Effects of Antilock Braking Systems on Motorcycle Fatal Crash Rates: An Update

May 2013

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ABSTRACT

Objective: Antilock braking systems (ABS) prevent wheels from locking during hard braking and may reduce motorcycle drivers' reluctance to apply full braking force. Prior research found that ABS reduced motorcycle fatal crash rates during 2003-08 by 37 percent with 95 percent confidence interval (9 percent, 58 percent). The objective of the current study was to provide an updated examination of the effects of ABS on fatal motorcycle crash rates.

Methods: Motorcycle drivers involved in fatal crashes per 10,000 registered vehicle years during 2003-11 were examined for 13 motorcycle models offering optional ABS. Fatal crash rates for motorcycles with ABS were compared to rates for the same models without ABS.

Results: ABS was associated with a 31 percent reduction in the rate of fatal motorcycle crashes per 10,000 registered vehicle years. The 95 percent confidence interval for this effectiveness estimate was (9 percent, 48 percent). Both the updated estimate and its confidence interval were within the confidence interval of the 2003-08 estimate due largely to the precision afforded by larger sample size.

Conclusions: Further evidence shows that ABS is highly effective in preventing fatal motorcycle crashes.

Keywords: Motorcycle ABS, Fatal motorcycle crashes, Crash avoidance technologies, Antilock brakes, Motorcycle crashes

INTRODUCTION

Improper braking is a major factor in motorcycle crashes. Improper braking, particularly overbraking and resulting loss of control, was identified as a major pre-crash factor in a 1981 in-depth study of the causes of motorcycle crashes (Hurt et al., 1981) and again, 20 years later, in the Motorcycle Accident In-Depth Study (MAIDS; Association of European Motorcycle Manufacturers, 2004). Braked motorcycles lost stability in 43 percent of the crashes studied by Roll et al. (2009).

Operating the brakes on most motorcycles is much more complicated than on four-wheel vehicles. Most motorcycles have separate controls for the front and rear brakes, with the front brake usually controlled by a lever on the right handlebar and the rear brake controlled by a pedal operated by the rider's right foot. During braking, a rider must decide how much force to apply to each control. As with other types of vehicles, much more deceleration can be obtained from braking the front wheel than from braking the rear wheel.

Motorcycles are inherently less stable than four-wheel vehicles and rely on riders' skills to remain upright during demanding maneuvers such as hard braking. Braking too hard and locking a wheel creates an unstable situation. Locking the front wheel is particularly dangerous, with falling down being almost certain. A locked rear wheel is more controllable, but still can lead to loss of control with a concurrent steering input, as in an emergency avoidance maneuver. In such situations, riders concerned about wheel lock may be reluctant to apply full force to the brakes, particularly the front brake, resulting in braking that is not adequate to avoid or mitigate impact. Both the Hurt et al. (1981) and MAIDS (Association of European Motorcycle Manufacturers, 2004) studies had examples of crashes due to either loss of control due to wheel lock or failure to adequately brake.

To address the issue of underbraking (especially of the front wheel), manufacturers have developed braking systems that essentially link the actions of the front and rear brake controls. These systems, referred to collectively as combined braking systems (CBS), apply braking force to both wheels when either control is engaged. The degree to which braking force is applied to the front wheel, for example, when the pedal for the rear brake is depressed varies by system, but the concept is the same. CBS has been shown to reduce stopping distances of experienced riders on closed test tracks (Green,

2006) and would be expected to be beneficial in situations in which a rider underbrakes or does not brake the front wheel. With CBS, however, it is still possible to lock a wheel during hard braking.

Antilock braking systems (ABS) have been adapted and tuned for motorcycles to help riders solve this dilemma. Like ABS systems on other types of vehicles, motorcycle ABS systems monitor wheel speed and reduce brake pressure if imminent wheel lock is detected. Brake pressure is then increased, and the system evaluates and adjusts brake pressure many times per second if necessary. These systems allow riders to apply brakes fully in an emergency without fear of wheel lock. ABS and CBS are not necessarily related; either or both can be implemented on a motorcycle.

