Effectiveness of Motorcycle Antilock Braking Systems (ABS) in Reducing Crashes, the First Cross-National Study

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Objectives: This study set out to evaluate the effectiveness of motorcycle antilock braking systems (ABS) in reducing real-life crashes.

Since the European Parliament has voted on legislation making ABS mandatory on all new motorcycles over 125 cc from 2016, the fitment rate in Europe is likely to increase in the coming years. Though previous research has focused on mostly large displacement motorcycles, this study used police reports from Spain (2006–2009), Italy (2009), and Sweden (2003–2012) in order to analyze a wide range of motorcycles, including scooters, and compare countries with different motorcycling habits.

Methods: The statistical analysis used odds ratio calculations with an induced exposure approach. Previous research found that head-on crashes were the least ABS-affected crash type and was therefore used as the nonsensitive crash type for ABS in these calculations. The same motorcycle models, with and without ABS, were compared and the calculations were carried out for each country separately. Crashes involving only scooters were further analyzed.

Results: The effectiveness of motorcycle ABS in reducing injury crashes ranged from 24% (95% confidence interval [CI], 12–36) in Italy to 29% (95% CI, 20–38) in Spain, and 34% (95% CI, 16–52) in Sweden. The reductions in severe and fatal crashes were even greater, at 34% (95% CI, 24–44) in Spain and 42% (95% CI, 23–61) in Sweden.

The overall reductions of crashes involving ABS-equipped scooters (at least 250 cc) were 27% (95% CI, 12–42) in Italy and 22% (95% CI, 2–42) in Spain. ABS on scooters with at least a 250 cc engine reduced severe and fatal crashes by 31% (95% CI, 12–50), based on Spanish data alone.

Conclusions: At this stage, there is more than sufficient scientific-based evidence to support the implementation of ABS on all motorcycles, even light ones. Further research should aim at understanding the injury mitigating effects of motorcycle ABS, possibly in combination with combined braking systems.

Keywords: ABS, antilock, crash, injury, motorcycle, PTW

Introduction

Previous research has shown that the average fatality rate per vehicle kilometer on motorcycles is considerably higher than fatality rates involving any other types of vehicles (Jung et al. 2013). In addition, the risk of being killed or severely injured when involved in an injury crash has been approximately the same since the 1980s for motorcycle riders, whereas crashworthiness improvements have reduced the risk for car occupants by more than 50% (Rizzi et al. 2009). Consequently, there is a need for interventions aimed at reducing crash risk and severity in order to reduce injury risks for motorcyclists.

Analysis of in-depth studies (Hurt et al. 1981; MAIDS 2004) has shown that motorcycle riders braked prior to collision in 49%–56% of all investigated crashes. In crashes between motorcycles and passenger cars, motorcyclists were reported to brake in 65%–75% of cases (Rizzi et al. 2009; Sporner et al. 2003). Hence, enhanced stability during braking could have great potential in reducing motorcycle crashes and injuries.

Motorcycle anti-lock braking systems (ABS) were introduced in the late 1980s in order to improve stability by maintaining wheel rotation under hard braking. At the moment, no mopeds are fitted with ABS, although it is more and more common on scooters; that is, light motorcycles mostly designed for urban commuting. Furthermore, ABS on motorcycles is increasingly integrated with combined braking systems (CBS), which essentially link the front and rear brakes (Highway Loss Data Institute [HLDI] 2013). This system applies braking force to both wheels when either control is engaged.
CBS has been shown to reduce the stopping distances of experienced motorcycle riders (Green 2006). Though there are a variety of technologies on the market (Teoh 2013), wheel lock-up is not prevented with CBS alone.

Several studies based on real-life data have reported the benefits of motorcycle ABS (HLDI 2013; Rizzi et al. 2009; Teoh 2013). In 2013, the HLDI used regression analysis to quantify the effects of ABS on insurance losses in the United States during 2003–2012. The study estimated a statistically significant 31% reduction in collision claim frequency for motorcycles with ABS together with CBS. Because ABS alone was associated with a 20% reduction in collision claims, this suggests that CBS could provide an additional benefit.

