cars by ESC and Rollover (FARS 1995-2003)

Rollover		Yes	No	Total
ESC	No	223	877	1,100
	Yes	46	300	346
	Total	269	1,177	1,446

39.7% reduction in odds of Rollover for passenger cars equipped with ESC. 95% CI (19.0%, 60.4%)

Table 12 Cross-Classification of SUVs by ESC and Rollover (FARS 1995-2003)

Rollover		Yes	No	Total
ESC	No	111	160	271
	Yes	32	170	202
	Total	143	330	473

72.9% reduction in odds of Rollover for SUVs equipped with ESC. 95% CI (60.7%, 85.0%)

4.5 Effects of ESC on Roads That Were Not Dry

The following analysis is restricted to crashes that occurred on roads in which the surface conditions were not dry. These include wet roads, roads with snow, icy roads, and roads with sand, dirt, or oil. Most crashes occurred on dry surfaces, so focusing on roads that were not dry reduces sample size considerably. When dealing with small sample sizes, stronger effects of ESC are required than when dealing with larger sample sizes in order for the effects to be statistically significant. As in earlier sections, cases are defined as vehicles involved in single-vehicle crashes, and controls are defined as vehicles involved in multiple-vehicle crashes.

Table 13 shows the cross-classification of passenger car crashes on roads that were not dry by ESC and accident type. Note that the sample size is reduced to 261 and that only 50 vehicles were equipped with ESC. Based on these data, the percentage reduction in the odds of a single-vehicle crash for passenger cars equipped with ESC was 25.2%. However, this result is not statistically significant because the 95% confidence interval (-22.2, 72.5%) contains 0.0%. In this context, a negative percentage corresponds to an *increase* in the odds of a single-vehicle crash. The wide confidence interval is a consequence of a weak association in combination with the relatively small sample size.

Similarly, Table 14 shows the same analysis on roads that were not dry for SUVs. The percentage reduction in the odds of a single-vehicle crash is estimated at 30.4%, but this result

* 95% confidence intervals are shown in parentheses.

is also not significant because the 95% confidence interval contains 0.0%. The sample size of 82 is very small and the confidence interval is very wide. Therefore, for these fatal data, there appears to be no significant reduction in the odds of a single-vehicle crash for vehicles with ESC when the surface condition is not dry. However, the analysis for mostly nonfatal crashes on roads that were not dry using the GES data led to significant findings[†].

Table 13 Cross-Classification of Passenger Cars by ESC and Accident Type on Roads That Were Not Dry (FARS 1995-2003)

Accident Type		SVC	MVC	Total
ESC	No	95	116	211
	Yes	19	31	50
	Total	114	147	261

25.2% reduction in odds of SVC for Passenger Cars equipped with ESC. 95% CI (-22.2%, 72.5%)

Table 14 Cross-Classification of SUVs by ESC and Accident Type on Roads That Were Not Dry (FARS 1995-2003)

Accident Type		SVC	MVC	Total
ESC	No	21	24	45
	Yes	14	23	37
	Total	35	47	82

30.4% reduction in odds of SVC for SUVs equipped with ESC. 95% CI (-31.2%, 92.0%)

5. Analysis of ESC for Passenger Cars and Sport Utility Vehicles (GES Data)

Based on the FARS data in the previous section, associations between the presence of ESC and percentage reductions in the odds of single-vehicle crashes were analyzed. Multiple-vehicle crashes served as the basis for comparison to single-vehicle crashes. The motivation for that strategy was based on the idea that single-vehicle crashes are more likely associated with loss of control in which ESC technology could play a beneficial role. Multiple-vehicle crashes, on the other hand, served as the control group since outcomes for vehicles in those crashes are presumed to be independent of the presence or absence of ESC technology. That is, the outcome in a multiple-vehicle crash is presumed to be the same, regardless of the presence or absence of ESC. A study by Bahouth (2005), however, found an 11.8% reduction in the odds of a multiple-vehicle frontal crash for vehicles equipped with ESC.

In this section, GES data are analyzed to asses the effects of ESC on loss-of-control type crashes. Unlike the FARS data, which contain records of vehicles involved in fatal crashes, the

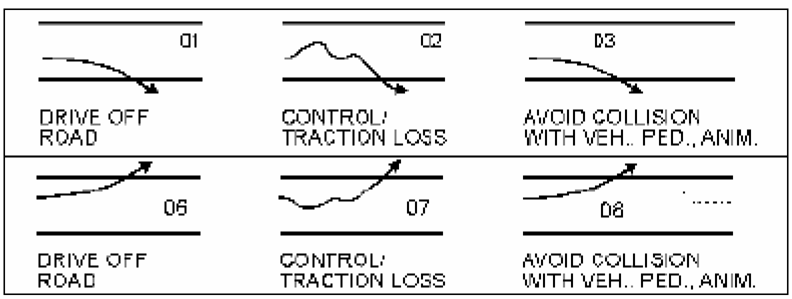
[†] Results using GES data were quite different. See the section describing the analysis of the GES data on roads that were not dry.

GES data contain records of vehicles involved in nonfatal crashes, as well as a relatively small number of vehicles involved in fatal crashes. Therefore, the analysis presented in this section is representative of crashes that in general were less severe to vehicle occupants in terms of injury severity. There are several benefits derived by using GES data for this analysis. First, the GES data has more cases for analysis than the FARS database. This is an advantage because sample size is an issue in this study. ESC is a relatively new technology and vehicles with ESC as standard equipment must be readily identified in available crash databases. Second, the GES database has an accident type variable that makes it possible to identify vehicles that ran off the road and whose crash outcomes were more likely to depend on the presence or absence of ESC. In addition, the accident type variable makes it possible to identify a more well-defined control group than is provided by the consideration of all multiple-vehicle crashes.

5.1 Definition of Cases and Controls

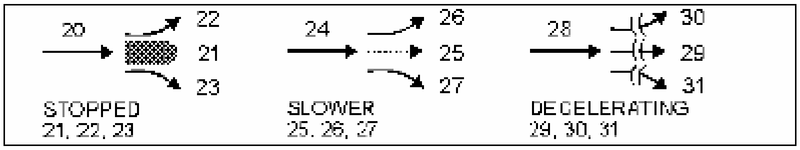
In the GES database, an accident type variable is coded that classifies vehicles into one of more than ninety different accident types (see Appendix E for a pictorial display of all types). The focus of this presentation is to distinguish accident types that could benefit from ESC technology from those accident types that would most likely not benefit from ESC technology. Figure 3 shows accident types that can be identified in the GES database in which it is known that the vehicle ran off the roadway either due to loss of control or to avoid hitting a fixed object. These crash types correspond to numbers 01, 02, 03, 06, 07, and 08 as shown in Appendix E. Vehicles classified into one of these six categories are designated as cases.

Figure 3 Crash Types Identified Related to Loss of Control



The control group, which consists of vehicles involved in crashes that would most likely not benefit from ESC technology and were not a result of loss of control, includes accident types 21, 22, 23, 25, 26, 27, 29, 30, and 31. In these accident types, vehicles were the struck vehicles in rear-end crashes. Figure 4 shows a pictorial representation of accident types that define the control group. Cases and controls are defined in this manner to better distinguish and separate those vehicles involved in crashes in which ESC could have played a beneficial role, from those vehicles involved in crashes in which ESC would most likely have had no effect.

Figure 4 Crash Types Identified That Most Likely Would Not Benefit from ESC Technology



5.2 Effects of ESC on Loss-of-Control Type Crashes

GES data for crash years 1995 through 2003 were analyzed to investigate the effects of the presence of electronic stability control (ESC) on vehicles in certain kinds of crashes. Passenger cars with model years between 2000 and 2004 were identified with ESC available as standard equipment. In addition, passenger cars of similar makes and models with model years between 1995 and 1999 were identified in which ESC was not available. Table 15 shows numbers of passenger cars identified with and without ESC by model year.

