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Effect of Electronic Stability Control on Automobile Crash Risk

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Per vehicle crash involvement rates were compared for otherwise identical vehicle models with and without electronic stability control (ESC) systems. ESC was found to affect single-vehicle crashes to a greater extent than multiple-vehicle crashes, and crashes with fatal injuries to a greater extent than less severe crashes. Based on all police-reported crashes in 7 states over 2 years, ESC reduced single-vehicle crash involvement risk by approximately 41 percent (95 percent confidence limits 33–48) and single-vehicle injury crash involvement risk by 41 percent (27–52). This translates to an estimated 7 percent reduction in overall crash involvement risk (3–10) and a 9 percent reduction in overall injury crash involvement risk (3–14). Based on all fatal crashes in the United States over 3 years, ESC was found to have reduced single-vehicle fatal crash involvement risk by 56 percent (39–68). This translates to an estimated 34 percent reduction in overall fatal crash involvement risk (21–45).

Keywords Crash Avoidance; Rollover; Loss of Control

According to the National Highway Traffic Safety Administration (NHTSA, 2004), approximately 6.3 million motor vehicle crashes occurred in the United States during 2002. Of these, about 38,000 crashes involved fatalities. Thirty percent of all crashes involved only a single vehicle, but among fatal crashes, 58 percent involved a single vehicle.

Single-vehicle crashes often are characterized by a driver losing steering control of the vehicle, often due to excessive speed (Campbell et al., 2003; Najm et al., 2003). Slippery roads, sharp curves, and obstacles in the roadway are factors in many single-vehicle crashes, as are driver inattention due to distraction, alcohol impairment, or drowsiness. Single-vehicle crashes typically are of three types with some overlap: impacts with pedestrians, impacts with fixed objects such as trees, and impacts involving rollover. Because of their high centers of gravity, sport utility vehicles (SUVs) are involved in many rollovers. Fatal rollover rates of SUVs have been shown to be more than three times those of passenger cars (Deutermann, 2002).

Electronic stability control (ESC) is a vehicle control system comprising sensors, brakes, engine control modules, and a microcomputer that continuously monitors how well the vehicle responds to the driver's steering input. The computer compares a driver's commands to the actual behavior of the vehicle. In general, when the sensors indicate the vehicle is leaving the intended line of travel, ESC applies the brake pressure needed at each individual wheel to bring the vehicle back on track. In some cases ESC also reduces the force exerted by the engine. The way ESC systems are programmed to respond to the information from the sensors varies among vehicle models. Some systems intervene sooner and take away more driver control of speed than others.

ESC first appeared in Europe in the 1995 model year and in the U.S. market a few years later (Memmer, 2001). As is typical of new technologies, ESC initially was available as optional equipment on luxury cars. However, by model year 2001 it was standard on a number of high-selling vehicles and available as an option in many more. For the 2004 model year, ESC was on all cars and light trucks manufactured by Audi, BMW, and Mercedes, and on some models produced by just about every other automaker. The marketing names of ESC systems vary. For example, BMW refers to its system as Dynamic Stability Control (DSC), Mercedes calls it Electronic Stability Program (ESP), Toyota calls it Vehicle Stability Control (VSC), Ford calls it AdvanceTrac, and General Motors uses the names StabiliTrak, Active Handling, and Precision Control.

The performance of ESC has been demonstrated on the test track. For example, in test drives of Toyota vehicles around a slippery curve, 45 percent of drivers without ESC ran out of the lane, but only 5 percent of drivers with ESC did so (Yamamoto & Kimura, 1996). The potential benefits of ESC in maintaining vehicle control also have been demonstrated using an advanced driving simulator. High-fidelity virtual models of an Oldsmobile Intrigue car and Ford Expedition SUV were developed for the National Advanced Driving Simulator. Simulations were run on these models with and without ESC. When subjected

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to simulations of various critical situations, 28 percent of the drivers without ESC and 3 percent of those with ESC lost control of their vehicles (Papelis et al., 2004). However, neither test track driving nor simulators are necessarily good predictors of real-world performance. For example, the performance of antilock braking systems (ABS) on test tracks was impressive, but the real-world crash experience was disappointing (Farmer, 2001; Kahane, 1994). It has been hypothesized that drivers in the real world reacted inappropriately to ABS, thereby counteracting its effectiveness.