During the last few years, actions have been taken by many stakeholders in order to increase the fitment rate of motorcycle ABS (Swedish Transport Administration [STA] 2012). According to the Swedish Moped and Motorcycle Industry Federation (2013), the fitment rate among new motorcycles in Sweden increased from approximately 15% in 2008 to 70% in 2012. Furthermore, according to the Bosch Corporation (2013), the fitment rate of ABS among motorcycles with at least a 250 cc engine increased in Europe from 27% in 2007 to 36% in 2010. Since the European Parliament has voted on legislation to make ABS mandatory on all new motorcycles over 125 cc from 2016, the fitment rate in Europe will increase in the coming years.

Until the early 2000s, motorcycle ABS was mostly fitted on up-market models, similar to electronic stability control (ESC) on passenger cars (Lie et al. 2006). Though Teoh (2013) and the HLDI (2013) did include some light motorcycles in their studies, previous research on real-life crashes in Europe mainly focused on large displacement motorcycles, which are often used for leisure riding. The effectiveness of ABS on scooters needs to be further investigated, because these light powered 2-wheelers (PTWs) are mostly used for urban commuting, in congested road environments with less favorable road and weather conditions.

Though scooters accounted for 12% of all new registered motorcycles in Sweden in 2012 (Swedish Moped and Motorcycle Industry Federation 2013), they were represented in the 10 most sold motorcycle models in Italy and Spain during the same period (European Association of Motorcycle Manufacturers 2013). It would be useful, therefore, to expand the evaluation of ABS with crash data from southern European countries with larger motorcycle fleets—in 2012, 6.4 million motorcycles were registered in Italy, 2.8 million in Spain, and only 0.3 million in Sweden (European Association of Motorcycle Manufacturers 2013). Crash rates also differ across these countries, suggesting possible exposure differences. In 2008, for instance, motorcyclists accounted for 29%, 22%, and 16% of all road fatalities in Italy, Spain, and Sweden, respectively, but 35%, 31%, and 23%, respectively, in urban areas (Road Safety Data, Collection, Transfer and Analysis [DaCoTA] 2012). Furthermore, in 2009, 63% of all motorcycle fatalities occurred during the May–September period in Italy, 52% in Spain, and 83% in Sweden (DaCoTA 2012), suggesting different motorcycling habits across these countries.

The objectives of the present study were to
- estimate the effectiveness of ABS in reducing real-life crashes involving a wide range of motorcycle models, including scooters and
- compare the effectiveness of motorcycle ABS between Sweden and 2 other countries, Italy and Spain, that may have dissimilarities in vehicle fleets characteristics, different motorcycling habits, and different road environments.

### Material

The present study used national police records from Italy, Spain, and Sweden. In these 3 countries, crashes on public roads causing at least one injured person are recorded by the police. However, there are some coding differences that are briefly described below. Only crashes involving at least one injured motorcyclist were included.

### Italy

In Italy, the national road crash database is managed by the Italian Institute of Statistics. Crashes included in the national database must have occurred on the public road network and involved at least one injured person. However, it is not possible to distinguish between slightly and severely injured riders. The crash type classification includes the following main categories:
- Frontal collisions
- Side-frontal collisions
- Side collisions
- Rear-end collisions
- Single-vehicle
- Collisions with a pedestrian
- Collisions with a train

### Spain

The Spanish national road crash database is managed by the General Directorate of Transport. Crashes occurring on public roads causing at least one injured are recorded by the police. The crash type classification in Spain is similar to the Italian one. However, 4 injury levels are used, fatal, serious, slight, and uninjured, as assessed by the police.

### Sweden

The Swedish Transport Accident Data Acquisition is managed by the Swedish Transport Agency and includes police records that can be merged with hospital data. In Sweden, crashes on public roads causing at least one injured person are recorded by the police. Four injury levels (fatal, serious, slight, and uninjured) are also assigned by the officer attending the crash scene. The crash type definition normally describes the precrash direction of travel of the vehicles rather than the direction of impact force (i.e., a head-on crash can involve a frontal-side impact).
The standard deviation of the effectiveness was calculated on the basis of a simplified odds ratio variance; see below (Evans 1998; Lie et al. 2006; Strandroth et al. 2012). This method gives symmetric confidence limits but the effectiveness is not overestimated.