Note that the sample size obtained from GES data is considerably larger than the sample size obtained from FARS data. For model years between 1995 and 1999, 2,835 vehicles were identified without ESC, and for model years between 2000 and 2004, 1,087 vehicles were identified with ESC as standard equipment, resulting in a total sample size of 3,922. Appendix C shows the number of passenger cars with and without ESC by vehicle make. Vehicle model is not shown in Appendix C because, unlike FARS data, the model variable in the GES database has many missing values and is not coded in great detail. If any doubt existed as to whether a vehicle in the GES database had or did not have ESC technology, the Vehicle Identification Number (VIN) was matched against a file containing the ESC status for the vehicle of interest.

Table 15 Numbers of Passenger Cars Identified with and without ESC by Model Year (GES 1995-2003)

ESC Not Available						ESC Standard Equipment					
1995	1996	1997	1998	1999	Total	2000	2001	2002	2003	2004	Total
897	557	559	442	380	2,835	344	344	240	145	14	1,087

To investigate the effects of ESC on crashes associated with loss of control, passenger cars are cross-classified into a 2x2 contingency table. The two cross-classifying factors of interest are the presence or absence of ESC, and whether the vehicle was involved in a crash associated with loss of control. Table 16 shows the contingency table and the number of passenger cars falling into each category. In this table, the sample is restricted to the accident types depicted in Figures 3 and 4. Therefore, loss of control (yes) implies that the vehicle ran off the road, while loss of control (no) implies that the vehicle was in a rear-end crash and was struck from behind. Even after imposing these restrictions, the total sample size is 1,118.

Table 16 Cross-Classification of Passenger Cars by ESC and Accident Type (GES 1995-2003)

Loss of Control		Yes	No	Total
ESC	No	318	498	816
	Yes	68	234	302
	Total	386	732	1,118

54.5% reduction in odds of loss of control for cars equipped with ESC. 95% CI (40.6%, 68.3%).

Based on the data in Table 16, the odds of involvement in a crash associated with loss of control for a passenger car that did not have ESC were 318/498=0.6386. Similarly, the odds of involvement in a crash associated with loss of control for a passenger car that had ESC were 68/234=0.2906. Therefore, the percentage reduction in the odds of involvement in a crash associated with loss of control when a passenger car was equipped with ESC as standard equipment was 1 - (0.2906/0.6386) = 54.5%. The 95% confidence interval for this percentage is (40.6%, 68.3%). Note that this analysis, which is based on the accident type variable in the GES database, provides better definition of loss of control than does analysis of single-vehicle crashes versus multiple-vehicle crashes.

The same procedure outlined above for passenger cars is applied to SUVs. Table 17 shows the number of SUVs identified in the GES files with and without ESC by model year. For model years between 1995 and 1999, 1,634 SUVs were identified without ESC, and for model years between 2000 and 2004, 627 SUVs were identified with ESC as standard equipment, resulting in a total sample of 2,261. Appendix C shows the number of SUVs with and without ESC by vehicle make. As described above in the case for passenger cars, vehicle model is not shown.

Table 17 Numbers of Sport Utility Vehicles Identified with and without ESC by Model Year (GES 1995-2003)

ESC Not Available						ESC Standard Equipment					
1995	1996	1997	1998	1999	Total	2000	2001	2002	2003	2004	Total
290	194	404	372	374	1,634	139	252	171	61	4	627

Table 18 is a contingency table of the number of SUVs cross-classified by ESC and accident type. Even though the data are restricted to the accident types described in Figures 3 and 4 for defining cases and controls, the sample size is 746. According to the data in Table 18, the odds of involvement in a crash associated with loss of control for an SUV that did not have ESC were 232/333=0.6967. Similarly, the odds of involvement in a crash associated with loss of control for an SUV with ESC as standard equipment were 31/150=0.2067. Therefore, the percentage reduction in the odds of involvement in a crash associated with loss of control when an SUV was equipped with ESC was 1 - (0.2067/0.6967) = 70.3%. The 95% confidence interval for this percentage is (57.8%, 82.8%).

Table 18 Cross-Classification of Sport Utility Vehicles by ESC and Accident Type (GES 1995-2003)

Loss of Control		Yes	No	Total
ESC	No	232	333	565
	Yes	31	150	181
	Total	263	483	746

70.3% reduction in odds of loss of control for SUVs equipped with ESC. 95% CI (57.8%, 82.8%)

5.3 Effects of ESC on Loss-of-Control Type Crashes by Age and Gender

As for the FARS data analysis, a generalized additive model (GAM) can be fit to the GES data for passenger cars to assess the effects of ESC on loss-of-control crashes according to age and gender. The model has the benefit of predicting the odds of a loss-of-control crash while adjusting simultaneously for the effects of ESC, age, and gender. Important interactions among the three variables can also be taken into account. The age variable is fit as a continuous variable and is modeled as a smooth term. Table 19 shows the fit of a GAM to the GES data. In this model there are important interactions between age and gender, and age and ESC. Note, however, that there is no significant interaction between ESC and gender. Unlike the FARS analysis, this implies that the percentage reduction in the odds of a loss-of-control crash for a vehicle equipped with ESC was different for each age, but that the odds were statistically the same for each gender.

Table 19 Fit of a Generalized Additive Model to the GES Data for Passenger Cars (GES 1995-2003)

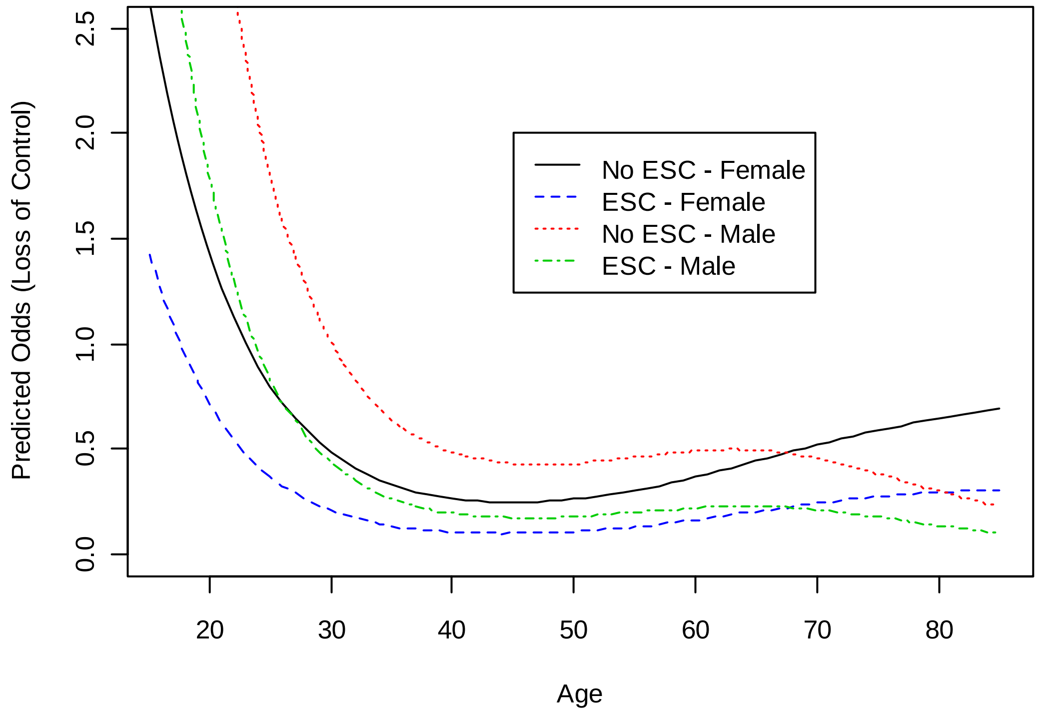
Parameter	Estimate	Std. Error	T Ratio	P-Value
Intercept	-0.816	0.108	-7.58	<0.001
ESC	-0.827	0.172	-4.80	<0.001
Gender	0.583	0.140	4.17	<0.001

Approximate Significance of Smooth Terms:

	Edf	Chi-Square	P-Value
s(Age) x Male	2.25	35.15	<0.001
s(Age) x Female	2.25	12.33	0.006
s(Age) x ESC yes	2.25	12.28	0.006
s(Age) x ESC no	2.25	22.02	<0.001

Due to the interactions in this model, the effects of ESC are best demonstrated with the aid of predicted values generated by the model. Figure 5 shows the predicted odds of a loss-of-control crash by age, gender, and ESC. Until the approximate age of sixty-eight, males without ESC had the highest predicted odds of a loss-of-control crash. Until the same age, females with ESC had the lowest predicted odds of a loss-of-control crash. However, unlike the FARS data analysis, in the GES data, young females tend to show the high odds of loss of control that was characteristic of young males, although to a lesser extent. In addition, although the predicted benefits of ESC are the same for each gender, they differ according to age due to the smooth interaction term between age and ESC.

