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The Effectiveness of Electronic Stability Control in Reducing Real-World Crashes: A Literature Review

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Objective. *Electronic stability control (ESC) is designed to help drivers maintain heading control of their vehicles in high-speed or sudden maneuvers and on slippery roads. The wider proliferation of ESC across the vehicle fleet has allowed evaluation of its effects in real-world crashes in many countries, including Japan, Germany, Sweden, France, Great Britain, and the United States. This article provides a summary of the findings.*

Methods. *Studies that examined the real-world effectiveness of ESC were reviewed. Crash effects have been examined for different roadways, using differing analytic methods, different crash severities, and different make/model vehicles including both cars and SUVs. The review discusses the methodological differences and examines the findings according to vehicle type, crash type and severity, and road conditions.*

Results. *The overwhelming majority of studies find that ESC is highly effective in reducing single-vehicle crashes in cars and SUVs. Fatal single-vehicle crashes involving cars are reduced by about 30–50% and SUVs by 50–70%. Fatal rollover crashes are estimated to be about 70–90% lower with ESC regardless of vehicle type. A number of studies find improved effectiveness in reducing crashes when road conditions are slippery. There is little or no effect of ESC in all multi-vehicle crashes; however, there is a 17–38% reduction in more serious, fatal multi-vehicle crashes.*

Conclusions. *Given the extraordinary benefits of ESC in preventing crashes, especially those with more serious outcomes, the implementation of ESC should be accelerated to cover the full range of passenger vehicles in both developed and developing markets.*

Keywords ESC; Crash Avoidance; Loss of Control

Electronic stability control (ESC) is an evolution of antilock brake technology designed to help drivers maintain heading control of their vehicles in high-speed or sudden maneuvers and on slippery roads. Antilock brakes (ABS) have wheel speed sensors and the ability to apply brake pressure to individual wheels. ESC has additional sensors that monitor how well the vehicle is responding to a driver's steering input. If the sensors determine that the vehicle is straying from the chosen path, brake pressure will be automatically applied as necessary at individual wheels to bring the vehicle back to the direction that the driver is steering. In addition, in many cases engine power is reduced by means of an electronic throttle, thus slowing the vehicle down even more.

Manufacturers first began equipping vehicles with ESC, introduced under many different names, in the mid-1990s in Europe, and the technology appeared in other markets several years later. As with many new technologies, ESC first appeared as an option on more expensive luxury vehicles but within a few years was being offered as standard equipment on these and other less expensive models. Although Europe and Japan initially led the way, ESC is now standard on many vehicles in the United States. According to the Insurance Institute for Highway Safety (IIHS), in the U.S. market ESC was standard on 40% of 2006 passenger vehicle models and optional on another 15% (IIHS, 2006a). By the 2007 model year, 51% of U.S. passenger vehicle models were offered with ESC as standard equipment and an additional 14% offered it as an option (note that these percentages are of individual make/models and do not reflect the percentages in the vehicle fleet). In European countries there are large differences in the percentage of vehicles with ESC, with Germany leading the way (Baum, 2007).

Early studies on test tracks and using an advanced driving simulator indicated that ESC had the potential to be very effective in reducing loss-of-control crashes. For example, when vehicles equipped with and without ESC were driven around a slippery track, only 5% of drivers with ESC ran out of the lane compared with 45% of drivers whose vehicles were not equipped with ESC (Yamamoto & Kimura, 1996). Using an advanced driving simulator and high-fidelity models of a sports utility vehicle (SUV) and a passenger car, Papelis and others (2004) found that drivers without ESC lost control 28% of the time in critical driving situations compared with only 3% of

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those with ESC. (Critical conditions included a sudden maneuver to avoid a vehicle, sudden wind gusts, and potential departure from the road on a curve.) As promising as these results were, past experience has taught us that track test or driving simulator results may not be replicated in the real world. For example, while reductions in stopping distances were seen on the test track and crash reductions were predicted for vehicles with ABS, studies of real-world effectiveness failed to live up to those expectations (Farmer, 2001; Kahane, 1994). As a result, there were some reservations about whether ESC would be as effective in real-world crashes.

In the real world many loss-of-control crashes involve only one vehicle and are the result of excessive speeds, sudden maneuvers to avoid obstacles, and slippery road surfaces, with rollovers often resulting from these crashes. Rollovers are especially prevalent when vehicles with a higher center of gravity are involved, such as SUVs and pickup trucks. For example, in the United States, single-vehicle rollover crashes accounted for 46% of occupant deaths in SUVs in 2005, compared with 37% of occupant deaths in pickups and 20% in cars (IIHS, 2006b).

The wider proliferation of ESC across the vehicle fleet has allowed for evaluation of its effects in real world crashes in many countries. Studies to assess the effectiveness of ESC now have been conducted in Japan, Germany, Sweden, France, Great Britain, and the United States. These studies have used different methodologies, various crash databases, and examined the effects of ESC among different vehicle models. The purpose of this paper is to review and summarize the results of this literature, focusing on methodological differences and disparities in the outcomes of interest—for example, crash type and severity.