\[
S_d = \sqrt{\sum_{i=1}^{4} \frac{1}{n_i}}
\]

where \( n \) is the number of crashes of each type. The 95% confidence limits of the effectiveness in relation to nonsensitive crashes were calculated according to the following equations (Evans 1998; Lie et al. 2006; Strandroth et al. 2012):

\[
\Delta E_{\text{ens}} = 100 \times R \times S_d \times 1.96
\]

\[
E_{\text{ens}\text{LOWER}} = E_{\text{ens}} - \Delta E_{\text{ens}}
\]

\[
E_{\text{ens}\text{UPPER}} = E_{\text{ens}} + \Delta E_{\text{ens}}.
\]

The overall effectiveness in crash reduction (i.e., all crash types) and the 95% confidence limits can therefore be calculated as follows (Lie et al. 2006; Strandroth et al. 2012):

\[
E = E_{\text{ens}} \times \frac{A_{\text{ABS}} + A_{\text{non-ABS}}}{N_{\text{ABS}} + N_{\text{non-ABS}}}
\]

\[
\Delta E = \Delta E_{\text{ens}} \times \frac{A_{\text{ABS}} + A_{\text{non-ABS}}}{N_{\text{ABS}} + N_{\text{non-ABS}}}
\]

\[
E_{\text{LOWER}} = E - \Delta E
\]

\[
E_{\text{UPPER}} = E + \Delta E.
\]

The analysis was performed in 3 main steps, as described below.

**Step 1—ABS Fitment**

The vehicle identification numbers (VINs) of the motorcycles involved in the crashes were included in the Italian data. Each VIN was checked and in some cases the manufacturers were contacted in order to retrieve information about ABS, CBS, and Traction Control Systems (TCS) fitments.

With regard to the Spanish and Swedish crash data, it was possible to identify the ABS fitment through model name and model year. However, some models with optional ABS (e.g., BMW and Harley Davidson models) were excluded from the Spanish material. The same process was carried out separately, because Sweden and Spain generally had different ABS fitment rates during the analyzed periods. The additional fitment of CBS and TCS was also checked.

The material in the present study was considered to be sufficient enough to attempt a direct comparison between the same motorcycle models, with and without ABS, as in Teoh (2011, 2013). However, crash data involving only the ABS version of some models (i.e., most BMW models in Sweden) were included in the study as well.

Standard, on/off, touring, and sport-touring models had an engine displacement of at least 600 cc. The model year ranged from 1997 to 2012 in the Swedish material, whereas

### Table 1. Overview of the available crash data

|                         | Italy | Spain | Sweden |
|-------------------------|-------|-------|--------|
| Period                  | 2009  | 2006–2009 | 2003–2012 |
| Crashes for analysis    | 13,695 | 57,160 | 8,720  |
| Urban crashes           | 9,918  | 37,635 | 4,112  |
| Scooters                | 8,575  | 23,794 | 362    |
| 18- to 24-year-old riders | 2,665 | 5,635 | 1,223  |
| 25- to 34-year-old riders | 3,701 | 22,220 | 2,109  |
|                           | 27%    | 39%    | 24%    |

A brief overview of the material available for analysis is given in Table 1. The material from a previous Swedish study (Rizzi et al. 2009) based on 2003–2008 records was updated with more recent crash data (2009–2012). The Italian material included crashes that occurred in 2009, whereas the Spanish one was the larger data set in the study, including crash data from 2006 to 2009. The share of motorcycle crashes that occurred in urban areas was higher in Italy and Spain (72% and 66%, respectively) than in Sweden (47%). In addition, the share of scooters varied greatly across these 3 countries, from 20% in Sweden to 63% in Italy. The age group 18–34 had lower crash involvement in Sweden (47%) than in Italy and Spain (46% and 49%, respectively).

**Method**

A statistical analysis was carried out using odds ratio calculations with an induced exposure approach, as in previous studies (Evans 1998; Lie et al. 2006; Strandroth et al. 2012). With this approach, the key point is to identify at least one crash type or situation in which ABS can be reasonably assumed (or known) not to be effective. If the only noteworthy difference in terms of crash risk is ABS, the relation between motorcycles with and without ABS in that a nonsensitive situation would be considered as the true exposure measure. This means that any deviation from the relation in nonsensitive situations is considered to be a result of ABS; see Eq. (1).

\[
R = \frac{A_{\text{ABS}}}{N_{\text{ABS}}} + \frac{A_{\text{non-ABS}}}{N_{\text{non-ABS}}},
\]

where \( A_{\text{ABS}} \) is the number of crashes sensitive to ABS, involving motorcycles with ABS; \( A_{\text{non-ABS}} \) is the number of crashes sensitive to ABS, involving motorcycles without ABS; \( N_{\text{ABS}} \) is the number of crashes nonsensitive to ABS, involving motorcycles with ABS; and \( N_{\text{non-ABS}} \) is the number of crashes nonsensitive to ABS, involving motorcycles without ABS.