The first published study of the real-world effectiveness of ESC was from Japan. The study of three Toyota car models reported a 35 percent reduction in single-vehicle crash rates after ESC was installed (Aga & Okada, 2003). Cars of model years without ESC experienced 2.5 single-vehicle crashes per 10,000 vehicles per year, whereas those of model years with ESC as standard equipment experienced only 1.6 crashes per 10,000 vehicles per year. Rates of head-on collisions also declined, from 1.8 to 1.3 crashes per 10,000 vehicles per year. The study accounted for vehicle age differences as well as general trends in crash rates, but there was no discussion of what other vehicle changes may have been made along with or subsequent to the installation of ESC. It is unclear, then, whether other safety improvements may have influenced the declining crash rates.

In Germany, ESC became standard equipment on all Mercedes passenger vehicles in model year 2000. Based on a sample of more than 2 million crashes, researchers reported a decline in the rate of at-fault crashes (per 100 vehicle registrations) of Mercedes vehicles from 1.32 in 1998–1999 to 1.10 in 2001–2002 (Unselt et al., 2004). In addition, the percentage of crashes due to loss of control declined from 21 to 12 percent. A loss-of-control crash is one in which the driver loses control of a vehicle "without the influence of other road users." As with the Toyota study, it is unclear what other safety improvements may have accompanied the increasing presence of ESC.

Researchers in Sweden studied 442 injury crashes of cars with ESC and 1,967 crashes of similar cars without ESC (Tingvall et al., 2004). The cars with and without ESC were matched by style and size, in some cases using different model years of the same car model or platform. However, no attempt was made to control for vehicle age differences. Rear-end impacts on dry roads, assumed to be unaffected by the presence of ESC, were used as a measure of induced exposure. It was estimated that ESC reduced the risk of all other types of crashes by 22 percent. Crash risk on wet roads was estimated to have been reduced by 32 percent.

The first study of ESC effectiveness in the United States used multiple-vehicle crashes as the measure of induced exposure (Dang, 2004). The odds of being involved in a single-vehicle crash (versus multiple-vehicle) were compared for vehicle models with ESC and earlier versions of the same models. The Swedish and Japanese studies reported that ESC reduced certain types of multiple-vehicle crashes, so such an induced exposure analysis should result in conservative estimates of ESC effectiveness. On the other hand, there was no attempt to control for other vehicle design changes, which could have inflated the ESC effectiveness estimates. Unlike the earlier studies, separate effectiveness estimates were provided for cars and SUVs. Largely because of rollovers, SUVs typically have higher single-vehicle crash rates than cars and may benefit more from ESC. Estimated reduction in the odds of a single-vehicle crash was 35 percent for cars and 67 percent for SUVs. Reduction in the odds of a fatal single-vehicle crash was 30 percent for cars and 63 percent for SUVs.

The present study seeks to improve effectiveness estimates for ESC in the U.S., and to compute estimates for single-vehicle and multiple-vehicle crashes combined. Although stability control is less prevalent in the U.S. vehicle fleet than in Sweden's, the greater size of the U.S. fleet means there are more crashes involving ESC-equipped vehicles and, thus, no need to rely on induced exposure methods. Rather, crash involvement rates per vehicle registration were computed. Comparison vehicles were restricted to earlier models that were physically identical to the ESC-equipped vehicles except for the presence of ESC. Effectiveness estimates therefore were not confounded by other design differences. Estimates were adjusted to account for the comparison vehicles being consistently older than the ESC-equipped vehicles.

METHOD

Vehicle models eligible for the study were those equipped with ESC as standard equipment in the 2000 or 2001 model year. In addition, there must have been an earlier model year for which the design of the vehicle was identical except that ESC was not available or available only as an option. Model years with identical designs have identical platforms and the same safety equipment (front and side airbags). Vehicle models meeting these conditions are listed in Table I. The primary study group consisted of vehicles that changed from no ESC to standard ESC in consecutive model years. Vehicles in the secondary study group were those that changed from optional ESC to standard ESC in consecutive model years. When offered as an option, ESC typically is selected by relatively few new vehicle purchasers, sometimes fewer than 10 percent (Ulrich, 2003; Ward's, 2004).