EFFECTIVENESS EVALUATIONS

There are many potential confounding factors to consider when evaluating the independent effects of ESC on passenger vehicle crashes. When comparing the crashes or crash rates of drivers in vehicles that have ESC with those that do not there may be differences in vehicle designs and vehicle ages, in driver gender and age, and in where and how much the vehicles are driven. Effects also can be modified by calendar year differences in crash outcomes as a result of changes in seat belt use rates, speeding, alcohol-impaired driving, and changes in annual vehicle mileage due to economic conditions, to name a few.

A strong evaluation would compare crash rates of vehicles that are identical except for the presence of ESC in overlapping calendar years and control for differences in vehicle exposure or miles driven, as well as other confounding factors. For many reasons, such an ideal comparison is not possible. New vehicle technology may be introduced at the same time as other vehicle design changes are made. For example, there may be simultaneous changes in the vehicle platform, structure, or vehicle weight, and other safety features, such as additional airbags, may be added that could affect the risk of injury and fatality. Even if vehicles can be identified that are identical in all other respects than the addition of ESC, vehicles with ESC will tend to be newer than those that don't have the technology (unless it is possible to ascertain, among optional equipment, those that do and do not have ESC). Crash databases may not have sufficiently detailed vehicle make/model information to permit a precise identification of which vehicles are equipped with ESC. Vehicle identification numbers, if available, may allow a make/model determination to be made but there may be no way to tell whether ESC has been installed on that particular vehicle.

Methodological approaches. In spite of these limitations, there are analytic methods that can be used to control for many of the potential confounding factors. Some methods are better than others, but all make certain assumptions. There are two basic methods that have been used in most of the studies reviewed here. Both methods attempt to control for vehicle exposure, but different approaches are taken.

One approach, sometimes referred to as induced exposure or case control, takes advantage of what is known about the anticipated benefits of ESC. Using this method, the total number of crashes in which ESC is expected to be effective (cases) is divided by the total number of crashes where the technology is expected to have no effect (controls). The basic premise is that the control crashes will vary with changes in vehicle miles traveled, driver characteristics, numbers of vehicles on the road, among other factors. However, these control crashes should be unaffected by the presence of ESC. Therefore, they can serve as a proxy for the amounts and types of exposure.

Studies that have used this approach have made different assumptions about which crashes constitute cases and which constitute controls. Single-vehicle crashes, or some subset of them (e.g., loss of control), are most often considered cases. In other words, they are expected to be affected by ESC. Control crashes have varied among studies. Some authors have assumed that ESC plays no role in avoiding rear-end crashes (Bahouth, 2005, 2006; Green & Woodroffe, 2006; Lie et al., 2004, 2006; Tingvall et al., 2003); others have used multi-vehicle crashes as controls (Dang, 2004; Green & Woodroffe, 2006). In yet other studies the authors have used a combination of crash types (Kreiss et al., 2005; NHTSA, 2006; Page & Cuny, 2006; Thomas, 2006; see Table I). The ratio of the number of case crashes divided by the number of control crashes for vehicles with ESC is divided by the corresponding ratio for vehicles without ESC. If ESC reduces case crashes, the resulting odds ratio is smaller than one; if ESC results in increased crashes of that type, the odds ratio is larger than one. An odds ratio equal to one suggests that ESC makes no difference in the crashes of interest. The percent change can then be estimated as $100(1 - \text{odds ratio})$.

The second approach accounts for vehicle exposure directly (Bahouth, 2006; Farmer, 2004, 2006; NHTSA, 2006). In the studies reviewed here, the numbers of registered vehicles with and without ESC is utilized. Some studies have attempted to control for potential differences in driver and vehicle characteristics through comparison of vehicle make/models that are identical except for the presence or absence of ESC. Others may attempt