Thus, the effectiveness in reducing sensitive crashes can be expressed as follows (Evans 1998; Lie et al. 2006; Strandroth et al. 2012):

\[
E_{\text{ens}} = 100 \times (1 - R)\%.
\]
in Italy and Spain it was 2004 and onwards. The number of scooters in the Swedish material was too limited for analysis, although 2 supersport models were included. Scooters included in the Italian and Spanish materials had an engine displacement ranging from 250 to 600 cc. Table 2 shows the number of ABS and non-ABS motorcycles included in the analysis, per motorcycle category; an overview of the analyzed material is also shown in the Appendix (see Tables A1 and A2, online supplement), with the make/models used for calculations in each database. In total, some 90 motorcycle models were included in the analysis.

The distribution of CBS fitment across the ABS and non-ABS groups was analyzed for each country (see Table A3, online supplement). The CBS fitment rate among ABS motorcycles ranged from 35% in Spain to 51% in Sweden. However, the same rate was lower in the non-ABS group, ranging from 6% to 26%. Though CBS was uncommon among the analyzed scooters, the distribution across the ABS and non-ABS groups was similar (see Appendix, online supplement).

### Step 2—Nonsensitive Crashes

Previous research based on Swedish in-depth studies of motorcycle fatal crashes (Rizzi et al. 2009) has shown that head-on crashes (according to the Swedish definition) were the least ABS-sensitive crashes. An example can be a crash in which a motorcycle swerved for an animal on a rural road and collided with an oncoming vehicle.

As mentioned above, the crash type classification used in Italy and Spain differed from Sweden. In Sweden, a crash is classified as a head-on when 2 oncoming vehicles crash with any direction of impact. It was therefore necessary to make assumptions on which crash types could be used as nonsensitive in the Italian and Spanish data sets. It was hypothesized that frontal and side-frontal crashes in nonintersections could be a reasonable proxy of the Swedish head-on crash definition. For instance, a crash in which a PTW rider fell off in a curve on a rural road and slid into the side of an oncoming car would be classified as side-frontal in Spain in Italy. Analysis of the distribution of ABS-equipped motorcycles per crash type was also made to verify this hypothesis, because ABS motorcycles would logically be overrepresented in a nonsensitive crash type to ABS.

Checks were made to ensure that the analyzed material included a representative share of nonsensitive crashes for the 3 countries. The Spanish and Italian materials were compared with a previous overview of PTW crashes in Europe (2 Be Safe 2010), and official crash statistics were used for the Swedish material.

### Step 3—Induced Exposure Analysis

Calculations were made to verify that ABS was the only relevant difference between the ABS and non-ABS groups. This was done by analyzing the variation in the ratios in Eq. (1), depending on a number of factors that may affect crash risk involvement. These factors were speed area, road conditions, driver age and gender, vehicle age, weight-to-power ratio, engine displacement, motorcycle category, reported speeding (when available), and CBS and possible TCS fitment. The effectiveness calculations were performed according to Eqs. (1)–(10) for each country. Crashes involving only scooters were further analyzed.

### Results

The step 2 analysis showed that the crash type with the highest involvement of ABS-equipped motorcycles in Sweden was head-on (58%), which supported the findings of the previous study (Rizzi et al. 2009). The results for Italy and Spain suggested that frontal and side-frontal crashes at nonintersections could be used as nonsensitive crashes, because the involvement of ABS motorcycles in those crashes was highest (15% and 16%, respectively). These results are shown in Tables A4 and A5 (see online supplement). Side crashes also had a higher share of ABS motorcycles (14%), compared to all crash types in the analyzed material (12%), suggesting that these crashes were not particularly sensitive to ABS. Side crashes, however, were included in the sensitive group because this would give a conservative approach to the analysis, see Eq. (1).