Figure 5 Effects of Age, Gender and ESC on the Odds of a Loss-of-Control Type Crash for Passenger Cars (GES 1995-2003)



For example, for a twenty-year-old female without ESC, the predicted odds of a loss-of-control crash were 1.4279. For a twenty-year-old female with ESC, the predicted odds of a loss-of-control crash were 0.7138. Therefore, the percentage reduction in the odds of a loss-of-control crash for a twenty-year-old female with ESC was 1-(0.7138/1.4279)=50.0%. These same results also apply to a twenty-year-old male. This is because the model contains no interaction between gender and ESC. The estimated 95% confidence interval is

$$0.500 \pm 1.96\ (0.347)\ 0.500$$

or (16%,84%). The quantity 0.347 is an estimate of the standard error of the log odds ratio of a loss-of-control crash for a twenty-year-old female with ESC to a twenty-year-old female without ESC. This quantity is not provided as standard output from statistical software and was calculated using a bootstrap procedure based on 10,000 replications (for a discussion of the bootstrap procedure used for calculating standard errors, see, for example, Efron and Tibshirani, 1994).

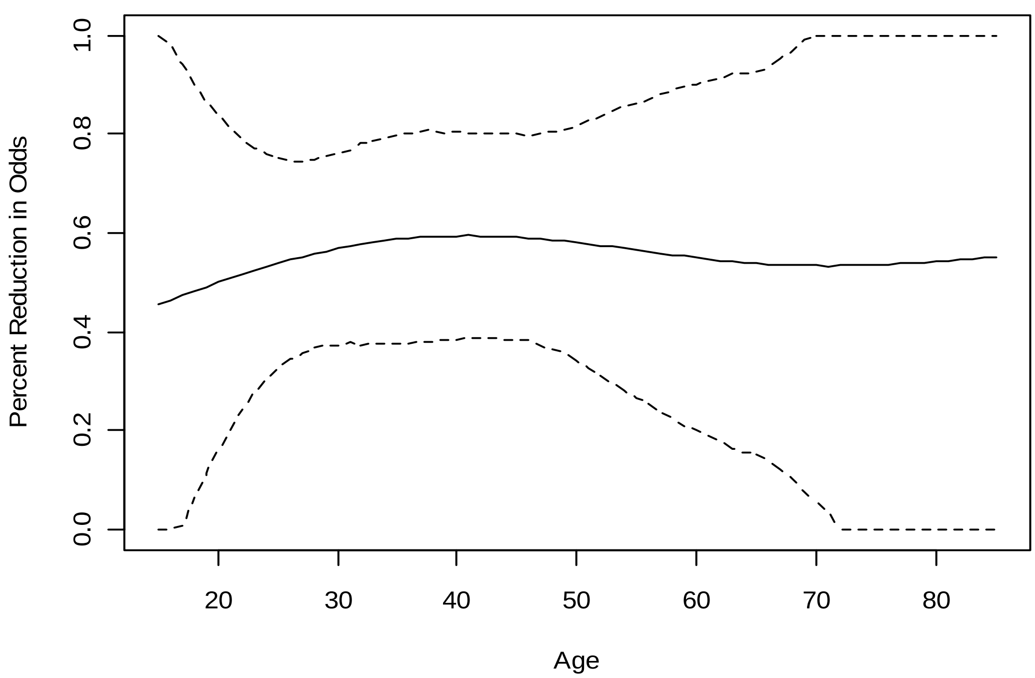
On the other hand, the estimate for a fifty-year-old female is different due to the interaction between age and ESC. For a fifty-year-old female without ESC, the predicted odds of a loss-of-control crash were 0.2626. For a fifty-year-old female with ESC, the predicted odds of a loss-of-control crash were 0.1101. Therefore the percentage reduction in the odds of a loss-of-control crash for a fifty-year-old female with ESC was 1-(0.1101/0.2626)=58.1%. Using the bootstrap procedure, the estimated 95% confidence interval is

$$0.581 \pm 1.96\ (0.292)\ (0.419)$$

or (34.1%, 82.1%). The confidence interval for a fifty-year-old female is narrower than the interval for a twenty-year-old female because there is more data in the neighborhood of a fifty-year-old than a twenty-year-old. Note that the two estimates, one for a twenty-year-old female (50.0%) and one for a fifty-year-old female (58.1%), are consistent and similar in magnitude with the overall estimate shown in Table 16 (54.5%) in which the percentage reduction was not adjusted for age and gender.

Performing these calculations at each age is a tedious task. Figure 6 shows the percentage reduction in the odds of a loss-of-control crash at each age along with the corresponding 95% confidence band. Confidence bands tend to be most narrow at ages where data are most abundant. The estimates shown in Figure 6 apply to both males and females. The minimum reduction occurs at age fifteen (45.5%), while the maximum reduction occurs at age forty-one (59.5%). This suggests that ESC technology could be most beneficial in reducing the odds of loss-of-control crashes for middle-aged drivers of passenger cars.

Figure 6 Predicted Percent Reduction in Odds of Loss-of-Control Crash Due to ESC for Passenger Cars (GES 1995-2003)



For SUVs, a generalized additive model can also be fit to account for the effects of age and gender. Table 20 shows the output from the fit of a model that has main effects for ESC and gender, and smooth interaction terms for age by gender and age by ESC. This model fits the same terms as the model shown in Table 19. Inclusion of the interaction term between age and ESC implies that the percentage reduction in the odds of a loss-of-control crash was different for each age. However, since there is no interaction between ESC and gender, the predicted percentage reductions were the same for males and females at every age. This implies that the benefits derived from ESC technology were approximately the same for males and females. This does not imply that the odds of a loss-of-control crash were the same for males and females, as was true for passenger cars, and as will be shown for SUVs. Note that the interaction between age and ESC is not significant at the 0.05 level, but the smooth term for age and ESC (no) is significant at 0.065 (see p-value).