Table I Review of key published studies evaluating ESC

Authors' publication date	Country	Makes/models ESC type	Databases	Methods	Findings (figures in parentheses represent 95% confidence intervals unless otherwise indicated)	Comments
Aga et al. (2003)	Japan	3 Toyota car models with and without ESC examined for first 5 years of vehicle life, 1994–2000 models	Police-reported injury crashes, 1994–2001 Institute for Traffic Accident Research and Data Analysis	Crash rates per vehicle years adjusting crudely for vehicle attrition. By vehicle damage severity, crash type, injury type	−35% SV crashes −30% HO crashes −40–50% moderate and severe damage −35% injury rates for SV and head-on	Limited set of vehicles with VSC. No adjustment for confounding factors, including vehicle age. Method details unclear. Not clear how registration data derived.
Tingvall et al. (2003) Lie et al. (2004)	Sweden	Mainly Mercedes, BMW, Audi, and VW cars, 1998–2003 models. Controls matched to be as close as possible to the case vehicle but not a perfect match	Police-reported crashes with at least one injury, calendar years 2000–02	Induced exposure using rear-ends on dry roads as control. All other crashes and road conditions constituted ESC relevant crashes	−22% (±21%) all excl. rear ends −9% (±28%) on dry roads −32% (±23%) on wet roads −38 % (±26%) snow/ice −28–59% by vehicle size	Confidence intervals are very wide. Vehicle matches imperfect and no control for confounding factors. Examined vehicle age effects but no adjustment made to estimates
Dang (2004)	USA	Mercedes, BMW, and GM cars. Mercedes, and Toyota/ Lexus SUVs, 1997–2002 models. Separate estimates for cars and SUVs	Police-reported crashes from 5 U.S. states 1997–2002. FARS 1997–2003	Induced exposure using multi-vehicle crashes as controls. Also used logistic regression to control for vehicle age (rates per registered vehicle years). Similar but not identical vehicle makes/models with and without ESC	<u>Police-reported crashes:</u> Cars: −35% (±6%) SV crashes SUVs: −67% (±7%) SV crashes <u>Fatals:</u> Cars: −30% (±20%) SV crashes SUVs: −63% (±18%) SV crashes <u>Logistic regression:</u> Similar results, data not shown	Mostly luxury vehicles. Assumes multi-vehicle fatal crash risk is not affected by ESC, but some evidence to the contrary (Farmer, 2006). No adjustment for vehicle age effects in main analyses
Farmer (2004)	USA	Mostly German and Japanese vehicles. Cars and SUVs with and without ESC, 1998–2002 models. Combined estimates for SUVs and cars	Police-reported crashes from 7 U.S. states 2001–02. FARS 2001–03. R.L. Polk vehicle registration data	Rates per registered vehicle. Compared identical makes/ models with standard ESC vs. models with no or optional ESC. Adjusted for vehicle age	<u>All/injury crashes cars–SUVs:</u> −7% (−10%, −3%) All crashes −41% (−48%, −33%) SV crashes −3% (−6%, +1%) MV crashes −9% (−14%, −3%) All injury −41 % (−52%, −27%) SV/injury −5% (−10%, +2%) MV injury <u>Fatals:</u> −34% (−45%, −21%) All fatal −56% (−68%, −39%) SV fatal −17% (−34%, +4%) MV fatal	Limited set of mostly luxury vehicles. Few vehicles from U.S. manufacturers. Adjusted for vehicle age and controlled for other driver and vehicle factors by restricting comparison to vehicle makes/ models with no design changes other than ESC. Small numbers precluded separate car, SUV estimates
Unselt et al. (2004)	Germany	Mercedes cars, model years not clearly specified. All other cars on road served as comparison vehicles	Obtained a 50% sample of police-reported crashes, 1998–2002 from the German Federal Statistical Office	Compared percentage of loss of control (LOC) crashes for Mercedes cars for each calendar year with same crashes for other non-Mercedes cars	Percentage of LOC crashes decreased from 21% in 1998–99 to 12% in 2000–01 during phase-in of ESC. Slight reduction in LOC crashes for other cars starting in 2000–01 (percents not shown)	Very crude analyses. Does not compare vehicles with and without ESC directly; i.e., no control for when ESC was introduced. No control for other confounding factors

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Table I Review of key published studies evaluating ESC *(Continued)*