ABS has shown strong benefits for motorcyclists. Studies conducted on closed test tracks have demonstrated that ABS improves braking performance of both novice and experienced riders (Vavryn and Winkelbauer, 2004) and in a variety of situations (Green, 2006). In the Vavryn and Winkelbauer study, both novice and experienced motorcyclists achieved higher average braking decelerations with an ABS-equipped motorcycle than with a non-ABS motorcycle. The Green study found that stopping distances tended to be shorter for ABS-equipped motorcycles in most test conditions, and typically fewer trials were required to achieve the best result with ABS compared to without. Importantly, Green noted that riders without substantial experience or skill were able to achieve high levels of performance using motorcycles equipped with ABS.

Other studies evaluated the potential for ABS to prevent real-world crashes. Crash reconstructions for a small sample of serious motorcycle crashes identified from insurance liability claims were used to determine how certain crashes could have been affected by ABS (Gwehenberger et al., 2006). About half of the crashes were deemed to be relevant to ABS, and the majority of those involved another vehicle violating the motorcyclist's right-of-way. It was estimated that between 17 and 38 percent of the crashes deemed to have been ABS-relevant could have been avoided had the motorcycles been equipped with ABS. No results were provided on how ABS might have affected the severities of the crashes that were deemed inevitable. Two more studies employing similar methods estimated that ABS has the potential to prevent 38 to 50 percent of serious motorcycle crashes (Rizzi et al., 2009; Roll et al., 2009).

The effects of ABS on insurance claim rates were evaluated in two studies by the Highway Loss Data Institute (HLDI, 2009, 2013). HLDI studied collision coverage, which pays for damage to one's own vehicle when no one else is at fault; medical payment coverage, which pays medical expenses to the insured rider; and bodily injury liability coverage, which pays medical costs to others when the insured rider is at fault. The most recent results for ABS effectiveness included a 20 percent reduction in collision claim rate per insured vehicle year, a 28 percent reduction in medical payment claim rate, and a 22 percent reduction in bodily injury liability claim rate. All of these estimates were statistically significant and controlled for vehicle make, model, garaging state, and age; rated driver age, gender, and marital status; insurance risk group and deductible; registered vehicle density; and calendar year (HLDI, 2013). These results were similar to those of HLDI (2009). HLDI also compared motorcycles with ABS and CBS as a bundled option with those same models without either technology and found a 31 percent reduction in collision claim rate. This suggests a benefit of CBS beyond that of ABS, but the comparison was based on a relatively small sample of motorcycles.

In another study, HLDI found that ABS was more effective during the first three months of collision insurance policies (HLDI, 2012). New policies represent a number of possible scenarios - for example, a person who is new to motorcycling, an experienced rider who buys a new motorcycle, or a rider who changes insurance company. During the first 90 days of policies, motorcycles with ABS were 30 percent less likely to file a collision claim than the non-ABS versions of the same motorcycles. For policies in effect 91-720 days, ABS motorcycles were 19 percent less likely to file collision claims than the non-ABS versions.

A 2011 study found that ABS reduces motorcycle fatal crash rate per registrations by a statistically significant 37 percent (Teoh, 2011). The study included fatal crashes occurring during 2003-08 and involving motorcycle models with optional ABS. The fatal crash rate for motorcycles with ABS was compared to the rate for the same models without ABS. To examine the possibility of selection bias that would exist if people choosing optional ABS behave differently than those who do not elect to purchase ABS, the study compared the presence of various driver and crash factors among the ABS and non-ABS cohorts. For instance, if people with safer riding habits are more likely to buy ABS, it is plausible that they may have lower rates of speeding and alcohol use, and lower rates of helmet use. No substantial or statistically significant differences were observed.

In an effort to account for potential confounding factors, the National Highway Traffic Safety Administration (NHTSA, 2010) conducted a study of motorcycle ABS effectiveness using an alternative approach. This involved defining a group of crashes likely affected by ABS and a comparison group comprised of crash types deemed not relevant to ABS to serve as an alternative measure of exposure. The study found no statistically significant effects of ABS on motorcycle crash risk. However, as acknowledged by the authors, a drawback to this method is that it is difficult to identify types of crashes for which ABS would not be relevant. Additionally, this method does not necessarily account entirely for selection bias, as behavioral differences between the ABS and non-ABS groups of drivers could result in differing distributions of crash type.

