Effectiveness of Antilock Braking Systems in Reducing Fatal Motorcycle Crashes

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October 2008

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ABSTRACT

The effect of antilock braking systems (ABS) on motorcyclist fatal crash risk in 2005-06 was studied by comparing fatal crash rates per registrations of motorcycles with and without ABS. Study motorcycles included those for which ABS was optional equipment and could be identified as present by the model name. Fatal motorcycle crashes per 10,000 registered vehicle years were 38 percent lower for ABS models than for their non-ABS versions.

INTRODUCTION

Annual motorcyclist deaths in the United States have more than doubled, from 2,077 in 1997 to 4,697 in 2006 (Insurance Institute for Highway Safety, 2008), and motorcycle registrations have increased by about two-thirds, from 5,167,693 in 2000 (earliest year for which data are available) to 8,642,243 in 2006, according to data from R.L. Polk and Company. Many factors contribute to motorcycle crashes, but improper braking was identified as a major pre-impact factor in a study of motorcycle crash causation (Hurt et al., 1981) and again, 20 years later, in the Motorcycle Accident In-Depth Study (MAIDS) (Association of European Motorcycle Manufacturers, 2004).

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 extreme maneuvers such as hard braking. Braking too hard and locking a wheel creates an unstable situation. Locking the front wheel is particularly dangerous, with loss of control being almost certain. A locked rear wheel is more controllable but still can lead to loss of control if the rider simultaneously tries to steer the motorcycle, as in an emergency avoidance maneuver. However, in an emergency requiring full stopping power, riders concerned about wheel lock may be reluctant to apply full force to the brakes, particularly to the front brake. Both Hurt et al. (1981) and MAIDS (Association of European Motorcycle Manufacturers, 2004) had examples of both loss of control due to wheel lock and failure to adequately brake.

Although proper braking practices can be taught, rider training courses have not been shown to be effective in reducing motorcycle crashes (Mayhew and Simpson, 1996) or have provided mixed results at best (Billheimer, 1998). In an effort to address the issue of under-braking (especially the front wheel), manufacturers have developed braking systems that essentially link the front and rear brake controls. These systems, collectively referred to here 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 pressed varies by design, 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 under-brakes (or does not brake) the front wheel to avoid locking it or causing the motorcycle to pitch forward. Even with CBS, however, it still is possible to lock a wheel during hard braking, often with catastrophic consequences.

ABS has been developed to help riders solve this dilemma. The system monitors wheel speed and reduces brake pressure when impending wheel-lock is detected. Brake pressure is increased when traction is restored, and the system evaluates and adjusts brake pressure many times per second. These systems allow riders to apply brakes fully in an emergency without fear of wheel-lock. ABS was first developed for commercial aircraft in 1929 (Maslen, 2008) and was first implemented in production automobiles with the 1971 Chrysler Imperial (Douglas and Schafer, 1971). BMW was the first manufacturer to implement ABS on a motorcycle with its K100RS Special model in 1988 (Tuttle, 2001). ABS and CBS are not necessarily related; either or both can be implemented on a motorcycle.

ABS has not significantly reduced crash risk for passenger vehicles (Farmer et al., 1997; Farmer, 2001), but there is reason to expect ABS will be more helpful to motorcycles because of the instability that occurs with any wheel-lock. Studies conducted on closed test tracks have demonstrated that ABS can reduce the motorcycle stopping distances (Green, 2006; Vavryn and Winkelbauer, 2004). It is clear that reducing wheel-lock is crucial in maintaining stability during hard braking. These results suggest that ABS has the potential to reduce motorcycle crashes in real-world situations. Serious motorcycle crashes identified from insurance claims were analyzed in a small study to determine, by crash reconstruction, how certain crashes would be affected by ABS (Allianz Center for Technology, 2005). About half of the 200 crashes studied were deemed to be relevant to ABS, and the majority of those involved another vehicle violating a motorcyclist's right-of-way. Crash reconstruction analyses showed that between 8 and 17 percent of these crashes could have been avoided had the motorcycles been equipped with ABS. No results were presented on how increased stability or stopping power provided by ABS might have decreased the severities of the crashes that were deemed inevitable.

A study by the Highway Loss Data Institute (HLDI), conducted in conjunction with the present study, found that motorcycles equipped with optional ABS had 19 percent fewer insurance claims for collision damage per insured vehicle year than the same motorcycle models without ABS (Moore and Yan, in process). The goal of the present study was to evaluate the effectiveness of ABS in reducing the rate of fatal motorcycle crashes on public roads in the United States. Specifically, rates of fatal crash involvement per registered vehicle were compared for motorcycle models with and without ABS installed as optional equipment.