Authors' publication date	Country	Makes/models ESC type	Databases	Methods	Findings (figures in parentheses represent 95% confidence intervals unless otherwise indicated)	Comments
Bahouth (2005)	USA	Lexus cars (1997–98 models) and SUVs (1999–2001) and Toyota SUVs (1999–2001). Combined estimates for cars and SUVs	Police-reported crashes from 6 U.S. states encompassing 1998–2003	Induced exposure using rear-ends as controls. ESC relevant crashes included SV and frontal MV. Adjusted for vehicle age effects. Similar but not identical vehicle makes/models with and without ESC. State data weighted to provide best estimate	−12% (−18%, −5%) MV frontal −53% (−58%, −46%) SV crashes	Limited set of vehicles from one manufacturer with VSC. Adjusts for vehicle age. Safety and structural attributes "generally" similar before and after ESC
Farmer (2006)	USA	Mostly German and Japanese manufacturers, with a few more makes/models than Farmer (2004) study. Cars and SUVs with and without ESC, 1998–2003 models. Separate estimates for SUVs and cars	Police-reported crashes from 10 U.S. states 2001–03. FARS 2001–04 R.L. Polk vehicle registration data	Same as Farmer (2004). Adjusted for vehicle age using more severe adjustment than before	Police-reported crashes *Injury crashes, cars:* −2% (−8%, +4%) All crashes −33 % (−45%, −20%) SV crashes +2% (−4%,+9%) MV crashes −75% (−91%, −41%) SV rollover *Injury crashes, SUVs:* −7% (−12%, −1%) All crashes −56 % (−64%, −46%) SV crashes −1% (−5%,+8%) MV crashes −78% (−88%, −62%) SV rollovers Fatal crashes, cars: −38% (−51%, −22%) All crashes −53% (−68%, −32%) SV crashes −25% (−44%, +1%) MV crashes −77% (−91%, −49%) SV rollover Fatal crashes, SUVs: −46% (−56%, −34%) All crashes −59% (−72%, −42%) SV fatals −37% (−51%, −18%) MV fatals −80% (−89%, −64%) SV rollover	Limited set of mostly luxury and high performance vehicles. Few vehicles from U.S. manufacturers. Adjusted for vehicle age (more severe adjustment than in 2004 paper) and controlled for other driver and vehicle factors by restricting comparison to vehicle makes/models with no design changes other than ESC
Bahouth (2006)	USA	Same as 2005 paper. Combined estimates for cars and SUVs	Police-reported crashes from 10 U.S. states encompassing 1998–2003 FARS 1998–2003	Induced exposure using rear-ends as controls. ESC relevant crashes included all non-rear crashes. Separated crashes according to police-reported injury using KABCO scale. Adjusted for vehicle age. For FARS analyses calculated involvement rates per registered vehicle	Police-reported crashes: −53% (−73%, −18%) incapacitating, fatal injury crashes (K+A) −31% (−43%, −15%) non-incapacitating, possible injury crashes (B+C) FARS −34% (−40%, −26%) All fatals −56% (−64%, −47%) SV fatals	Very limited set of vehicles. Small numbers of fatal crashes. Adjusts for vehicle age. Safety and structural attributes "largely" similar before and after ESC
Green and Woodroffe (2006)	USA	Cars with standard ESC (2000–03 models) vs. similar models without ESC (1995–99). SUVs with standard ESC (2000–03) vs. similar models without ESC (1996–99). Predominantly German and Japanese manufacturers. Separate estimates for cars and SUVs	NASS/GES 1995–2003 FARS 1995–2003	Induced exposure using MV crashes as controls for FARS analyses; rear-end crashes for NASS/GES. SV, ROR, rollover are crashes of interest in FARS analyses; LOC for NASS/GES. NASS/GES analyses based on unweighted data. Compares similar but not identical make/model vehicles with and without standard ESC. Most analyses do not include adjustments for vehicle age	Police-reported (NASS/GES): Cars: −54% (−68%, −41%) LOC SUVs: −70% (−83%, −58%) LOC FARS: Cars: −30% (−48%, −13%) SV −40% (−60%, −19%) rollover SUVs: −50% (−69%, −30%) SV −73% (−85%, −61%) rollover	Limited set of mostly luxury vehicles. Assumes multi-vehicle fatal crash risk not affected by ESC. Analyses not adjusted for vehicle age and other changes in vehicle platforms or safety features that might exist between models with and without ESC. Crashes of interest in NASS/GES analyses restricted to run off road so sample size is small

Table I Review of key published studies evaluating ESC (*Continued*)

Authors' publication date	Country	Makes/models ESC type	Databases	Methods	Findings (figures in parentheses represent 95% confidence intervals unless otherwise indicated)	Comments
Kreiss et al. (2005)	Germany	Vehicle makes/models where more than 80% equipped with ESC vs. models without ESC, 1999–2002 models. No further specification of makes/models	Police-reported crashes from the German Federal Statistical Office, 1998–2002	Induced exposure using crashes with vehicles turning onto or off, or crossing a road, pedestrians crossing, and crashes with stationary vehicles as controls. ESC comparison crashes include LOC	−32% in all LOC crashes (95% CIs not given) −56% (−71%, −31%) in fatal LOCs	Vehicle makes/models not specified, but appear to be comparing dissimilar vehicles. Examines role of various factors but no direct control for vehicle age and other changes in vehicle platforms or safety features that might exist between models with and without ESC in point estimates (misclassification results in underestimate of effect)
Lie et al. (2006)	Sweden	Cars with standard ESC vs. no ESC. Controls matched to be as close as possible to the case vehicle but not a perfect match. Model years 1998–2005	Police-reported crashes with at least one injury, calendar years 1998–2004	Induced exposure using rear-ends on dry roads as control. All other crashes and road conditions constituted ESC relevant crashes	−17% (± 9%) injury (excl. rear) −31% (± 10%) SV, oncoming, overtaking −41% (± 15%) serious/fatal SV etc. −44 % (± 20%) fatal SV etc. −56% (± 24%) serious/fatal SV in the wet	Method assumes, but cannot confirm, that there are no other vehicle or driver differences in the comparison and control vehicles. Tighter confidence intervals than 2003/04 studies
NHTSA (2006)	USA	1997–2004 model year cars and SUVs with and without ESC. Separate estimates for cars and SUVs Same makes/models as Dang (2004) study	Police-reported crashes from 7 U.S. states encompassing 1997–2003. Used median of estimates from 7 states as best estimate. FARS 1997–2004	Induced exposure using crashes not expected to benefit from ESC as controls (low-speed, rear-end, not at-fault, stopped, backing, etc.). ESC-relevant comparison crashes include SV, MV at-fault, crashes involving other road users (pedestrians, animals, etc.). Similar but not identical vehicle makes/models with and without ESC	<u>Police-reported crashes:</u> <u>Cars:</u> −34% (−46%, 20%)* SV crashes −71% (−78%, −60%)SV rollover −11% (−18%, −4%) MV at-fault SUVs: −59% (−68%, −47%) SV crashes −84% (−90%, −75%) SV rollover −16% (−24%, −7%) MV at-fault <u>Fatals:</u> Cars: −35% (−51%, −20%) SV crashes −69% (−87%, −52%) SV rollover −19% (−39%, +2%) MV at-fault SUVs: −67% (−78%, −55%) SV crashes −88% (−95%, −81%) SV rollover −38% (−60%, −16%) MV at-fault	Mostly luxury vehicles. No adjustment for vehicle age effects. No control for other changes in vehicle platforms or safety features that might exist between models with and without ESC
Page and Cuny (2006)	France	Renault Laguna cars, with and without ESC (precise model years not given). Model with ESC also fitted with brake assist	Police reported injury/fatality crashes in French national crash database, 2000–03	Induced exposure using crashes not expected to benefit from ESC as controls (see paper for complete list). ESC-relevant comparison crashes include SV and LOC. Removed all crashes involving braking because Laguna model with ESC also fitted with brake assist. Logistic regression used to adjust for confounding variables	−43% (−75%, +30%) ESC relevant crashes (SV and LOC)	Very limited sample size and vehicle representation. Difficult to determine vehicle type and presence of ESC from database. Renault Laguna with ESC also fitted with brake assist. Small numbers for logistic regression resulting in very wide confidence intervals for adjusted estimates