Checks were also performed to compare the crash type distributions in each country with official statistics or previous studies (2 Be Safe 2010). The findings showed that these were very similar, suggesting that the analyzed material was representative and that the effectiveness would not be overstated (see Table A6, online supplement, for further results). Analysis of the variation of the ratios \( \frac{N_{ABS}}{N_{non-ABS}} \) and \( \frac{N_{ABS}}{N_{non-ABS}} \) showed no substantial variations from the overall trends, except for Swedish riders aged 18 to 24 in the non-ABS group, who were found to have a greater sensitive/nonsensitive ratio. The fitment of TCS was not found to influence the sensitive/nonsensitive ratio, based on the limited number of ABS motorcycles that could have been fitted with this system (\( n = 37 \) for Italy; \( n = 71 \) for Spain; \( n = 50 \) for Sweden). With regard to the fitment of CBS, no major deviations from the overall results were found.

The results of the analysis with induced exposure are presented in Tables 3–5, along with their 95% confidence intervals (CIs). The overall reduction in injury crashes among ABS-fitted motorcycles was statistically significant in all countries (see Table 3). The reductions were 24% (95% CI, 12–36) in

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**Table 2. Distribution of ABS and non-ABS motorcycles, per motorcycle category**

| Motorcycle Category  | Italy | Spain | Sweden |
|----------------------|-------|-------|--------|
|                      | ABS   | Non-ABS | ABS | Non-ABS | ABS | Non-ABS |
| Standard             | 12 (%) | 37 (%) | 24 (%) | 50 (%) | 15 (%) | 31 (%) |
| On/Off               | 23 (%) | 11 (%) | 7 (%) | 4 (%) | 27 (%) | 11 (%) |
| Scooter              | 49 (%) | 47 (%) | 29 (%) | 23 (%) | — (%) | — (%) |
| Supersport           | — (%) | — (%) | 5 (%) | 7 (%) | — (%) | — (%) |
| Sport touring        | 12 (%) | 5 (%) | 14 (%) | 19 (%) | 25 (%) | 31 (%) |
| Touring              | 4 (%) | 1 (%) | 26 (%) | 3 (%) | 28 (%) | 20 (%) |
| Total (n)            | 100 (%) | 100 (%) | 100 (%) | 100 (%) | 100 (%) | 100 (%) |

in the Italian and Spanish data sets. It was hypothesized that frontal and side-frontal crashes at nonintersections could be used as nonsensitive crashes, because the involvement of ABS motorcycles in those crashes was highest (15% and 16%, respectively). These results are shown in Tables A4 and A5 (see online supplement). Side crashes also had a higher share of ABS motorcycles (14%), compared to all crash types in the analyzed material (12%), suggesting that these crashes were not particularly sensitive to ABS. Side crashes, however, were included in the sensitive group because this would give a conservative approach to the analysis, see Eq. (1).
Table 3. Overall effectiveness of motorcycle ABS on injury crashes, with 95% CI

| Injury crashes                        | Italy (%) | Spain (%) | Sweden (%) |
|---------------------------------------|-----------|-----------|------------|
| All crash types                       | 24±12     | 29±9      | 34±18      |
| All crash types in urban areas        | 22±15     | 28±12     | 46±21      |
| All crash types in rural areas        | 27±19     | 30±14     | 21±31      |
| Crashes in intersections              | 25±20     | 29±13     | 46±16      |
| Rear-end crashes                      | 27±21     | 15±20     | 33±27      |

Table 5. Overall effectiveness of motorcycle ABS per crash severity, only scooters (at least 250 cc), with 95% CIs

| Injury crashes          | Italy (%) | Severe and fatal crashes | Spain (%) | Severe and fatal crashes | Sweden (%) |
|-------------------------|-----------|--------------------------|-----------|--------------------------|------------|
| All crash types         | 27±15     | 22±20                    | 31±19     |                          |            |
| All crash types in urban areas | 29±16     | 20±25                    | 41±15     |                          |            |
| All crash types in rural areas | 19±42     | 34±26                    | 21±44     |                          |            |
| Crashes in intersections | 31±23     | 35±20                    | 84±21     |                          |            |
| Rear-end crashes        | 24±32     | 28±27                    | 67±43     |                          |            |

Italy, 29% (95% CI, 20–38) in Spain, and 34% (95% CI, 16–52) in Sweden. All results for rural and urban areas were statistically significant, except for Sweden, although no statistically significant difference was found for crashes for those motorcycles fitted with ABS in injury crashes on rural and urban roads. The results for injury crashes in intersections as well as rear-end injury crashes were also statistically significant, with the exception of Italy. The effectiveness of ABS in these crash types was similar to that for all injury crashes, although the Swedish reduction of crashes in intersections was higher at 46% (95% CI, 30–62).