METHODS

Data on fatal motorcycle crashes were extracted from the Fatality Analysis Reporting System (FARS), a national census of fatal crashes occurring on public roads that is maintained by the National Highway Traffic Safety Administration. Exposure data consisted of national motorcycle registration records obtained from R.L. Polk and Company. Each vehicle record in both databases was indexed by its vehicle identification number (VIN), which encodes vehicle information, and the first 10 digits of the VINs were used to determine make, model name, and model year according to records in a motorcycle features database created and maintained by HLDI. Vehicles with missing or invalid 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 discernable directly from the model name (e.g., Honda Gold Wing vs. Honda Gold Wing ABS). This eliminated bias due to the comparison of different makes or styles of motorcycles. Although ABS has been an option on BMW models for much longer than the study period, the BMW systems cannot be identified from the model name alone. All BMW models were excluded. The final study population (Table 1) included eight make/model motorcycles, each with both ABS and non-ABS versions. Some vehicles were excluded due to zero registrations of the ABS model during the study years in the Polk records. Because none of the study vehicles with ABS were available in model year 2000 or earlier, the analysis was restricted to 2001 or later model year vehicles. Among the motorcycles included, all of the Hondas (both ABS and non-ABS) were equipped with standard CBS; CBS was not available on any of the others.

Table 1
Study motorcycles

Non-ABS motorcycles		ABS motorcycles	
Model years	Make/model	Model years	Make/model
2001-06	Honda Gold Wing	2001-06	Honda Gold Wing ABS
2001-06	Honda Interceptor 800	2002-06	Honda Interceptor 800 ABS
2001-06	Honda Reflex	2001-06	Honda Reflex ABS
2003-06	Honda ST1300	2003-06	Honda ST1300 ABS
2002-06	Honda Silver Wing	2003-06	Honda Silver Wing ABS
2003-06	Suzuki Burgman 650	2006	Suzuki Burgman 650 ABS
2001-06	Triumph Sprint ST	2006	Triumph Sprint ST ABS
2003-05	Yamaha FJR1300	2004-06	Yamaha FJR1300 ABS

At the time this study was conducted, registration data were available only for 2000 and 2005-07, and FARS data were not yet available for 2007. There were no registrations of the ABS versions of these motorcycles in 2000. Therefore, data were analyzed for years 2005-06. Fatal crash rates per 10,000 registered vehicle years for each motorcycle model, both ABS and non-ABS versions, were calculated by dividing 10,000 times the number of motorcyclist fatal crash involvements in 2005-06 by the number of motorcycles registered during these years. Because registration counts spanned 2 years, the denominator was interpreted as registered vehicle years instead of registrations.

Fatal crash rates per vehicle registrations for ABS and non-ABS motorcycle models were compared by calculating a rate ratio (RR) equal to the crash rate for ABS models divided by the crash rate for non-ABS models. If ABS has no effect, then the rate ratio should be 1.0. A rate ratio of less than 1.0 would indicate the fatal crash rate for ABS models is lower than the rate for non-ABS models. Similarly, a rate ratio greater than 1.0 would indicate the fatal crash rate for ABS models is higher than the rate for non-ABS models. One way to calculate the rate ratio is to calculate the rate for non-ABS motorcycles as total crash involvements divided by total registered vehicle years, and analogously for ABS motorcycles. However, to reduce any bias that may have occurred from relative differences in registrations among motorcycle models, an alternative rate for non-ABS motorcycles was calculated as the weighted average of fatal crash rates for each vehicle model, where the weights were taken as the number of registered vehicle years of ABS-equipped motorcycles. Thus, for any given motorcycle model the ABS and non-ABS fatal crash rates received the same weight in calculating the overall fatal crash rates for motorcycles with and without ABS.

Ninety and 95 percent confidence intervals (CIs) for the rate ratios were calculated based on standard error estimates derived by assuming that the number of fatal crash involvements follows a Poisson distribution as follows:

$$\mathrm{Var}(\ln(\mathrm{RR})) = \mathrm{Var}_{\mathrm{ABS}} + \mathrm{Var}_{\text{non-ABS}}$$

where $\mathrm{Var}_{\mathrm{ABS}} = \frac{1}{\sum_{i=1}^{8} \mathrm{X}_{i,\mathrm{ABS}}}$ and $\mathrm{Var}_{\text{non-ABS}} = \frac{\sum_{i=1}^{8} \mathrm{r}_i^2 \mathrm{X}_{i,\text{non-ABS}}}{\left(\sum_{i=1}^{8} \mathrm{r}_i \mathrm{X}_i\right)^2}$

with $\mathrm{X}_{i,\mathrm{ABS}}$ as the number of fatal crash involvements of the i^{th} model motorcycle equipped with ABS, analogously for $\mathrm{X}_{i,\text{non-ABS}}$, and r_i as the ratio of registered vehicle years of the ABS model to registered vehicle years of the non-ABS model for model *i*.