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Table I Review of key published studies evaluating ESC *(Continued)*

Authors' publication date	Country	Makes/models ESC type	Databases	Methods	Findings (figures in parentheses represent 95% confidence intervals unless otherwise indicated)	Comments
Thomas (2006)	Great Britain	Cars with standard ESC versus cars without ESC. In general previous version of car without ESC was selected. No further details provided	Police-reported injury crashes, from STAT19 national crash casualty database, 2002–04	Induced exposure using crashes involving vehicles that are essentially stationary before the crash as controls versus other crashes as cases (see paper for complete list)	−3% (± 2.6%) all injury crashes −19% (±8%) serious/ fatal injury −20 all inj. skidding crashes −40% serious/fatal inj. skidding −50% all injury rollover −2% SV −1% serious/fatal injury SV −24% fatal SV	No information on which make/model cars comprised ESC and non-ESC. Number of fatalities small. No adjustment for vehicle age effects. No control for other changes in vehicle platforms or safety features that might exist between models with and without ESC
Highway Loss Data Institute (2006)	USA	1997–2004 model luxury cars, sports cars, and SUVs (separate estimates for each). Mostly luxury vehicles and mostly German and Japanese manufacturers	Insurance claims data. Based on up to the first 3 years of experience for each make/model. Collision frequency and costs	Compared claims frequency and average loss costs for vehicles with and without ESC. Collision and property damage liability (PDL) claims, and claims for personal injury protection examined	Overall collision losses −17% luxury cars −15% sports cars −16% SUVs Overall PDL losses −5% luxury cars −4% sports cars −2% SUVs	Examining changes in claims losses not effectiveness in affected vs. non-affected crashes. Insurance claims involve predominantly low-severity crashes, with large proportion of rear-ends which seem to be unaffected by ESC. Comparison vehicles are makes/models with no design changes other than ESC

HO = head-on crashes, MV = multiple-vehicle crashes, SV = single-vehicle crashes, LOC = loss of control crashes, CIs = confidence intervals.
[1]90% Confidence intervals.

to control for driver and vehicle differences using regression analyses (although some make no adjustments for potential differences). The advantage of this approach is that no assumptions need to be made about which crash types might be affected by ESC and which might not. Thus, the effects of ESC can be evaluated among all crash types without the potential confounding effects of crash type. The expected number of crashes in vehicles with ESC can be estimated as the product of the observed crash rates of the non-ESC vehicles and the registration counts for the ESC-equipped vehicles. The risk ratio is the sum of the observed crash counts of the ESC vehicles divided by the expected crash counts. As indicated above, a risk ratio of less than one would be expected if ESC reduces crashes; greater than one would indicate an increased crash risk and so on.

Other study variations. Aside from the basic methodological differences outlined above, there are other significant differences in the approaches used. Automakers are equipping their vehicles with various versions of ESC and marketing the systems under various names. For example, Dynamic Stability Control is the name used by BMW and Jaguar; Electronic Stability Program is used by Mercedes-Benz, Audi, and Volkswagen; Vehicle Stability Control by Lexus and Toyota; Vehicle Stability Assist by Honda and Acura; AdvanceTrac by Ford; Electronic Stability Control by Hyundai; Dynamic Stability and Traction Control by Volvo; and StabiliTrak, Active Handling, and Precision Control by General Motors.