Information on all police-reported crashes of these vehicles in Florida, Illinois, Kansas, Maryland, Missouri, New Mexico, and Utah during 2001–2002 was extracted from the State Data System maintained by NHTSA. The State Data System is made up of police-reported crash data submitted annually to NHTSA by a selected group of states and modified to a common file structure (NHTSA, 2003). Vehicle make, model, and model year were identified by decoding the vehicle identification numbers (VINs). The seven states listed above were those for which both 2001 and 2002 calendar year crash files containing VINs were available at the time of the study. Information on fatal crashes of these vehicles during 2001–2003 was extracted from the Fatality Analysis Reporting System (FARS), an electronic database of fatal crashes occurring on U.S. public roadways.

Table I Vehicle models used for study of electronic stability control (ESC)

	Model years	
Primary group	Without ESC	With ESC standard
Acura 3.5 RL four-door	1999	2000–2002
Audi S4 Quattro four-door	2000	2001–2002
Audi TT Coupe	2000	2001–2002
Audi TT Coupe Quattro	2000	2001–2002
BMW 323i four-door	1999	2000
BMW 328i four-door	1999	2000
BMW M Coupe two-door	1999–2000	2001–2002
BMW M Roadster convertible	1998–2000	2001–2002
BMW Z3 Coupe 2.8 two-door	1999	2000
BMW Z3 Roadster 2.3 convertible	1999	2000
BMW Z3 Roadster 2.8 convertible	1999	2000
Jaguar XJ8 four-door LWB	1998–2000	2001
Lexus LX 470 four-door 4WD	1998–1999	2000–2002
Lexus RX 300 four-door 2WD	1999–2000	2001–2002
Lexus RX 300 four-door 4WD	1999–2000	2001–2002
Mercedes SLK class convertible	1998–2000	2001–2002
Toyota 4Runner four-door 2WD	1998–2000	2001–2002
Toyota 4Runner four-door 4WD	1998–2000	2001–2002
Toyota Land Cruiser four-door 4WD	1998–2000	2001–2002
Volkswagen Eurovan	1999–2000	2001–2002
Secondary group	With ESC optional	With ESC standard
Audi A8 Quattro four-door	2000	2001–2002
BMW 528i four-door	1999	2000
BMW 528it station wagon	1999	2000
Cadillac Seville four-door	1998	1999–2000
Chevrolet Corvette two-door	1998–2000	2001–2002
Chevrolet Corvette convertible	1998–2000	2001–2002
Jaguar VDP LWB four-door	1998	1999–2002
Mercedes C class four-door 2WD	1998–1999	2000
Mercedes CLK class two-door	1998–1999	2000–2002
Mercedes E class four-door 2WD	1999	2000–2002
Mercedes E class four-door 4WD	1999–2000	2001–2002
Mercedes E class station wagon 2WD	1999	2000–2002
Mercedes E class station wagon 4WD	1999–2000	2001–2002
Mercedes M class four-door 4WD	1998	1999–2001
Mercedes CLK class convertible	1999	2000–2002
Mercedes SL class convertible	1998	1999–2002
Volvo C70 two-door	2000	2001–2002
Volvo C70 convertible	2000	2001–2002

2WD = two-wheel drive, 4WD = four-wheel drive, LWB = long wheelbase.

Vehicle registration counts by state, calendar year, model year, and vehicle model were obtained from the National Vehicle Population Profile of R.L. Polk and Company. Registration data are collected in July of each year, so they do not include new vehicles first registered in the second half of the year. To ensure consistency of crash rates per registration, both crash and registration counts were restricted to calendar years subsequent to each model year. In other words, crash and registration counts of 2001 models during calendar year 2001 were not included.