The purpose of the current study was to update Teoh (2011) with the most recent data.

METHODS

Data on fatal motorcycle crashes were extracted from the Fatality Analysis Reporting System (FARS), a national census of fatal crashes on public roads that is maintained by NHTSA. Exposure data consisted of national motorcycle registration records obtained from R. L. Polk and Company. Each record in both databases was indexed by its vehicle identification number (VIN), and the first 10 digits were used to determine make, model, and model year. ABS availability and motorcycle type were determined from a vehicle information database maintained by HLDI. Motorcycles with invalid/missing VINs were excluded.

To be included in the study, a motorcycle model was required to have ABS as an option, and the presence of that option must have been discernible by the presence of an ABS indicator in the VIN or equivalently from the model name (e.g., Honda Gold Wing vs. Honda Gold Wing ABS). This eliminated bias due to comparison of different makes or, especially, styles of motorcycles, the driver death rates of which have been shown to vary widely (Teoh and Campbell, 2010). The final study population (Table 1) included 13 make/model motorcycles, each with both ABS and non-ABS versions. Some motorcycles were excluded due to zero registrations of the ABS versions during the study period or no involvements in fatal crashes for both the ABS and non-ABS versions. For each motorcycle model, model years included in the study were identical for ABS and non-ABS versions.

Among the motorcycles included in Table 1, all of the Hondas and the Suzuki Burgman 650 (both ABS and non-ABS) were equipped with standard CBS; CBS was not available on any of the other motorcycles. Similar to the HLDI (2013) study, an attempt was made to study the effect of ABS and CBS combined relative to the presence of neither. The analysis was repeated for additional motorcycles with ABS and CBS as a bundled option (for these models, the comparison was ABS and CBS versus conventional brakes). However, the sample of such motorcycles was too small to produce a meaningful rate ratio estimate and results of this analysis were not presented.

Data were analyzed for fatal crashes and registrations occurring during 2003-11. Fatal crash rates per 10,000 registered vehicle years for each motorcycle model, both ABS and non-ABS versions, were calculated. If ABS does not affect the risk of fatal motorcycle crashes, then fatal crash rates per registered vehicle years for each motorcycle model should not vary by whether or not it has ABS. Under this assumption, an expected count of drivers involved in fatal crashes was computed for each ABS motorcycle model as the product of the fatal crash rate per registered vehicle year for the non-ABS version and the number of registered vehicle years of the ABS version. A rate ratio estimating the effect of ABS was calculated as the sum of the observed number of drivers in fatal crashes for ABS motorcycles (O) divided by the sum of their expected number of drivers in fatal crashes (E). This is also known as the standardized mortality ratio. It standardizes the exposure distributions of the two study groups to limit possible confounding due to some motorcycles being more likely to have ABS than others. Using formulas derived by Silcocks (1994), a 95 percent confidence interval for the rate ratio was computed as (L, U), where:

$$L = \beta_{0.025}(O, E+1) / [1 - \beta_{0.025}(O, E+1)]$$

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

where $\beta_p(a,b)$ is the $100 \times p^{th}$ percentile from the beta distribution with parameters a and b.

In addition to the main analysis, information was extracted from FARS describing driver age, speeding behavior, blood alcohol concentration (BAC), and helmet use; number of involved vehicles; and crash location (rural vs. urban) for ABS and non-ABS cohorts. Missing BAC values were accounted for using multiple imputation results available in FARS. Speeding was coded if the motorcycle driver was cited for speeding or if contributing driver factors indicated that the motorcycle was exceeding the posted limit or travelling too fast for conditions. Helmet law type (universal coverage, partial coverage in which only some riders (usually those below a certain age) must wear helmets, and no law) was coded for the state in which a crash occurred and varied over time in states with changes in laws.

RESULTS

Table 2 presents fatal crash involvements, registered vehicle years, and the fatal crash rate per 10,000 registered vehicle years for the study motorcycles during 2003-11. Honda motorcycles, especially the Gold Wing model, dominated the sample, but there was a lower fatal crash rate for the ABS version for all but three of the motorcycle models. Overall, the fatal crash rate per 10,000 registered vehicle years was 3.8 for the ABS motorcycles, compared with 5.2 for the same motorcycles not equipped with ABS.