Although the hardware in these systems is similar, there are variations in the way the systems are programmed to respond once loss of control is detected, with sportier models generally allowing more wheel spin and sliding while still maintaining control. These differences potentially could influence ESC system effectiveness; however, no studies to date have had a sufficient sample size to separate out the effects of different systems. A few studies have examined just one variant of ESC on different models (Aga & Okada, 2003; Bahouth, 2005, 2006; Page & Cuny, 2006; Unselt et al., 2004) but most have amalgamated the effects of different makes and models.

In the United States, ESC is offered most often on SUVs, followed by cars, but far fewer pickup trucks offer the technology. All U.S. studies have examined both cars and SUVs (Bahouth, 2005, 2006; Dang, 2004; Farmer, 2004, 2006; Green & Woodroffe, 2006; NHTSA, 2006). In other countries, where SUVs are less common, studies typically have examined passenger cars (Aga & Okada, 2003; Kreiss et al., 2005; Lie et al., 2004, 2006; Page & Cuny, 2006; Thomas, 2006; Tingvall et al., 2003; Unselt et al., 2004). A few studies, particularly more recent analyses, have been able to separate out the effects of ESC among cars and SUVs but many have looked only at cars or have combined both vehicle types.

The choice of vehicles to include in the analysis has important implications. Comparing the same makes/models with and without ESC can help limit the extraneous influence of driver factors, since it is reasonable to assume that people who drive particular makes and models, regardless of whether the vehicle is equipped with ESC, are similar in many respects (age, gender, driving style, belt use, etc.). Comparing different vehicle makes—for example, Audis with Fords—can introduce driver differences that need to be controlled for. However, even when matching makes and models there still may be differences in vehicle structure, weight, and the safety features available. Manufacturers often make platform changes and introduce new safety features concurrently with a vehicle redesign, such as airbags and ESC.

During the period when ESC was being introduced, many vehicles also were being equipped for the first time with side airbags and manufacturers were making improvements to the vehicles' frontal structures to meet frontal offset test requirements now in place in many countries. A methodological refinement that can help overcome these problems is to compare only makes and models that are identical in all other respects except for the introduction of ESC (Farmer, 2004, 2006). One limitation of this approach is that the analyses are confined to a more restricted group of vehicles. However, the results are less subject to the influence of other confounding factors.

RESULTS

The findings of the reviewed studies should be interpreted in light of the assumptions made and approaches used. As mentioned earlier, because the comparisons are made across model years, the vehicles with ESC typically are newer than vehicles without the technology. Studies have demonstrated that older vehicles have higher crash risks (Blows et al., 2003; Farmer & Lund, 2006; Poindexter, 2003; White et al., 1994). Farmer and Lund (2006) reported that fatality risk rises with each additional vehicle year of age. For example, the risk for two-year-old models is approximately 2% higher than the risk for one-year-old models, and the risk for three-year-old models is an additional 5% higher. Thus, studies that do not adjust for vehicle age effects may be overestimating the effects of ESC.

Another assumption that may have implications for effect size when using the induced exposure method is the choice of control crashes. If a chosen control crash type is itself affected by ESC, estimates can be either higher or lower than estimated. If ESC reduces control crashes, effects will be underestimated. If it increases control crashes effects will be overestimated.

Single Vehicle Crashes

Table 1 lists study details, including study methodology, vehicles examined, and study findings. Limitations and strengths of the study designs also are discussed.

Researchers have examined the effects of ESC on single-vehicle police-reported crashes, police-reported injury crashes, and fatal crashes including some combinations of these categories. Some studies have examined cars, some have examined SUVs, and some have combined estimates for the two vehicle types. The estimated effects of ESC on single-vehicle crashes are mostly positive and are remarkably similar regardless of the methods used. When examining police-reported single-vehicle crashes (most of which involved injury), cars with ESC had about a third fewer crashes of this type than cars without the technology (Aga & Okada, 2003; Dang, 2004; Farmer, 2006; NHTSA, 2006). SUVs had 56–67% fewer such crashes (Dang, 2004; Farmer, 2006; NHTSA, 2006), and for cars and SUVs combined there were about 40–50% fewer crashes (Bahouth, 2005; Farmer, 2004). Some researchers combined single-vehicle crashes with other crash types, or looked specifically at loss of control crashes. Reductions across these more diverse crash types were estimated at 31–54% for cars with ESC (Green & Woodroffe, 2006; Kreiss et al., 2005; Lie et al., 2006; Page & Cuny, 2006), 70% for SUVs (Green & Woodroffe, 2006). An exception to this pattern was found in Great Britain (Thomas, 2006). In this study of police-reported injury crashes, there was no significant reduction in single vehicle crashes.