If ESC has no effect on crash risk, then crash rates per registration should be the same for the ESC-equipped and non-ESC versions of each model. It follows that an expected crash count for the ESC-equipped version could be computed as the product of the crash rate for the non-ESC version and the registration count for the ESC version. Expected crash counts were calculated for each of the vehicle models in Table I. A risk ratio then was computed as the sum of the observed crash counts for ESC-equipped vehicles divided by the sum of the expected crash counts. Risk ratios were computed for various levels of crash severity (all police-reported crashes, injury crashes, fatal crashes) and crash type (multiple-vehicle, single-vehicle). Ninety-five percent confidence limits on the risk ratios were computed using a formula derived by Silcocks (1994). The lower and upper confidence limits were as follow:

$$\text{lower} = \beta_{0.025}(\mathrm{O}, \mathrm{E}+1)/[1-\beta_{0.025}(\mathrm{O}, \mathrm{E}+1)] \quad \text{and}$$

$$\text{upper} = \beta_{0.975}(\mathrm{O}+1, \mathrm{E})/[1-\beta_{0.975}(\mathrm{O}+1, \mathrm{E})],$$

where O is the sum of observed crash counts, E is the sum of expected crash counts, and $\beta_{\mathrm{p}}(x, y)$ is the pth percentile from the beta distribution with parameters x and y.

Table II Passenger vehicle crash involvements, by vehicle age, 2000–2001

Vehicle age (Years)	Registration-years	Crash involvements	Involvement rate per 100,000 registration-years	Involvement rate relative to age 1
1	31,633,553	1,833,000	5,794	1.00
2	28,807,286	1,639,000	5,690	0.98
3	27,326,339	1,572,000	5,753	0.99
4	25,859,993	1,541,000	5,959	1.03
5	26,064,834	1,539,000	5,905	1.02
6	26,094,344	1,531,000	5,867	1.01

Source: General Estimates System (Poindexter, 2003).

Risk ratios were computed separately for the primary and secondary vehicle groups. Subtracting the primary group risk ratio from one yields an estimate of the proportional reduction in crash risk associated with installation of ESC. Because a small percentage of the comparison vehicles in the secondary vehicle group were equipped with ESC, the risk ratio for this group leads to a conservative estimate of ESC effectiveness.

Some researchers have reported increases in crash risk with vehicle age (Blows et al., 2003; White et al., 1994). The ESC vehicles in Table I are 1–3 years newer than the vehicles without ESC, which could lead to overestimates of ESC effectiveness. A recent NHTSA research note examined the effect of vehicle age on crash involvement rates per registration (Poindexter, 2003). Table II summarizes some of the results. There does not seem to be an increase in crash risk until a vehicle gets to be 4 years old, at which point the risk increases by approximately 3 percent. However, because some of the vehicles in Table I were 4 years old (the 1998 models), adjusting the results for these vehicles was appropriate. Thus for each vehicle group that included 1998 models, the expected crash involvements were divided by 1.03. Notice that the adjustment was applied to all subsequent model years grouped with 1998, so the adjusted risk ratios were likely a bit too high.

RESULTS

Crash involvements of the study vehicles in Florida, Illinois, Kansas, Maryland, Missouri, New Mexico, and Utah during 2001–2002 are listed in Table III. More crashes of primary study vehicles occurred in Florida and Missouri than expected, whereas fewer crashes than expected occurred in the other states. However, none of the differences were statistically significant. Overall there were 2,387 crash involvements of ESC-equipped primary study vehicles, only 1 percent fewer than expected. This difference was not statistically significant.

All of the states except Kansas had fewer crashes of secondary study vehicles than expected. Overall there were 3,722 crash involvements of ESC-equipped secondary study vehicles, 10 percent fewer than expected. This difference was statistically significant.