The rate ratio estimate for ABS versions of study motorcycles relative to non-ABS versions of the same motorcycles was 0.690 with an associated 95 percent confidence interval (0.519, 0.913). The rate ratio estimate corresponds to a statistically significant 31 percent estimated reduction (computed as (RR-1)x100%) in the fatal crash rate per 10,000 registered vehicle years for the ABS versions compared to the non-ABS versions.

Influences on the observed rate ratio of known risk factors for fatal motorcycle crashes were investigated by comparing the distributions of these factors among ABS motorcycles and non-ABS motorcycles included in the study, as summarized in Table 3. The average driver age for non-ABS motorcycles involved in fatal crashes was 53, compared to 54 for ABS motorcycles. Drivers of non-ABS motorcycles were slightly more likely to have been cited for speeding or to have blood alcohol concentrations of 0.08 g/dL or higher. The non-ABS fatal crash involvements also were slightly more likely to occur in states with helmet laws, both universal and partial, and to involve only the motorcycle. However, taken as a whole, these results do not show any substantial difference between the two groups of study motorcycles. None of the differences in risk factors presented in Table 3 was statistically significant at the 0.05 level.

The fleet of study motorcycles was compared to all motorcycles in the United States with optional ABS, including those that were not VIN-discernible, and to the entire U.S. motorcycle fleet in Table 4. Based on the driver death rate variation observed in Teoh and Campbell (2010), motorcycle type was chosen as the basis for comparison among these three groups of motorcycles. Even more so than in Teoh (2011), the motorcycle type distribution of the study motorcycles approximated that of all motorcycles with optional ABS. While ABS generally is starting to be offered on a greater variety of motorcycles, cruisers still lag behind in terms of having an ABS option, compared with the entire U.S. fleet.

DISCUSSION

The results of the current study indicate that ABS is highly effective in reducing motorcyclists' fatal crash rates. The fatal crash rate was 31 percent lower for ABS-equipped motorcycles than for the same models without ABS. Results of this analysis are similar to those of Teoh (2011) and indicate that ABS is proving to be effective as ABS begins to be offered on an increasing number of make/models. The evidence of ABS effectiveness from the current study is bolstered by a similar type of analysis of insurance claims that found statistically significant reductions in claim rates for collision, medical payment, and bodily injury liability coverages while controlling for possibly confounding factors. The results of these studies provide confirmatory evidence of the benefit of ABS expected from engineering principles, test track trials, and crash reconstruction analyses. The robustness of the results reported in the prior and current studies of fatal crashes and the studies of insurance claim rates point to real safety benefits of ABS.

However, this study is not free of limitations. ABS was studied as optional equipment, so the cohort of motorcyclists who choose ABS may differ in some substantive way from those who decline to purchase it. In particular, motorcyclists who choose ABS may be more concerned about safety than those who decline, thus leading to lower fatal crash rates through other safer riding practices. Investigation of known risk factors did not reveal evidence of such a selection bias. However, levels of these factors were not known for riders who were not involved in fatal crashes. Therefore, it was not possible to accurately quantify how such factors influenced the observed reduction in fatal crash rate for ABS motorcycles. It is also possible, however, that riders who choose to invest in ABS ride more miles than those who decline, which would result in an upward bias in the fatal crash rate per registered vehicle year for the ABS cohort relative to the non-ABS cohort. As purported to occur in passenger vehicles (Grant and Smiley, 1993; Winston et al., 2006), motorcyclists may tend to drive ABS-equipped motorcycles more aggressively than non-ABS motorcycles, also resulting in a higher than expected crash rate for the ABS cohort, and thus underestimating the effectiveness of ABS. Without more extensive data, it was not possible to estimate the magnitude or direction of any bias in the estimated rate ratio comparing crash rates for ABS and non-ABS motorcycles. NHTSA (2010) used an alternative approach to deal with some possible sources of bias, but that method relied on defining a sample of crash types unrelated to ABS. Police crash report data lack sufficient detail to reliably determine whether most crash types would be relevant to ABS, so the lack of a statistically significant result in that study does not refute other research.