Table 20 Fit of a Generalized Additive Model to the GES Data for SUVs (GES 1995-2003)

Parameter	Estimate	Std. Error	T Ratio	P-Value
Intercept	-0.643	0.132	-4.87	<0.001
ESC	-1.200	0.233	-5.15	<0.001
Gender	0.376	0.173	2.17	0.030

Approximate Significance of Smooth Terms:

	Edf	Chi-Square	P-Value
s(Age) x Male	2.25	17.68	0.001
s(Age) x Female	2.25	1.67	0.644
s(Age) x ESC yes	2.25	1.88	0.598
s(Age) x ESC no	2.25	7.24	0.065

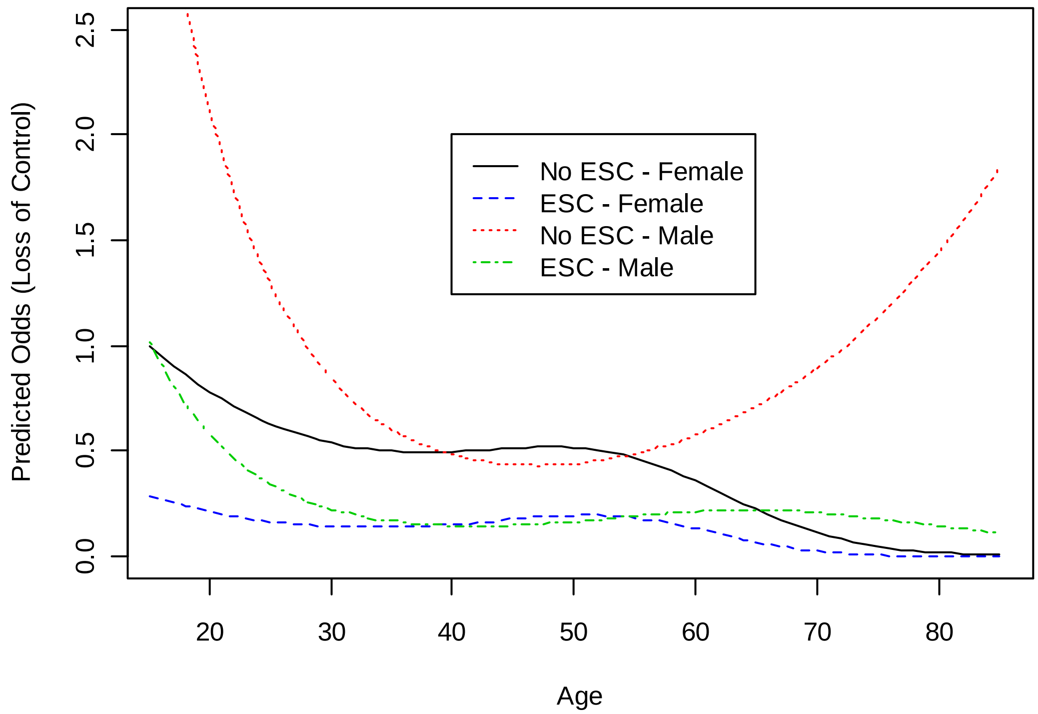
As was done for passenger cars, the effects of age and gender on the percentage reduction in the odds of a loss-of-control crash for SUVs can be shown using the predicted values generated by the model. Figure 7 shows the predicted odds of a loss-of-control crash by age, gender, and ESC. The plot shows that young males without ESC, say less than thirty years old, and older males without ESC, say greater than seventy years old, had the highest predicted odds of a loss-of-control crash. Keep in mind, however, that the plot does not suggest that males tended to benefit more from ESC technology than females. At any age, predicted odds ratios are the same for males and females, and can be approximated by dividing the two lines for the same gender corresponding to the cases in which ESC was not available, and ESC was standard equipment.

For example, for a twenty-five-year-old male without ESC, the predicted odds of a loss-of-control crash were 1.2970. For a twenty-five-year-old male with ESC, the predicted odds of a loss-of-control crash were 0.3435. Therefore, the percentage reduction in the odds of a loss-of-control crash for a twenty-five-year-old male in an SUV equipped with ESC was 1-(0.3435/1.2970)=73.5%. A 95% confidence interval is

$$0.735 \pm 1.96\ (0.343)\ (0.265)$$

or (55.7%, 91.3%). The quantity 0.343 was estimated using a bootstrap procedure. These results are the same for a twenty-five-year-old-female. That is, gender is irrelevant in this analysis with respect to the estimated effectiveness of ESC.

Figure 7 Effects of Age, Gender, and ESC on the Odds of a Loss-of-Control Type Crash for Sport Utility Vehicles (GES 1995-2003)

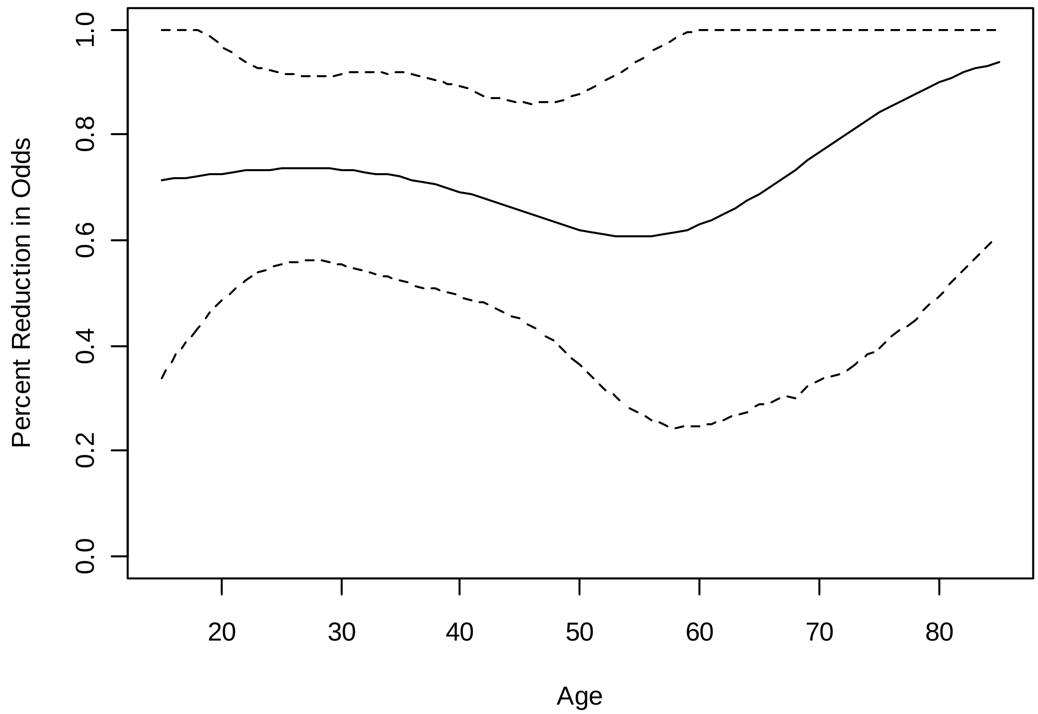


For a fifty-year-old male without ESC, the predicted odds of a loss-of-control crash were 0.4410. For a fifty–year-old male with ESC, the predicted odds of a loss-of-control crash were 0.1672. Therefore, the percentage reduction in the odds of a loss-of-control crash for a fifty-year-old in an SUV equipped with ESC, regardless of gender, was 1-(0.1672/0.4410) = 62.1%. The estimated 95% confidence interval is

$$0.621 \pm 1.96\ (0.346)\ (0.379)$$

or (36.4%, 87.8%). Performing these calculations at each age is a tedious task. Figure 8 shows the percentage reduction in the odds of a loss-of-control crash at each age along with the corresponding 95% confidence band. These estimates apply to both males and females. The minimum occurs at age fifty-five (60.6%), while the maximum occurs at age eighty-five (93.8%). Note that after age fifty-five, there is a steady increase in the percent reduction. This suggests that ESC technology could be particularly beneficial to older drivers of sport utility vehicles.

Figure 8 Predicted Percent Reductions in Odds of Loss-of-Control Crash Due to ESC for SUV (GES 1995-2003)



5.4 Effects of ESC on Roads That Were Not Dry

Since ESC is designed to keep a vehicle on the road in loss-of-control situations, either in understeering or oversteering conditions, an important question to answer is whether ESC is more effective on wet or dry road surfaces. For the data collected from the GES database in this study, most crashes occurred on dry road surfaces. This can result in small sample sizes for analyses on roads that were not dry. Table 21 shows a cross-classification of 843 passenger cars that were involved in crashes on dry surfaces by ESC and loss of control. For passenger cars that were not equipped with ESC, the odds of loss of control were 179/419=0.4272. For passenger cars equipped with ESC as standard equipment, the odds of loss of control were 50/195=0.2564. Therefore, the estimated percentage reduction in the odds of a loss-of-control crash on dry surface was 1-(0.2564/0.4272) =40.0%. The 95% confidence is (18.6%, 61.4%).