Injury crash involvements in the seven states during 2001–2002 are listed in Table IV. Injury crashes are those for which the police report refers to at least one injured person, including fatalities and those designated as *possible* injuries. There were 794 injury crash involvements of ESC-equipped primary study vehicles, 3 percent fewer than expected, but the difference was not statistically significant. There were 1,251 injury

Table III Crash involvements of ESC study vehicles in seven states, by state, 2001–2002

State	Registration-years	Crashes	Registration-years	Expected crashes*	Observed crashes
Primary group	Without ESC		With ESC standard		
Florida	120,980	2,717	39,788	833.45	852
Illinois	50,593	2,566	18,687	940.54	940
Kansas	7,141	287	2,168	61.45	45
Maryland	31,361	887	10,570	273.51	231
Missouri	13,059	626	4,459	181.34	193
New Mexico	7,327	238	1,783	51.71	51
Utah	7,996	397	1,848	79.58	75
Total	238,457	7,718	79,303	2,421.57	2,387
					Risk ratio = 0.99
					95% confidence limits (0.93, 1.04)
Secondary group	With ESC optional		With ESC standard		
Florida	67,672	1,320	70,110	1402.30	1,338
Illinois	34,435	1,461	36,365	1750.28	1,529
Kansas	3,359	75	3,116	71.64	77
Maryland	18,574	424	18,239	396.97	386
Missouri	8,004	338	7,508	339.50	271
New Mexico	1,988	52	2,083	58.43	49
Utah	1,870	65	2,383	95.08	72
Total	135,901	3,735	139,805	4,114.20	3,722
					Risk ratio = 0.90
					95% confidence limits (0.87, 0.95)

*Adjusted for vehicle age.

Table IV Injury crash involvements of ESC study vehicles in seven states, by state, 2001–2002

State	Registration-years	Crashes	Registration-years	Expected crashes*	Observed crashes
Primary group	Without ESC		With ESC standard		
Florida	120,980	1,567	39,788	456.82	421
Illinois	50,593	516	18,687	158.05	169
Kansas	7,141	60	2,168	14.34	13
Maryland	31,361	365	10,570	107.07	88
Missouri	13,059	160	4,459	40.69	57
New Mexico	7,327	88	1,783	18.43	14
Utah	7,996	161	1,848	25.18	32
Total	238,457	2,917	79,303	820.58	794
					Risk ratio = 0.97
					95% confidence limits (0.88, 1.07)
Secondary group	With ESC optional		With ESC standard		
Florida	67,672	683	70,110	752.99	699
Illinois	34,435	306	36,365	354.83	277
Kansas	3,359	14	3,116	12.05	18
Maryland	18,574	180	18,239	170.07	156
Missouri	8,004	77	7,508	75.72	64
New Mexico	1,988	19	2,083	21.87	11
Utah	1,870	23	2,383	33.20	26
Total	135,901	1,302	139,805	1,420.74	1,251
					Risk ratio = 0.88
					95% confidence limits (0.82, 0.95)

*Adjusted for vehicle age.

crash involvements of ESC-equipped secondary study vehicles, 12 percent fewer than expected.

Fatal crash involvements during 2001–2003 are listed in Table V for each relevant vehicle model. Based on the 362 fatal crash involvements and nearly 2 million registrations of the vehicles without ESC, there were approximately 141 expected fatal crash involvements of the ESC-equipped primary study vehicles. The actual count of 70 fatal crash involvements was, therefore, 50 percent lower than expected. As for the ESC-equipped secondary study vehicles, 135 were involved in fatal crashes, 21 percent fewer than expected. This difference was not quite statistically significant.

Effectiveness estimates were computed separately by crash type. These are summarized in Tables VI and VII. Estimated effects of ESC on multiple-vehicle crash risk were sometimes positive and sometimes negative, but only the positive effects were statistically significant. Among the primary study vehicles, ESC was associated with a 35 percent reduction in multiple-vehicle fatal crash risk. Among the secondary study vehicles, ESC was associated with a 7 percent reduction in overall multiple-vehicle crash risk and a 9 percent reduction in multiple-vehicle injury crash risk.