lower 95% confidence limit $= \exp[\ln(\mathrm{RR}) - 1.96(\mathrm{Var}(\ln(\mathrm{RR})))^{1/2}]$

upper 95% confidence limit $= \exp[\ln(\mathrm{RR}) + 1.96(\mathrm{Var}(\ln(\mathrm{RR})))^{1/2}]$

RESULTS

Table 2 presents fatal crash involvements, registered vehicle years, and the rate of fatal crash involvements per 10,000 registered vehicle years for the study motorcycles during 2005-06. Motorcycles manufactured by Honda, particularly the Gold Wing model, dominated the sample, but the pattern for all but two of the motorcycles was a lower fatal crash rate for ABS-equipped motorcycles. Across all ABS-equipped motorcycles, the rate of fatal crash involvements per 10,000 registered vehicle years was 4.1, compared with 6.7 for the same motorcycles not equipped with ABS.

Table 2
Motorcycle fatal crash involvements and registered vehicle years, 2005-06

	Non-ABS models			ABS models		
	Fatal crash involvements	Registered vehicle years	Rate (x 10^4)	Fatal crash involvements	Registered vehicle years	Rate (x 10^4)
Honda Gold Wing	63	93,608	6.7	6	19,547	3.1
Honda Interceptor 800	8	10,437	7.7	3	2,307	13.0
Honda Reflex	6	14,858	4.0	1	2,644	3.8
Honda ST1300	2	7,003	2.9	2	3,580	5.6
Honda Silver Wing	11	12,273	9.0	1	1,278	7.8
Suzuki Burgman 650	8	9,618	8.3	0	309	0.0
Triumph Sprint ST	1	4,476	2.2	0	135	0.0
Yamaha FJR1300	8	8,734	9.2	2	6,486	3.1
Total	107	161,007	6.7*	15	36,286	4.1

*Overall non-ABS rate is weighted by registered vehicle years of ABS-equipped motorcycles.

The effect of ABS on fatal crash involvement is given by the rate ratio estimate for ABS-equipped motorcycles against non-ABS motorcycles. This estimate and associated 90 and 95 percent confidence intervals are provided in Table 3. The rate ratio estimate corresponds to an approximate 38 percent reduction (computed as (RR-1)×100%) in the rate of fatal crash involvements per 10,000 registered vehicle years for the ABS models over the (weighted) non-ABS models.

Table 3
Estimated rate ratios and confidence intervals for those estimates for comparing ABS and non-ABS fatal crash rates

Rate ratio	0.615
95% confidence interval	(0.352, 1.074)
90% confidence interval	(0.385, 0.982)

DISCUSSION

Results of this analysis provide evidence that ABS is effective in reducing fatal motorcycle crashes. Study motorcycles with ABS had a fatal crash involvement rate 38 percent lower than that for their non-ABS versions during the study years.

Although the estimated effect of 38 percent is large, it is not statistically significant at the customary 0.05 level. ABS is a relatively recent option on motorcycles, and the option was purchased on only 18 percent of registered study vehicles during 2005-06. More data are required to obtain a more precise estimate of ABS effectiveness in reducing fatal motorcycle crashes. However, as the estimate becomes more precise, it is quite likely that it will continue to indicate a benefit of ABS. If there were no effect of ABS on fatal crash involvement, an estimate as large as the 38 percent reduction in this study would be expected to occur by chance less than 10 percent of the time. Thus, there is considerable confidence that ABS is preventing fatal crashes among motorcyclists. This confidence is bolstered by the fact that a separate analysis of insurance collision coverage losses among crashes of all severities also shows a reduction in crashes of about 19 percent for motorcycles equipped with ABS (Moore and Yan, 2008). These results provide confirmatory evidence of the expected benefit of ABS from engineering principles, test-track trials, and a crash reconstruction analysis.