As in Teoh (2011), the current study included virtually all motorcycles with optional ABS in which the presence of the option could be identified from the VIN. Although this represented several different types of motorcycles, it does not constitute a random sample of all motorcycles in terms of design parameters such as intended use, power, or weight. The effectiveness of ABS may vary by motorcycle type, particularly with respect to vehicle dynamics during hard braking (e.g., the likelihood of lifting the rear wheel or even toppling) and on riders' driving habits. However, there is little reason to believe that ABS would not be beneficial to types of motorcycles that could not be included in these studies. This cannot be evaluated until ABS is available on a broader variety of motorcycles. An alternative, and in some ways stronger, study design would be to compare motorcycle models before and after ABS became standard equipment. This was not possible for models existing during 2003-11, but likely will be an avenue of future research as more manufacturers offer models with standard ABS. BMW made ABS standard equipment on its motorcycle fleet beginning in the 2012 model year.

ABS cannot be expected to prevent or mitigate all crashes, as demonstrated by Gwehenberger et al. (2006) and Rizzi et al. (2009). For example, ABS would not affect the likelihood or severity of a crash involving a motorcycle struck from behind by another vehicle. There are other examples of crashes in which motorcycle ABS would not be relevant, but it is difficult to categorize them by crash type. The small sample of ABS motorcycles and the lack of detailed information on pre-crash events in FARS precluded examination of the effects of ABS on crashes that would or would not likely have been influenced by its presence.

ACKNOWLEDGEMENTS

This work was supported by the Insurance Institute for Highway Safety.

REFERENCES

Association of European Motorcycle Manufacturers. MAIDS In-depth investigations of accidents involving powered two wheelers. Final report 1.2. Brussels, Belgium: Association of European Motorcycle Manufacturers; 2004.

Grant B, Smiley A. Driver response to antilock brakes: a demonstration of behavioral adaptation. *Proceedings of the Canadian Multidisciplinary Road Safety Conference VIII*, pp. 211-220. Ottawa, Ontario: Transport Canada; 1993.

Green D. A comparison of stopping distance performance for motorcycles equipped with ABS, CBS, and conventional hydraulic brake systems. Paper presented at the 2006 International Motorcycle Safety Conference, March 28-38, Long Beach, CA; 2006.

Gwehenberger J, Schwaben I, Sporner A, Kubitzki J. Schwerstunfälle mit Motorrädern - Analyse der Unfallstruktur und der Wirksamkeit von ABS. VKU Verkehrsunfall und Fahrzeugtechnik, Issue 1. Springer Automotive Media/GWV Fachverlage GmbH; 2006.

Highway Loss Data Institute. Motorcycle antilock braking system (ABS). Insurance special report A-81. Arlington, VA: Highway Loss Data Institute, 2009.

Highway Loss Data Institute. Evaluation of motorcycle antilock braking systems (ABS) and ABS in conjunction with combined control braking systems (CCBS). *Bulletin* 30(10). Arlington, VA: Highway Loss Data Institute; 2013.

Hurt HH, Ouellet JV, Thom DR. Motorcycle accident cause factors and identification of countermeasures; Volume 1: Technical report, Final report. Washington, DC: U.S. Department of Transportation; 1981.

National Highway Traffic Safety Administration. Motorcycle antilock braking systems and crash risk estimated from case-control comparisons. Submitted to Docket No. NHTSA-2002-11950. Washington, DC: U.S. Department of Transportation; 2010.

Rizzi M, Strandroth J, Tingvall C. The effectiveness of antilock brake systems on motorcycles in reducing real-life crashes and injuries. *Traffic Injury Prevention* 2009;10:479-87.

Roll G, Hoffmann O, König J. Effectiveness evaluation of antilock brake systems (ABS) for motorcycles in real-world accident scenarios. *Proceedings of the 21st International Technical Conference on the Enhanced Safety of Vehicles* (CD-ROM). Washington, DC: National Highway Traffic Safety Administration; 2009.

Silcocks P. Estimating confidence limits on a standardized mortality ratio when the expected number is not error free. *Journal of Epidemiology and Community Health* 1994;48:313-17.

Teoh ER. Effectiveness of antilock braking systems in reducing motorcycle fatal crash rates. *Traffic Injury Prevention* 2011;12:169-73.