Estimated effects on single-vehicle crashes, especially single-vehicle rollovers, were consistently positive and statistically significant. Among the primary study vehicles, ESC was associated with a 50 percent reduction in overall single-vehicle crash risk, a 43 percent reduction in single-vehicle injury crash risk, and a 69 percent reduction in single-vehicle fatal crash risk. Among the secondary study vehicles, ESC was associated with a 34 percent reduction in overall single-vehicle crash risk, a 39 percent reduction in single-vehicle injury crash risk, and a 44 percent reduction in single-vehicle fatal crash risk. Estimated effects on single-vehicle rollover crash risk, although statistically significant, were based on very few crashes. So, although the effect of ESC on rollover risk is likely greater than that on overall single-vehicle crash risk, a precise estimate of effectiveness is not yet possible.

Finally, results for the primary and secondary study groups were combined. These are summarized in Table VIII. ESC was associated with a 41 percent reduction in overall single-vehicle crash risk, a 41 percent reduction in single-vehicle injury crash risk, and a 56 percent reduction in single-vehicle fatal crash risk. Estimated effects of ESC on multiple-vehicle crashes also were positive but not statistically significant. As single-vehicle crashes account for a progressively higher proportion of injury and fatal crashes, the estimated risk reduction due to ESC was 7 percent in all crashes, 9 percent in injury crashes, and 34 percent in fatal crashes.

DISCUSSION

Logically, the best estimate of ESC effectiveness should be the one based only on primary study vehicles. It was anticipated that ESC effectiveness estimates would be lower in the secondary group because some of the vehicles used to calculate expected crash counts were equipped with ESC as an option. However, the estimated effects of ESC on overall multiple-vehicle crash risk were higher in the secondary study group than in the

Table V Fatal crash involvements of ESC study vehicles, by vehicle model, 2001–2003

State	Registration-years	Crashes	Registration-years	Expected crashes*	Observed crashes
Primary group	Without ESC		With ESC standard		
Acura 3.5 RL four-door	37,768	5	71,181	9.42	3
Audi S4 Quattro four-door	15,841	3	14,498	2.75	1
Audi TT coupe	9,837	2	2,414	0.49	0
Audi TT coupe Quattro	11,644	1	19,892	1.71	1
BMW 323i four-door	74,267	6	124,177	10.03	12
BMW 328i four-door	46,508	6	51,524	6.65	1
BMW M coupe two-door	5,886	0	960	0.00	0
BMW M Roadster convertible	24,118	6	2,278	0.55*	0
BMW Z3 coupe 2.8 two-door	2,146	0	738	0.00	0
BMW Z3 Roadster 2.3 convertible	17,658	3	45,957	7.81	3
BMW Z3 Roadster 2.8 convertible	5,240	3	12,670	7.25	1
Jaguar XJ8 LWB four-door	19,187	1	2,060	0.10*	0
Lexus LX 470 four-door 4WD	53,901	11	69,783	13.83*	5
Lexus RX 300 four-door 2WD	141,717	9	85,866	5.45	5
Lexus RX 300 four-door 4WD	338,516	33	135,105	13.17	8
Mercedes SLK class convertible	94,043	11	41,701	4.74*	1
Toyota 4Runner four-door 2WD	427,777	105	93,902	22.38*	16
Toyota 4Runner four-door 4WD	544,441	134	125,229	29.92*	10
Toyota Land Cruiser four-door 4WD	119,380	22	19,702	3.53*	3
Volkswagen Eurovan	9,427	1	8,426	0.89	0
Total	1,999,302	362	928,063	140.67	70
					Risk ratio = 0.50
					95% confidence limits (0.37, 0.67)
Secondary group	With ESC optional		With ESC standard		
Audi A8 Quattro four-door	6,761	1	388	0.06	0
BMW 528i four-door	60,087	7	94,107	10.96	7
BMW 528it station wagon	9,793	0	8,651	0.00	1
Cadillac Seville four-door	81,359	7	197,428	16.49*	24
Chevrolet Corvette two-door	161,909	43	60,650	15.64*	10
Chevrolet Corvette convertible	97,631	19	37,556	7.10*	2
Jaguar VDP LWB four-door	15,240	0	32,133	0.00	2
Mercedes C class four-door 2WD	208,517	16	79,823	5.95*	6
Mercedes CLK class two-door	48,900	8	53,767	8.54*	2
Mercedes E class four-door 2WD	129,559	8	223,625	13.81	18
Mercedes E class four-door 4WD	39,257	1	21,082	0.54	0
Mercedes E class station wagon 2WD	7,229	1	14,720	2.04	1
Mercedes E class station wagon 4WD	18,412	1	7,953	0.43	0
Mercedes M class four-door 4WD	99,445	23	358,982	80.61	46
Mercedes CLK class convertible	18,038	2	51,294	5.69	6
Mercedes SL class convertible	24,112	1	53,767	2.16*	6
Volvo C70 two-door	3,023	0	2,866	0.00	1
Volvo C70 convertible	12,979	0	11,461	0.00	3
Total	1,042,251	138	1,310,253	170.01	135
					Risk ratio = 0.79
					95% confidence limits (0.63, 1.00)