Table 21 Cross-Classification of Passenger Cars by ESC and Accident Type on Dry Surface (GES 1995-2003)

Loss of Control		Yes	No	Total
ESC	No	179	419	598
	Yes	50	195	245
	Total	229	614	843

40.0% reduction in odds of loss of control for cars equipped with ESC. 95% CI (18.6%, 61.4%).

Table 22 shows a cross-classification of 265 passenger cars that were involved in crashes on surfaces that were not dry. These road conditions include wet, snow or slush, ice, sand or dirt or oil, and other surfaces. Most of these crashes (223) occurred on a wet surface. Note that sample size is reduced for this table. For passenger cars not equipped with ESC, the odds of loss of control were 137/74=1.8514. For passenger cars equipped with ESC as standard equipment, the odds of loss of control were 17/37=0.4595. Therefore, the percentage reduction in the odds of loss of control for passenger cars equipped with ESC on roads that were not dry was 1-(0.4595/1.8514)=75.2%. The 95% confidence interval is (59.3%, 91.1%).

Table 22 Cross-Classification of Passenger Cars by ESC and Accident Type on Surfaces That Were Not Dry (GES 1995-2003)

Loss of Control		Yes	No	Total
ESC	No	137	74	211
	Yes	17	37	54
	Total	154	111	265

75.2% reduction in odds of loss of control for cars equipped with ESC. 95% CI (59.3%, 91.1%).

A formal test is available for determining if the percentage reduction on surface conditions that were not dry was significantly greater than the percentage reduction on dry surfaces. A logistic regression model can be fit that treats loss of control (yes, no) as the response variable. The independent variables are ESC (yes, no), surface condition (dry, not dry), and the interaction between ESC and surface condition. The interaction term contains the important information. If the interaction term is significantly less than zero, the reduction on surfaces that were not dry was significantly greater than the reduction on dry surfaces. Appendix F explains this test in detail.

The fit of the model is shown in Table 23. The percentage reductions in the odds of loss of control due to ESC on dry surfaces and surfaces that were not dry, shown in Table 21 and Table 22, respectively, can be reproduced from this model. For example, $1-\exp(-0.510) = 40.0\%$ is the reduction shown in Table 21. Note that -0.510 is the model estimate attached to ESC. Similarly, $1-\exp(-0.510-0.883) = 75.2\%$ is the reduction shown in Table 22, where -0.883 is the estimate attached to the interaction between ESC and surface condition. As explained in Appendix F, the interaction term is significantly less than zero if the Z-value is less than -1.65. Since -2.36<-1.65, we conclude that the percentage reduction in the odds of loss of control due to ESC for passenger cars was significantly greater on surface conditions that were not dry than on surface conditions that were dry.

Table 23 Fit of Logistic Regression Model to Determine Significance of Surface Condition for Passenger Cars (GES 1995-2003)

Parameter	Estimate	Std. Error	Z-Value	P-Value
Intercept	-0.850	0.089	-9.53	<0.001
ESC	-0.510	0.182	-2.81	0.005
Surface	1.466	0.170	8.64	<0.001
ESC x Surface	-0.883	0.374	-2.36	0.018

In a similar manner, Tables 24 and 25 show the percentage reductions in the odds of a loss-of-control crash due to ESC on dry surfaces and surfaces that were not dry for sport utility vehicles. On dry surfaces, the percentage reduction was 52.5% with a 95% confidence interval of (29.8%, 75.2%). On surfaces that were not dry, the percentage reduction was 88.2% with a 95% confidence interval of (76.4%, 100.0%). The usual methods shown in previous tables for calculating these quantities can be used to obtain these results. The sample size on surfaces that were not dry is fairly small. Note that only five vehicles with ESC had a loss-of-control crash.

Table 24 Cross-Classification of Sport Utility Vehicles by ESC and Accident Type on Dry Surface (GES 1995-2003)

Loss of Control		Yes	No	Total
ESC	No	113	256	369
	Yes	26	124	150
	Total	139	380	519

52.5% reduction in odds of loss of control for SUV equipped with ESC. 95% CI (29.8%, 75.2%)

Table 25 Cross-Classification of Sport Utility Vehicles by ESC and Accident Type on Surfaces That Were Not Dry (GES 1995-2003)

Loss of control		Yes	No	Total
ESC	No	119	73	192
	Yes	5	26	31
	Total	124	99	223

88.2% reduction in odds of loss of control for SUV equipped with ESC. 95% CI (76.4%, 100.0%).

To determine if 88.2% is statistically greater than 52.5%, a logistic regression model is fit to the data in Tables 24 and 25, and the interaction term between ESC and surface condition is examined for significance. Table 26 shows the fit of the model. The quantity 1-exp(-0.744) = 52.5% is the estimated reduction on dry surface, while 1-exp(-0.744-1.393) = 88.2% is the estimated reduction on surfaces that were not dry. The test of interest is whether the interaction term is significantly less than zero. Since the Z-value = -2.46 < -1.65, we reject the null hypothesis and conclude that the percent reduction in the odds of a loss-of-control crash for SUVs was greater on surfaces that were not dry than on surfaces that were dry.

Table 26 Fit of Logistic Regression Model to Determine Significance of Surface Condition for SUVs (GES 1995-2003)

Parameter	Estimate	Std. Error	Z-Value	P-Value
Intercept	-0.818	0.113	-7.24	<0.001
ESC	-0.744	0.244	-3.06	0.002
Surface	1.307	0.187	7.00	<0.001
ESC x Surface	-1.393	0.566	-2.46	0.014

6. Parallel Analysis – Different Makes and Models, Similar Model Years (GES Data)

Until now, the effects of ESC on reducing the likelihood of loss-of-control crashes were assessed by comparing vehicles with similar makes and models, but different model years. Vehicles without ESC and model years between 1995 and 1999 were compared to vehicles with ESC and model years between 2000 and 2004. This approach has the advantage of reducing variability due to similar makes and models, but also introduces a source of variability due to different model years. For example, one might argue that drivers of similar makes and models are likely to come from similar socioeconomic backgrounds and, therefore, also share similar driving habits and skills. This could be particularly true for drivers of vehicles with ESC since vehicles with ESC tend to be high-end luxury models. On the other hand, other braking system technologies introduced concurrently with ESC that were not available in earlier model years, could have beneficial effects along with ESC in loss-of-control situations. The strategy employed in this section is to compare vehicles with different makes and models that have similar model years. This approach tends to add a source of variability into the problem due to different vehicle makes, but reduces a source of variability due to model year. Thus, there are advantages and disadvantages to both approaches.

Table 27 shows numbers of passenger cars identified in GES files with and without ESC by model year. These data are restricted to the accident types shown in Figure 3 and Figure 4. Vehicles with ESC and model years between 2000 and 2004 have already been defined in this study and are the same as those used in Section 5. A total of 797 vehicles with the same model years was identified without ESC (see Appendix G for a description of makes, models, counts, and percentages).

Table 27 Numbers of Passenger Cars Identified with and without ESC by Model Year (GES 1999-2003[‡])

ESC Not Available						ESC Standard Equipment					
2000	2001	2002	2003	2004	Total	2000	2001	2002	2003	2004	Total
303	235	171	78	10	797	88	96	70	44	4	302

[‡] These years refer to GES crash years, not model years. For example, a 2000 model year vehicle could have been involved in a crash in 1999. Similarly, a 2004 model year vehicle could have been involved in a crash in 2003.