The substantial effectiveness estimate observed in this study is not, however, without limitations. ABS was studied as optional equipment, so the cohort of motorcyclists who choose to purchase ABS may differ 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 due to safer riding practices. Because of the small sample of ABS-equipped motorcycles, it was not possible to carefully examine how rider factors such as helmet use and speeding differ between the two groups. For example, 78 percent of the non-ABS riders were helmeted, compared with 60 percent (9 of 15) of the ABS riders. Also, the prevalence of these factors is not known for riders of study motorcycles that were not involved in fatal crashes. Therefore, it was not possible to study how such factors influenced the observed reduction in fatal crash rate for ABS-equipped motorcycles. Aside from differences in rider factors, it is also possible that riders who choose ABS accumulate more miles than those who decline, which would result in an upward bias in the fatal crash rate for the ABS cohort relative to the non-ABS cohort. As may have occurred in passenger vehicles (Grant and Smiley, 1993), motorcyclists may tend to drive ABS motorcycles more aggressively than non-ABS motorcycles, also resulting in a higher than expected crash rate for the ABS group. Without more extensive data, it is not possible to know the magnitude or nature of any bias of the estimated rate ratio comparing crash rates for ABS and non-ABS motorcycles.

With or without ABS, CBS also may reduce the likelihood of certain types of crashes. However, due to the small sample of non-CBS motorcycles in this study, the effect of CBS could not be evaluated. Still, CBS is not expected to bias the results because the braking systems of the ABS and non-ABS motorcycles differed only by whether or not they were equipped with ABS. In other words, each ABS/non-ABS pair either did or did not have CBS. ABS showed a benefit in both the CBS and non-CBS groups, suggesting the presence of CBS on some of the motorcycles did not confound the observed effect of ABS.

ABS cannot be expected to prevent or mitigate all types of crashes, as demonstrated in the Allianz Center for Technology (2005) study. For example, ABS would not affect the outcome or likelihood of a crash involving a motorcycle struck from behind. The small sample of ABS motorcycles in FARS and the lack of detailed information on precrash events in FARS precluded examination of the effects of ABS on crashes that would likely be influenced by its presence.

ACKNOWLEDGMENTS

Motorcycle VINs were decoded by Marvin Campbell of the Highway Loss Data Institute, which also maintains the database used to decode these VINs. Adrian Lund, Anne McCartt, and Charles Farmer of the Insurance Institute for Highway Safety contributed helpful comments and suggestions. This work was supported by the Insurance Institute for Highway Safety.

REFERENCES

Allianz Center for Technology. (2005) AZT Accident Research on Effectiveness of ABS in Motorbikes. *Presented at 2005 RCAR Conference*,

Association of European Motorcycle Manufacturers. 2004. MAIDS in-depth investigations of accidents involving powered two wheelers. Final Report 1.2. Brussels, Belgium

Billheimer, J.W. 1998. Evaluation of the California motorcyclist safety program. *Transportation Research Record* 1640:100-09.

Douglas, J. and Schafer, T. 1971. The Chrysler 'Sure-Brake:' The first production four-wheel anti-skid system. SAE Technical Paper Series 710248. Warrendale, PA: Society of Automotive Engineers.

Farmer, C.M. 2001. New evidence concerning fatal crashes of passenger vehicles before and after adding antilock braking systems. *Accident Analysis and Prevention* 33:361-69.

Farmer, C.M.; Lund, A.K.; Trempel, R.E.; and Braver, E.R. 1997. Fatal crashes of passenger vehicles before and after adding antilock braking systems. *Accident Analysis and Prevention* 29:745-57.

Grant, B. and Smiley, A. 1993. Driver response to antilock brakes: a demonstration of behavioural adaptation. *Proceedings of the Canadian Multidisciplinary Road Safety Conference VIII*. Ottawa, Ontario: Transport Canada.

Green, D. 2006. A comparison of stopping distance performance for motorcycles equipped with ABS, CBS and conventional hydraulic brake systems. *Presented at the 2006 International Motorcycle Safety Conference*, Long Beach, CA.

Hurt, H.H.; Ouellet, J.V.; and Thom, D.R. 1981. Motorcycle accident cause factors and identification of countermeasures; Volume 1: technical report. Report no DOT HS-805-862. Washington, DC: National Highway Traffic Safety Administration.

Insurance Institute for Highway Safety. 2008. Fatality facts, 2006: motorcycles. Arlington, VA. Available: http://www.iihs.org/research/fatality_facts_2006/motorcycles.html. Accessed: July 21, 2008.

Maslen, J. (Spring 2008) ABS: 30 years of life saving. *Roadsafe Magazine*. Available: http://www.roadsafe.com/magazine/2008spring/abs.htm. Accessed: July 23, 2008.

Mayhew, D.R. and Simpson, H.M. 1996. Effectiveness and role of driver education and training in a graduated licensing system. Ottawa, Ontario: Traffic Injury Research Foundation.

Moore, M. and Yan, Y. In process. Antilock braking systems for motorcycles and insurance collision losses. Arlington, VA: Highway Loss Data Institute.

Tuttle, M. 2001. One track mind. *Rider Magazine* July;28(7), p. 8.

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