*Adjusted for vehicle age.

primary group. Lacking an explanation for these inconsistencies and recognizing that these vehicles may not be representive of the general vehicle fleet, it was decided to combine the two vehicle groups. Even the combined group is biased toward high-performance vehicles, so the estimated effects given here may not apply to lower-priced cars.

In the combined analysis, vehicles with ESC had a single-vehicle crash risk approximately 41 percent lower than vehicles without ESC. This effect is similar to the 35 percent reduction for cars reported both in Japan (Aga & Okada, 2003) and in the U.S. (Dang, 2004). In fact, the 95 percent confidence interval for the reduction in single-vehicle crash risk ranges from 33 to 48 percent, which includes the 35 percent estimate. These results suggest that if all vehicles were equipped with ESC that performs as it did for the study vehicles, then approximately 800,000 of the 2 million single-vehicle crashes on U.S. roads each year could be avoided.

More than 20,000 fatal single-vehicle crashes occur each year in the United States, and ESC is particularly effective in reducing the risk of these. This is perhaps not surprising because ESC

Table VI Observed and expected crash involvements of primary ESC study vehicles

					95% Confidence limits	
Crash severity	Crash type	Observed crashes	Expected crashes*	Ratio	Lower	Upper
All	All	2,387	2421.57	0.99	0.93	1.04
	Multiple-vehicle	2,249	2144.07	1.05	0.99	1.11
	Single-vehicle	138	277.50	0.50	0.40	0.61
	Single-vehicle rollover	10	37.95	0.26	0.12	0.54
Injury	All	794	820.58	0.97	0.88	1.07
	Multiple-vehicle	735	716.88	1.03	0.92	1.14
	Single-vehicle	59	103.70	0.57	0.41	0.79
	Single-vehicle rollover	6	27.00	0.22	0.08	0.55
Fatal	All	70	140.67	0.50	0.37	0.67
	Multiple-vehicle	50	77.06	0.65	0.45	0.94
	Single-vehicle	20	63.61	0.31	0.18	0.53
	Single-vehicle rollover	5	37.72	0.13	0.04	0.34

*Adjusted for vehicle age.

systems only intervene when drivers are losing control, which often indicates high-speed driving. Although this estimate is based on very little data, ESC reduces fatal single-vehicle crash involvements by an estimated 56 percent.

There appears to be little, if any, effect of ESC on overall multiple-vehicle crash risk. The studies in Japan and Sweden reported positive effects of ESC on the risk of certain types of multiple-vehicle crashes, specifically head-on crashes and crashes on wet roads (Aga & Okada, 2003; Tingvall et al., 2004). However, similar breakdowns of the crashes in Tables VI–VIII did not result in statistically significant effects. In fact, the direction of the estimated effects differed for the primary and secondary vehicle groups. There may be a positive effect of ESC on multiple-vehicle fatal crash risk, although the data are as yet insufficient for statistical significance. ESC reduces overall fatal crash risk by an estimated 34 percent.

The effect of ESC on single-vehicle injury crash risk is the same as that for all single-vehicle crashes, probably due to the very liberal definition of injury used here. A restriction to crashes with serious injuries would have reduced the power of the statistical tests so much as to make the analyses meaningless. Even so, the greater concentration of single-vehicle crashes among injury crashes resulted in a slightly higher overall effectiveness.