The definition of cases and controls follows the same convention established in Section 5. That is, cases are vehicles involved in loss-of-control crashes defined by accident types 01, 02, 03, 06, 07, and 08 as shown in Figure 3, and controls are vehicles involved in rear-end struck crashes defined by accident types 21, 22, 23, 25, 26, 27, 29, 30, and 31 as shown in Figure 4. Table 28 shows the cross-classification of passenger cars by ESC and accident type. Note that the second row in Table 28 is the same as the second row in Table 16 since the same vehicles are represented in both tables. Based on methods for calculating percentage reductions, the estimated percentage reduction in the odds of a loss-of-control crash for passenger cars equipped with ESC was 40.3% and the 95% confidence interval is (21.9%, 58.7%).

Table 28 Cross-Classification of Passenger Cars by ESC and Accident Type (GES 2000-2003)

Loss of Control		Yes	No	Total
ESC	No	261	536	797
	Yes	68	234	302
	Total	329	770	1,099

40.3% reduction in odds of loss of control for cars equipped with ESC. 95% CI (21.9%, 58.7%).

The same methods applied to passenger cars can be applied to SUVs. Table 29 shows the number of SUVs identified with and without ESC by model year. Appendix G shows the makes, models, counts, and percentages for these vehicles. The SUVs with ESC are the same vehicles identified in the analyses in Section 5.

Table 29 Numbers of Sport Utility Vehicles Identified with and without ESC by Model Year (GES 2000-2003)

ESC Not Available						ESC Standard Equipment					
2000	2001	2002	2003	2004	Total	2000	2001	2002	2003	2004	Total
105	68	48	11	1	233	43	72	47	19	0	181

Table 30 shows the cross-classification of SUVs by ESC and accident type. As for passenger cars, the second row of the table is the same as the second row in Table 18. The estimated percentage reduction in the odds of a loss-of-control crash for SUVs equipped with ESC was 71.5% and the 95% confidence interval is (58.3%, 84.8%).

Table 30 Cross-Classification of Sport Utility Vehicles by ESC and Accident Type (GES 1999-2003)

Loss of Control		Yes	No	Total
ESC	No	98	135	233
	Yes	31	150	181
	Total	129	285	414

71.5% reduction in odds of loss of control for cars equipped with ESC. 95% CI (58.3%, 84.8%).

7. Summary and Discussion

A case-control (induced exposure) study design was implemented to investigate the effectiveness of electronic stability control on reducing certain types of crashes generally associated with loss of control. The cases were defined as vehicles in crashes whose outcomes were likely to depend on the presence or absence of ESC technology, while the controls were vehicles in crashes whose outcomes were most likely not dependent on the presence or absence of ESC. Cases and controls were then compared based on whether ESC was actually present in the vehicle as standard equipment, or not available.

The Fatality Analysis Reporting System (FARS) database was used to derive a sample of vehicles involved in fatal crashes, and data from the General Estimates System (GES) database were used to derive a sample of vehicles in mostly nonfatal crashes. Due to differences in expected outcomes in crashes associated with loss of control, separate results were reported for passenger cars and sport utility vehicles (SUVs). In case-control studies, standard procedures are available for calculating odds ratios and associated confidence intervals. The measure of association reported in this study was the percentage reduction in the odds of a loss-of-control type crash for vehicles equipped with ESC technology.

For the initial part of this study, data were collected from the FARS database for vehicles with model years between 1995 and 1999 in which ESC was not available, and vehicles were identified with similar makes and models with model years between 2000 and 2003 in which ESC was standard equipment. The percentage reduction in the odds of a single-vehicle crash for passenger cars equipped with ESC was estimated to be 30.5% (13.1%, 47.8%). For SUVs the estimated reduction was 49.5% (30.1%, 68.9%).

Some of the vehicles without ESC were older than vehicles with ESC at the time of the crash. The analyses were repeated, for both passenger cars and SUVs, after restricting the data to vehicles that were three years old or newer at the time of the crash. In both cases, significant reductions in the odds of single-vehicle crashes for vehicles with ESC were not compromised by the age of the vehicle.

Generalized additive models (GAMS) were fit to the FARS data to assess the effects of ESC while controlling for age and gender. Since the models for passenger cars and SUVs contained no significant interaction terms involving ESC, the estimated reductions in the odds of single-vehicle crashes for vehicles equipped with ESC were constant at any fixed age and any fixed gender. For passenger cars, the estimated percentage reduction was 28.2% (9.6%, 46.8%), and for SUVs the estimated percentage reduction was 48.5% (28.1%, 68.9%). Although the estimated percentage reductions in the odds of single-vehicle crashes due to ESC were constant across age and gender, the predicted odds of single-vehicle crashes varied by age and gender.

For example, plots comparing age and gender showed that young males had the highest predicted odds of being involved in single-vehicle crashes.

Other variables in the FARS database were used to define cases and controls to compare results found using single-vehicle crashes and multiple-vehicle crashes. The relation to roadway variable was categorized to define vehicles that both went off the roadway or remained on the roadway. For passenger cars equipped with ESC, the estimated percentage reduction in the odds of running off the road was 34.8% (17.7%, 51.8%). Using the same approach for SUVs, the estimated percentage reduction was 56.4% (37.3%, 75.4%). Thus, the estimated benefits of ESC based on the definition of cases and controls using relation to roadway agreed with, and in some sense were stronger than, the results based on single-vehicle (cases) and multiple-vehicle (control) crashes.

The effects of ESC on reducing the likelihood of vehicle rollover were also investigated. The estimated percentage reduction in the odds of rollover for passenger cars equipped with ESC was 39.7% (19.0%, 60.4%). The association was particularly strong for SUVs. For SUVs equipped with ESC, the estimated percentage reduction in the odds of rollover was 72.9% (60.7%, 85.0%).

To check for effects of ESC on road surfaces with less friction, data were restricted to crashes that occurred on roads that were not dry. These include wet roads, roads with snow, icy roads, and roads with sand, dirt, or oil. Restricting data to these surfaces resulted in small sample size since most crashes occurred on dry roads. For this subset of fatal crashes, no significant reductions in the odds of single-vehicle crashes were found for either passenger cars or SUVs equipped with ESC[§].

The preceding results derived using FARS data were repeated using GES data. A larger number of vehicles with ESC as standard equipment were readily identified in the GES database, making it possible to use the accident type variable to redefine cases and controls. Cases were defined as vehicles that ran off the road, either due to loss of control or to avoid collision with a fixed object. On the other hand, controls were defined as struck vehicles involved in rear-end crashes. These definitions tended to separate vehicles involved in crashes in which ESC could have played a beneficial role from those vehicles involved in crashes in which ESC would most likely have had no effect. The GES data provided sufficient sample sizes for making inference even after imposing these restrictions.

Vehicles with the same makes, models, and model years used in the FARS analysis were used in the study of the GES data. That is, vehicles were identified with model years between 1995

[§] Results using GES data were quite different. See the discussion describing the analysis of the GES data on roads that were not dry.

and 1999 in which ESC was not available, and vehicles with similar makes and models with model years between 2000 and 2004 were identified in which ESC was installed as standard equipment. The estimated percentage reduction in the odds of involvement in a loss-of-control crash for a passenger car equipped with ESC was 54.5% (40.6%, 68.3%). Applying the same procedure to SUVs, the estimated reduction was 70.3% (57.8%, 87.8%).

Generalized additive models (GAMs) were fit to the GES data to assess the effects of ESC on loss of control while adjusting for age and gender. Unlike the FARS analysis, significant interactions were found between age and ESC, meaning that the percentage reductions in the odds of loss of control for vehicles equipped with ESC varied by age. No interactions were found between gender and ESC, implying that percentage reductions did not differ between genders. For passenger cars, the minimum reduction of 45.5% occurred at age fifteen, while the maximum reduction of 59.5% occurred at age forty-one. Since most of the data were for drivers between the ages of twenty-five and fifty-five, the data were sparse at age fifteen and results were variable (see Figure 6 and 95% confidence bands). For SUVs, the minimum reduction of 60.6% occurred at age fifty-five, and the maximum reduction of 93.8% occurred at age eighty-five. Once again, the data at ages greater than fifty-five were fairly sparse, and results at age eighty-five were variable (see Figure 8 and associated 95% confidence bands). Nevertheless, the effects of ESC for SUVs were considerably stronger than for passenger cars.