A few studies in the United States have examined fatal crashes. For these more serious single-vehicle crashes, estimates for reductions among cars were around 30–35% in three studies (Dang, 2004; Green & Woodroffe, 2006; NHTSA, 2006) but a fourth estimated the reduction at 53% (Farmer, 2006). Combining cars and SUVs resulted in estimated reductions of 56% (Bahouth, 2006; Farmer, 2004), and SUVs alone resulted in a 50–67% reduction (Dang, 2004; Farmer, 2006; Green & Woodroffe, 2006; NHTSA, 2006). Again, one recent study in Great Britain (Thomas, 2006) found much lower effectiveness in single-vehicle fatal crashes. Among cars with ESC, these crashes were reduced by a non-significant 24%. Fatal crashes in this study were few in number so statistical significance was difficult to achieve.

The majority of studies that examined rollover crashes, whether they involved injury or fatality, cars or SUVs, found reductions of 69–88% (Farmer, 2006; Green & Woodroffe, 2006; NHTSA, 2006). However, Green and Woodroffe (2006) found a 40% reduction in fatal rollover crashes among cars and Thomas (2006) found a 50% reduction in injury rollover crashes among cars.

To summarize, in almost every study reviewed vehicles with ESC had significantly lower single-vehicle crash risk than vehicles without the technology. The estimated reductions were not markedly different as crash severity increased, but typically were higher for SUVs and for crashes involving rollovers.

Multi-Vehicle Crashes

Fewer studies have examined the effectiveness of ESC on multi-vehicle crashes. One study examined multi-vehicle head-on crashes (Bahouth, 2005), one examined at-fault multi-vehicle crashes (NHTSA, 2006), and a third looked at all multi-vehicle crashes combined (Farmer, 2004, 2006). In analyses of police-reported multi-vehicle crashes of all severities, including injury crashes, Farmer (2006) found no change due to ESC. Reductions of 12% were found in multi-vehicle head-on crashes (Bahouth, 2005), and reductions of 11–16% were found for at-fault multi-vehicle crashes (NHTSA, 2006). Analyses of fatal multi-vehicle crashes yielded higher estimated reductions ranging from 17–38% (Farmer, 2004, 2006; NHTSA, 2006). Thus, ESC does not seem to have much influence, if any, on less severe multi-vehicle crashes but leads to reductions in fatal multi-vehicle crashes that are smaller than those seen for single-vehicle crashes. Thus, studies using multi-vehicle crashes as controls may underestimate fatal crash effectiveness, although effectiveness estimates for crashes of all severities may be unaffected.

All Crashes Combined

Farmer (2004, 2006) estimated the effects of ESC in reducing all crashes combined. In the 2004 study, estimates for cars and SUVs were combined but in the 2006 study, separate estimates were provided. In the 2004 study, all police-reported crashes and injury crashes of SUVs and cars were 7–9% lower with ESC (Farmer, 2004), but in the 2006 study, which applied a more stringent adjustment for vehicle age differences, there were no differences in crash risk among cars or SUVs with and without ESC. Thomas (2006) also found very little difference in all injury crashes due to ESC. Among the more serious fatal crashes, ESC reduced all crashes by an estimated 34% for cars, and SUVs combined (Farmer, 2004), 38% for cars, and 46% for SUVs (Farmer, 2006). Both Lie et al. (2006) and Bahouth (2006) examined all crashes excluding rear-ends which served as a control. Estimated crash reductions using rear-ends, as a control (which are expected to be unaffected by ESC) ranged from 17 to 31% for all crashes and injury crashes (Lie et al., 2006; Bahouth, 2006) and 53% for serious injury and fatal crashes (Bahouth, 2006).

Other Crash Types

A number of studies examined the effectiveness of ESC in different road conditions (dry, wet, slippery, etc.). Tingvall et al. (2003) reported estimates that were higher for cars with ESC in wet and icy road conditions compared with dry roads (9% on dry roads vs. 32% in the wet, and 38% in snow and ice). Also, Thomas (2006) found higher effectiveness for ESC on wet or icy roads than on dry roads, and the differences were more pronounced for the more severe crashes (serious and fatal injury crashes were reduced by 9% on dry roads, 34% on wet roads, and 53% on icy/snowy roads). However, when Farmer (2006) examined the risk of multi-vehicle crashes under adverse conditions (wet, slippery roadways, or in foggy weather or on curves), he did not find increased benefits under those conditions.