Disappointing experience with antilock brakes may have contributed to the relatively slow acceptance of ESC in the United States. Stability control systems include ABS as a component but, unlike ABS, do not require a driver to activate the brakes. Except for the Toyota 4Runner, all of the vehicle models in Table I had antilock brakes as standard equipment for the model years both with and without ESC, and antilocks were optional on 1998–2000 4Runners. Even though antilocks are not particularly effective in preventing real-world crashes, it is possible that some portion of the risk reduction observed for the 4Runner was due to ABS rather than ESC. Table V allows for the computation of separate effect estimates for the Toyota 4Runner and the other

Table VII Observed and expected crash involvements of secondary ESC study vehicles

					95% Confidence limits	
Crash severity	Crash type	Observed crashes	Expected crashes*	Ratio	Lower	Upper
All	All	3,722	4114.20	0.90	0.87	0.95
	Multiple-vehicle	3,471	3731.08	0.93	0.89	0.97
	Single-vehicle	251	383.12	0.66	0.56	0.77
	Single-vehicle rollover	5	32.80	0.15	0.05	0.39
Injury	All	1,251	1420.74	0.88	0.82	0.95
	Multiple-vehicle	1,156	1265.45	0.91	0.84	0.99
	Single-vehicle	95	155.29	0.61	0.47	0.79
	Single-vehicle rollover	2	23.23	0.09	0.01	0.35
Fatal	All	135	170.01	0.79	0.63	1.00
	Multiple-vehicle	95	98.49	0.96	0.72	1.29
	Single-vehicle	40	71.52	0.56	0.37	0.83
	Single-vehicle rollover	10	32.02	0.31	0.14	0.65

*Adjusted for vehicle age.

Table VIII Observed and expected crash involvements of all ESC study vehicles

Crash severity	Crash type	Observed crashes	Expected crashes*	Ratio	95% Confidence limits Lower	95% Confidence limits Upper
All	All	6,109	6535.77	0.93	0.90	0.97
	Multiple-vehicle	5,720	5875.15	0.97	0.94	1.01
	Single-vehicle	389	660.62	0.59	0.52	0.67
	Single-vehicle rollover	15	70.74	0.21	0.11	0.37
Injury	All	2,045	2241.32	0.91	0.86	0.97
	Multiple-vehicle	1,891	1982.33	0.95	0.90	1.02
	Single-vehicle	154	258.99	0.59	0.48	0.73
	Single-vehicle rollover	8	50.23	0.16	0.07	0.34
Fatal	All	205	310.68	0.66	0.55	0.79
	Multiple-vehicle	145	175.55	0.83	0.66	1.04
	Single-vehicle	60	135.13	0.44	0.32	0.61
	Single-vehicle rollover	15	69.74	0.22	0.11	0.38

*Adjusted for vehicle age.

primary study vehicles. The 4Runner with ESC (and standard ABS) had 26 fatal crash involvements, 50 percent fewer than expected. The other primary study vehicles with ESC had 44 fatal crash involvements, also 50 percent fewer than expected. So the change in ABS from optional to standard equipment had little effect, if any, on fatal crash risk.

As mentioned earlier, there are a number of different versions of ESC in the vehicle fleet. This study includes vehicles with the ESP product (Audi, Mercedes, Volkswagen), the DSC product (BMW, Jaguar), the VSC product (Lexus, Toyota), StabiliTrak (Cadillac), Active Handling (Chevrolet), the Volvo DSTC (Dynamic Stability and Traction Control), and the Acura VSA (Vehicle Stability Assist). The data are as yet insufficient to compare effectiveness estimates for these products.

The data also are insufficient to compare ESC effectiveness in cars versus SUVs. Although effectiveness estimates were slightly higher for SUVs than for cars, the differences were not statistically significant, and not nearly as great as those reported by Dang (2004). The comparison also is confounded by different ESC versions for the cars and SUVs in this study.

In summary, electronic stability control has been highly effective in preventing single-vehicle crashes. It does not appear to increase the risk of other types of crashes. Future studies with more data may even find a reduction in some types of multiple-vehicle crashes. Overall, ESC should be a significant benefit to highway safety.

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