In the analysis of GES data, significant effects of ESC were found on roads that were not dry. This is in contrast to the results presented using FARS data. For passenger cars, the estimated percentage reduction in the odds of a loss-of-control crash on a dry surface was 40.0% (18.6%, 61.4%). On surfaces that were not dry, the estimated percentage reduction was 75.2% (59.3%, 91.1%). A statistical test was used, based on the fit of a logistic regression model, to show that the percentage reduction was significantly greater on surface conditions that were not dry. For SUVs, the estimated percentage reduction in the odds of a loss-of-control crash on dry surface was 52.5% (29.8%, 75.2%). On surfaces that were not dry, the estimated percentage reduction was 88.2% (76.4%, 100.0%). A statistical test also showed that for SUVs, the percentage reduction was significantly greater on surfaces that were not dry.

Finally, a parallel analysis was conducted using GES data for vehicles with different makes and models, but similar model years. This design has both advantages and disadvantages. One of the advantages is that newer models tend to share newer technologies. One of the disadvantages is that vehicles of different makes and models are compared. In this setup, the estimated percentage reduction in the odds of a loss-of-control crash for passenger cars equipped with ESC was 40.3% (21.9%, 58.7%), while the corresponding estimate for SUVs was 71.5% (58.3%, 84.8%).

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Appendix A: Number of Passenger Cars with and without ESC by Make and Model (FARS 1995-2003)

Passenger Cars		**ESC**					
		Not Available		**Standard**			
Make	**Model**	**Count**	%	**Count**	%	**Total**	%
Audi	80/90	5	0.5	0	0.0	5	0.3
	S4/S6	0	0.0	3	0.9	3	0.2
	Cabriolet	3	0.3	0	0.0	3	0.2
	A6	22	2.0	7	2.0	29	2.0
	A4	46	4.2	9	2.6	55	3.8
	A8	4	0.4	0	0.0	4	0.3
	TT	0	0.0	3	0.9	3	0.2
	Allroad	0	0.0	1	0.3	1	0.1
	Other auto	7	0.6	2	0.6	9	0.6
	Total	87	7.9	25	7.2	112	7.7
BMW	3-Series	254	23.1	79	22.8	333	23.0
	5-Series	69	6.3	34	9.8	103	7.1
	7-Series	24	2.2	12	3.5	36	2.5
	8-Series	2	0.2	0	0.0	2	0.1
	Z3	57	5.2	15	4.3	72	5.0
	Other auto	13	1.2	2	0.6	15	1.0
	Total	419	38.1	142	41.0	561	38.8
Jaguar	XJS/XK8	9	0.8	3	0.9	12	0.8
	XJ6/12/XJR	29	2.6	8	2.3	37	2.6
	S-Type	0	0.0	3	0.9	3	0.2
	XKR	0	0.0	4	1.2	4	0.3
	Other auto	2	0.2	1	0.3	3	0.2
	Total	40	3.6	19	5.5	59	4.1
Mercedes	200-420*****	66	6.0	0	0.0	66	4.6
	C Class	63	5.7	35	10.1	98	6.8
	S Class	29	2.6	23	6.6	52	3.6
	SL Class	9	0.8	7	2.0	16	1.1
	SLK Class	8	0.7	3	0.9	11	0.8
	CL Class	0	0.0	4	1.2	4	0.3
	CLK Class	0	0.0	16	4.6	16	1.1
	E Class	16	1.5	30	8.7	46	3.2
	Other auto	20	1.8	2	0.6	22	1.5
	Total	211	19.2	120	34.7	331	22.9
Infiniti	Q45	6	0.5	2	0.6	8	0.6
	G20	16	1.5	0	0.0	16	1.1
	I30	10	0.9	0	0.0	10	0.7
	G35	0	0.0	7	2.0	7	0.5
	M45	0	0.0	1	0.3	1	0.1
	Other auto	3	0.3	0	0.0	3	0.2
	Total	35	3.2	10	2.9	45	3.1
Lexus	ES250/300	157	14.3	0	0.0	157	10.9
	LS400/430	70	6.4	10	2.9	80	5.5
	SC300/400/430	29	2.6	2	0.6	31	2.1
	GS300/400/430	31	2.8	17	4.9	48	3.3
	Other auto	21	1.9	1	0.3	22	1.5
	Total	308	28.0	30	8.7	338	23.4
Grand total		1,100	100.0	346	100.0	1,446	100.0

Appendix B: Number of SUV with and without ESC by Make and Model (FARS 1995-2003)

SUV		ESC					
		Not Available		Standard			
Make	**Model**	**Count**	%	**Count**	%	**Total**	%
BMW	X5	0	0.0	22	10.9	22	4.7
	Total	0	0.0	22	10.9	22	4.7
Mercedes	ML Class	39	14.4	47	23.3	86	18.2
	G Class	0	0.0	1	0.5	1	0.2
	Total	39	14.4	48	23.8	87	18.4
Toyota	4-Runner	126	46.7	57	28.2	183	38.8
	Sequoia	0	0.0	38	18.8	38	8.1
	Total	126	46.7	95	47.0	221	46.8
Infiniti	QX4	11	4.1	0	0.0	11	2.3
	Total	11	4.1	0	0.0	11	2.3
Lexus	RX300/330	42	15.6	25	12.4	67	14.2
	LX450/470	52	19.3	12	5.9	64	13.6
	Total	94	34.8	37	18.3	131	27.8
Grand total		270	100.0	202	100.0	472	100.0

Appendix C: Numbers of Passenger Cars and SUVs with and without ESC by Make (GES 1995-2003)

Passenger Cars	ESC					
	Not Available		Standard			
Make	Count	%	Count	%	Total	%
Audi	95	11.6	24	7.9	119	10.6
BMW	240	29.4	138	45.7	378	33.8
Jaguar	28	3.4	13	4.3	41	3.7
Mercedes	143	17.5	103	34.1	246	22.0
Infiniti	52	6.4	4	1.3	56	5.0
Lexus	258	31.6	20	6.6	278	24.9
Total	816	100.0	302	100.0	1,118	100.0

Sport Utility Vehicles	ESC					
	Not Available		Standard			
Make	Count	%	Count	%	Total	%
BMW	0	0.0	20	11.0	20	2.7
Mercedes	32	5.7	34	18.8	66	8.8
Toyota	464	82.1	69	38.1	533	71.4
Infiniti	28	5.0	0	0.0	28	3.8
Lexus	41	7.3	58	32.0	99	13.3
Total	565	100.0	181	100.0	746	100.0

Appendix D: Calculation of Confidence Intervals

The percentage reduction in the odds of loss-of-control type crashes when electronic stability control (ESC) is standard equipment is calculated using the formula

$$1-\hat{\theta}$$

where $\hat{\theta}$ is the odds of loss of control given that a vehicle had ESC as standard equipment divided by the odds of loss of control given that ESC for a vehicle was not available. Thus, $\hat{\theta}$ is an odds ratio and methods are available for calculating confidence intervals. However, calculation of standard errors for odds ratios are best performed on the log scale due to faster convergence to asymptotic normality. Direct application of the delta method can be used for calculating the asymptotic standard error of $1-\hat{\theta}$ (for details, see, for example, Agresti, 2002). The delta method is a procedure for calculating the large sample distribution of a function of a random variable known to have a large sample normal distribution. The log odds ratio has a large sample normal distribution under the assumption of multinomial or independent binomial sampling.