Insurance Losses

The U.S. Highway Loss Data Institute (HLDI) has conducted the only study to examine changes in insurance losses in vehicles with ESC as standard equipment versus vehicles that had no ESC or offered it as an option (HLDI, 2006a). Insurance claims are far more numerous and typically less severe than police-reported crashes. Claims may range from less than $100 for damage sustained in a minor impact, up to the market value of a vehicle for a total loss (HLDI, 2006b). HLDI researchers compared insurance losses in vehicles with and without ESC under several coverage types. They compared claims frequencies and average loss costs for collision coverage (which insures against physical damage sustained in crashes to drivers' own vehicles and property damage liability (which insures against physical damage that at-fault drivers cause to other peoples' vehicles and property in a crash). The study vehicles consisted of 1997–2004 luxury model cars, sports cars, and SUVs, and losses were examined based on the first 3 years of the vehicle's life. Overall collision losses (which comprise the product of the claim frequencies and the average-loss payments per claim) were 16% lower among SUVs with ESC than among models without it, 17% lower among luxury cars, and 15% lower among sports cars. Overall property damage liability losses were little affected.

CONCLUSIONS

Many studies now confirm the benefits of ESC in a variety of world markets, on different roadways, using different analytic methods, and different make/model vehicles. Findings of the earliest studies now have been replicated as additional data have become available and more refined analyses have enabled a more detailed understanding of the effects of ESC under a range of conditions. There is strong evidence that ESC is highly effective in reducing single-vehicle crashes in cars and SUVs. Many studies now have estimated that ESC reduces fatal single-vehicle crashes by between 30 and 50% among cars and 50–70% among SUVs. Furthermore, fatal rollover crashes are estimated to be 70–90% lower with ESC regardless of vehicle type. Farmer (2006) estimated that in the United States alone, if all vehicles in the fleet were equipped with ESC, then at least 600,000 of the two million single-vehicle crashes could be avoided every year, and 10,000 fatal crashes prevented.

Because ESC can help prevent drivers from losing control of their vehicles, it was expected that it would reduce the incidence of single-vehicle crashes, especially the more severe ones. However, multi-vehicle crashes are much less often the result of loss of control, and the study findings reflect that. A number of studies indicate that there is little or no effect of ESC in police-reported multi-vehicle crashes and because such crashes are more numerous overall, police-reported crashes seem unaffected (Farmer, 2006). However, in fatal multi-vehicle crashes, some of which may result from loss of control, there is a smaller but significant benefit of having ESC on the vehicle. ESC often is described as being effective when road conditions are slippery. A few studies have found higher effectiveness in wet and icy conditions (Lie et al., 2003, 2006; Thomas, 2006) although Farmer (2006) did not.

Data from insurance claims reinforce these findings. The largest crash reductions for vehicles with ESC are among the more severe single-vehicle crashes. Thus, it was expected that collision claim losses, because they cover damage to an at-fault driver's own vehicle, would be somewhat reduced. In fact, the main benefit was to lower the average amount of insurance payments per claim by substantially reducing the most expensive claims. Property damage liability, which covers damage to other peoples' vehicles in crashes, which by definition involve more than one vehicle, saw little change.

While there is strong evidence that ESC systems are highly effective as a whole, no research has addressed whether there are variations in the effectiveness of the different systems available in the marketplace. There are well-known variations in the ways ESC systems are programmed and the ways in which they respond once loss of control is detected, with some vehicles intervening sooner to maintain vehicle control. However, it is uncertain whether these differences have resulted in variations in effectiveness.

One question sometimes raised is why ESC is so effective in reducing crashes when the predecessor technology, antilock brakes, was not. It has been suggested that many car owners may not know how to use antilock brakes effectively and in a survey of drivers with antilock-equipped cars, between 40 and 50% of respondents incorrectly thought they should pump the brakes (Williams & Wells, 1994). Another idea posited is that some motorists may drive more riskily because they perceive that antilock brakes allow them to brake better. However, one major difference between these technologies is reliance on the driver. To improve braking performance with antilock brakes the driver has to apply them in the correct manner. With ESC, once the vehicle sensors detect a loss of control, the ESC system quickly and automatically applies brake pressure to bring the vehicle back in line. The driver is required to do nothing more than steer the vehicle in the desired direction. A lack of reliance on the driver to do the right thing in an emergency likely is a key factor in the demonstrated effectiveness.

It has been suggested that features that provide direct and immediate feedback to drivers, such as braking or acceleration capabilities, can change the driving task with the result that some motorists may change their behavior (Hedlund, 2000; O'Neill & Williams, 1998). This raises the possibility that improved handling of vehicles with ESC could lead to risk compensation, thus reducing the potential benefits. Certainly there is no current evidence that this is the case given the dramatic benefits seen so far in certain crash types. Studies have yet to address the longer term benefits, thus continued evaluation of ESC as the vehicle fleet ages would help address this issue.

In recent years, ESC has become a more common feature on vehicles in the United States and around the world. In April 2007, the U.S. Department of Transportation announced plans to require ESC on all passenger vehicles sold in the United States by the 2012 model year. NHTSA estimated that 29% of the 2006 model vehicles sold in the United States already were equipped with ESC. However, some markets clearly lag behind in their adoption of this life-saving technology. Given the extraordinary benefits of ESC in preventing crashes, more should be done to accelerate the implementation of ESC in the full range of vehicles in both developed and developing markets.

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