Teoh ER, Campbell M. Role of motorcycle type in fatal motorcycle crashes. *Journal of Safety Research* 2010;41:507-12.

Vavryn K, Winkelbauer M. Braking performance of experienced and novice motorcycle riders: results of a field study. Paper presented at the 2004 International Conference on Transport and Traffic Psychology, Nottingham, United Kingdom; 2004.

Winston C, Maheshri V, Mannering F. An exploration of the offset hypothesis using disaggregate data; the case of airbags and antilock brakes. *Journal of Risk Uncertainty* 2006;32:83-9.

Table 1
Study motorcycles, each with ABS and non-ABS versions in these model years

Make/model	Model years
Honda Gold Wing	2001-2010
Honda Interceptor 800	2002-2009
Honda Reflex	2001-2007
Honda Silver Wing	2003-2010
Honda ST1300	2003-2010
Suzuki Bandit 1250	2007-2009
Suzuki Burgman 650	2005-2009
Suzuki SV650	2007-2009
Suzuki V-Strom 650	2007-2009
Triumph Sprint ST	2006-2010
Triumph Thunderbird	2010-2011
Triumph Tiger	2007-2010
Yamaha FJR1300	2004-2005

Table 2
Motorcycle fatal crash involvements and registered vehicle years, 2003-11

	non-ABS versions			ABS versions			
Make/model	Observed fatal crash involvements	Registered vehicle years	Rate per 10,000	Observed fatal crash involvements	Registered vehicle years	Rate per 10,000	Expected fatal crash involvements
Honda Gold Wing	254	503,466	5.0	50	128,521	3.9	64.8
Honda Interceptor 800	29	47,455	6.1	9	13,647	6.6	8.3
Honda Reflex	17	74,506	2.3	3	12,876	2.3	2.9
Honda Silver Wing	25	46,832	5.3	5	8,593	5.8	4.6
Honda ST1300	19	43,449	4.4	8	20,048	4.0	8.8
Suzuki Bandit 1250	4	7,970	5.0	1	2,262	4.4	1.1
Suzuki Burgman 650	22	38,323	5.7	4	10,393	3.8	6.0
Suzuki SV650	33	27,160	12.2	1	1,667	6.0	2.0
Suzuki V-Strom 650	10	21,068	4.7	0	3,965	0.0	1.9
Triumph Sprint ST	5	4,366	11.5	1	3,995	2.5	4.6
Triumph Thunderbird	3	911	32.9	1	639	15.6	2.1
Triumph Tiger	2	4,572	4.4	1	2,737	3.7	1.2
Yamaha FJR1300	18	21,536	8.4	3	21,316	1.4	17.8
Total	441	841,614	5.2	87	230,659	3.8	126.2

Table 3
Driver and crash factors of study motorcycles involved in fatal crashes, 2003-11

	non-ABS versions		ABS versions	
	N	%	N	%
Driver				
Age<30	37	8	4	5
Age 30-39	36	8	5	6
Age 40-49	68	15	20	23
Age 50+	300	68	58	67
speeding	111	25	15	17
BAC 0.08+ g/dL	76	17	11	13
Helmeted	334	76	65	75
Crash				
Single-vehicle	187	42	35	40
Rural location	281	64	57	66
Universal helmet law	180	41	33	38
Partial helmet law	237	54	45	52
No helmet law	24	5	9	10
Total	441		87	

Table 4
Registered vehicle years of 2002 model year and later[a] motorcycles by type, 2003-11

	Motorcycles with optional ABS included in study		All motorcycles with optional ABS		U.S. fleet	
	N	%	N	%	N	%
Cruiser/standard	11,782	1	72,488	3	14,317,340	49
Touring	561,880	57	1,210,026	54	4,720,899	16
Sport-touring	114,710	12	232,652	10	460,360	2
Sport/unclad sport	61,102	6	223,796	10	2,264,533	8
Supersport	0	0	18,777	1	3,332,302	11
Other	206,853	21	463,992	21	4,123,251	14
Total[b]	985,154		2,221,731		29,218,685	

[a]Information on non-study optional ABS motorcycles was not available from HLDI for model year 2001
[b]Does not include off-road motorcycles, all-terrain vehicles (ATVs), or snowmobiles