A large sample 95% confidence interval for the percentage reduction is

$$1-\hat{\theta} \pm 1.96\ \hat{\sigma}(1-\hat{\theta})$$

where $\hat{\sigma}(1-\hat{\theta})$ is the asymptotic standard error of $1-\hat{\theta}$. To apply the delta method, denote by β the log odds ratio and by $\hat{\beta} = \log\hat{\theta}$ the sample log odds ratio. The estimated standard error of $\hat{\beta}$, denoted by $\hat{\sigma}(\hat{\beta})$, is provided as standard output from statistical software packages, whether derived from analysis of 2 x 2 contingency tables or from model-based estimation. Let $g(\beta) = 1-\exp(\beta)$ and take $g'(\beta) = -\exp(\beta)$. Then, by the delta method, the asymptotic variance of $1-\exp(\hat{\beta}) = 1-\hat{\theta}$ is

$$\hat{\sigma}(\hat{\beta})^2\ \exp(\hat{\beta})^2 = \hat{\sigma}(\hat{\beta})^2\ \hat{\theta}^2$$

and the 95% confidence interval for $1-\theta$ is

$$1-\hat{\theta} \pm 1.96\ \hat{\sigma}(\hat{\beta})\ \hat{\theta}.$$

For example, in Table 1

$$1-\hat{\theta} = 1-\frac{124(610)}{222(490)} = 30.47\%.$$

The quantity $\hat{\sigma}(\hat{\beta}) = 0.1275$ is derived from statistical software and the 95% confidence interval is

$$0.3047 \pm 1.96\ (0.1275)\ (0.6953) = (13.1\%, 47.8\%).$$

Appendix E: Description of Accident Types

Category	Configuration	ACCIDENT TYPES (Includes Intent)				
I. Single Driver	A. Right Roadside Departure	01 DRIVE OFF ROAD	02 CONTROL/ TRACTION LOSS	03 AVOID COLLISION WITH VEH., PED., ANIM.	04 SPECIFICS OTHER	05 SPECIFICS UNKNOWN
	B. Left Roadside Departure	06 DRIVE OFF ROAD	07 CONTROL/ TRACTION LOSS	08 AVOID COLLISION WITH VEH., PED., ANIM.	09 SPECIFICS OTHER	10 SPECIFICS UNKNOWN
	C. Forward Impact	11 PARKED VEHICLE	12 STATIONARY OBJECT	13 PEDESTRIAN/ ANIMAL	14 END DEPARTURE	15 SPECIFICS OTHER / 16 SPECIFICS UNKNOWN
II. Same Trafficway Same Direction	D. Rear-End	20 STOPPED 21, 22, 23	24 SLOWER 25, 26, 27	28 DECELERATING 29, 30, 31	(EACH - 32) SPECIFICS OTHER	(EACH - 33) SPECIFICS UNKNOWN
	E. Forward Impact	34, 35 CONTROL/ TRACTION LOSS	36, 37 CONTROL/ TRACTION LOSS	38, 39 AVOID COLLISION WITH VEHICLE	40, 41 AVOID COLLISION WITH OBJECT	(EACH - 42) SPECIFICS OTHER / (EACH - 43) SPECIFICS UNKNOWN
	F. Sideswipe Angle	44, 45	46, 45, 47		(EACH - 48) SPECIFICS OTHER	(EACH - 49) SPECIFICS UNKNOWN
III. Same Trafficway Opposite Direction	G. Head-On	50, 51 LATERAL MOVE			(EACH - 52) SPECIFICS OTHER	(EACH - 53) SPECIFICS UNKNOWN
	H. Forward Impact	54, 55 CONTROL/ TRACTION LOSS	56, 57 CONTROL/ TRACTION LOSS	58, 59 AVOID COLLISION WITH VEHICLE	60, 61 AVOID COLLISION WITH OBJECT	(EACH - 62) SPECIFICS OTHER / (EACH - 63) SPECIFICS UNKNOWN
	I. Sideswipe/ Angle	64, 65 LATERAL MOVE			(EACH - 66) SPECIFICS OTHER	(EACH - 67) SPECIFICS UNKNOWN
IV. Change Trafficway Vehicle Turning	J. Turn Across Path	68, 69 INITIAL OPPOSITE DIRECTIONS	70, 71, 72, 73 INITIAL SAME DIRECTION		(EACH - 74) SPECIFICS OTHER	(EACH - 75) SPECIFICS UNKNOWN
	K. Turn Into Path	76, 77, 78, 79 TURN INTO SAME DIRECTION	80, 81, 82, 83 TURN INTO OPPOSITE DIRECTIONS		(EACH - 84) SPECIFICS OTHER	(EACH - 85) SPECIFICS UNKNOWN
V. Intersecting Paths (Vehicle Damage)	L. Straight Paths	86, 87	88, 89		(EACH - 90) SPECIFICS OTHER	(EACH - 91) SPECIFICS UNKNOWN
VI. Miscellaneous	M. Backing Etc.	92 BACKING VEHICLE	93 OTHER VEHICLE OR OBJECT		98 OTHER ACCIDENT TYPE 99 UNKNOWN ACCIDENT TYPE 00 NO IMPACT	

Appendix F: Test of Hypothesis for Difference in Percentage Reduction in Odds

The parameters in a logistic regression model have interpretations on the log odds scale. In what follows, the response variable is loss of control (0=no, 1=yes), the variable ESC has two levels (no, yes) with "no=0" coded as the baseline case, and the variable surface has two levels (dry, not dry) with "dry=0" coded as the baseline case. In the table below, $1-\exp(\beta_2)$ represents the percentage reduction in the odds of loss of control for a vehicle with ESC on dry roads. The quantity $1-\exp(\beta_2+\beta_4)$ represents the percentage reduction in odds of loss of control for a vehicle with ESC on surfaces that were not dry.

Parameter	Estimate	Std. Error	Z-Value	P-Value
Intercept	β_1	$se(\beta_1)$	Z_1	p_1
ESC	β_2	$se(\beta_2)$	Z_2	p_2
Surface	β_3	$se(\beta_3)$	Z_3	p_3
ESC x Surface	β_4	$se(\beta_4)$	Z_4	p_4

Therefore, to test the hypothesis that the percentage reduction was greater on surfaces that were not dry, the test is

$$H_0 : (1-\exp(\beta_2+\beta_4)) - (1-\exp(\beta_2)) = 0$$
$$H_1 : (1-\exp(\beta_2+\beta_4)) - (1-\exp(\beta_2)) > 0.$$

However, $(1-\exp(\beta_2+\beta_4))-(1-\exp(\beta_2)) > 0$ if and only if $\beta_4 < 0$. Therefore, one only needs to test whether the interaction term is less than zero, and the test reduces to

$$H_0 : \beta_4 = 0$$
$$H_1 : \beta_4 < 0.$$

Since this is a one-sided test, the critical value is -1.65 for a 95% level of significance. The test is therefore to reject H_0 if $Z_4 < -1.65$.

Appendix G: Numbers of Passenger Cars and SUVs with and without ESC by Make (GES 1999-2003)

Passenger Cars	ESC Not Available			ESC Standard	
Make - Model	**Count**	**%**	**Make**	**Count**	**%**
Chevrolet Impala	152	19.1	Audi	24	7.9
Chrysler Sebring	88	11.0	BMW	138	45.7
Honda Accord	398	49.9	Infiniti	4	1.3
Nissan Altima	159	19.9	Jaguar	13	4.3
			Lexus	20	6.6
			Mercedes	103	34.1
Total	797	100.0		302	100.0

Sport Utility Vehicles	ESC Not Available			ESC Standard	
Make - Model	**Count**	**%**	**Make**	**Count**	**%**
Ford Excursion	22	9.4	BMW	20	11.0
GMC Envoy	43	18.5	Mercedes	34	18.8
Honda Passport	18	7.7	Lexus	58	32.0
Jeep Grand Cherokee	40	17.2	Toyota	69	38.1
Land Rover	36	15.5			
Lincoln Navigator	15	6.4			
Nissan Pathfinder	59	25.3			
Total	233	100.0		181	100.0