The reductions in fatal and severe crashes with motorcycle ABS were generally greater, compared to all injuries, ranging from 34% (95% CI, 24–44) in Spain to 42% (95% CI, 23–61) in Sweden; see Table 4. The effectiveness of ABS in rural and urban areas was similar to the overall results for severe and fatal crashes for both countries, although the result for Swedish urban roads was not statistically significant. The results for severe and fatal rear-end crashes were even more impressive, ranging from 57% (95% CI, 45–69) in Spain to 60% (95% CI, 42–78) in Sweden. With regard to fatal and severe crashes in intersections, motorcycle ABS was found to reduce crash involvement by 48% (95% CI, 33–63) in Spain and 70% (95% CI, 62–78) in Sweden. As noted earlier, it was not possible to include Italian data in this comparison because suitable codes were not available.

Crashes involving only scooters were also analyzed; these findings for injury crashes in Italy and Spain are presented in Table 5. Both results were statistically significant and similar to the effectiveness found for all ABS-equipped motorcycles. The reductions in crash involvement with ABS-equipped scooters were 27% (95% CI, 12–42) in Italy and 22% (95% CI, 2–42) in Spain. The reduction in crash involvement in rural and urban areas did not deviate from the overall results for all motorcycles, although 2 results here were not statistically significant. Crashes at intersections were significantly reduced among ABS motorcycles and in line with the findings for all motorcycles, ranging from 31% (95% CI, 8–54) in Italy to 35% (95% CI, 15–55) in Spain. For rear-end injury scooter crashes, the Italian and Spanish results were similar to each other and to the overall results. The effectiveness in those crashes ranged from 24% to 28%, although the Spanish result was not statistically significant.

The calculations for fatal and severe crash reductions involving scooters could only be carried out on the Spanish data (see Table 5), where scooters with ABS had fewer severe and fatal crashes by 31% (95% CI, 12–50). This result was similar to the effectiveness for all analyzed motorcycles in Spain (34%). Again, the results for urban and rural areas did not differ from the overall results, although the effectiveness for rural roads was not statistically significant. The effectiveness of ABS on scooters in reducing severe and fatal rear-end crashes and crashes in intersection was found to be 84% and 67%, respectively.

Discussion

Overall Findings

The analysis showed statistically significant crash reductions for all ABS-equipped motorcycles, ranging from 24% in Italy to 34% in Sweden. The reduction of severe and fatal crashes was even more impressive, at 34% and 42% in Spain and Sweden, respectively.

In general, the results for Italy and Spain seemed in line with the Swedish ones. It can be argued that this did not necessarily need to be case, because southern European countries may have different motorcycling habits (everyday transport) than Nordic ones (leisure riding). This aspect was also in the different distributions of urban crashes and scooters across the 3 databases (see Table 1). The findings of this study do not seem unreasonable and are in line with previous research (HLDI 2013; Rizzi et al. 2009; Teoh 2013). An important finding of the present study was that ABS is effective in reducing crashes with scooters as well. Though this may seem logical, this finding could have great safety implications in those regions of the world where this kind of motorcycle is used on a daily basis as a mean of transportation, often the only available.

There are possible varying interpretations of these findings. First, it should also be noted that the present study used police records and therefore we could not perform any analysis of the actual functionalities of motorcycle ABS. However, previous research has shown that ABS generally provides shorter stopping distances and increased stability (Green 2006; Vavryn...
Assumptions Made

In undertaking studies such as this, it is necessary to make various assumptions in the computations and it is important to discuss these. The most critical step in the analysis was to determine the ABS nonsensitive crash type. Here, previous research addressing this issue was used (Rizzi et al. 2009), although this referred to Swedish crashes only. This was necessary in order to identify a basis for nonsensitive crash types in the Italian and Spanish databases. Checks were made to ensure that this assumption was valid. The magnitude of calculated benefits of ABS also suggests that this assumption was sound. Side crashes were found to be not particularly sensitive to ABS either, although it was argued that this would give conservative results: including such crashes among the sensitive ones would decrease the calculated effectiveness of motorcycle ABS.

Furthermore, it is important to stress that the nonsensitive crash type used in the calculations does not need to be exactly the same across the 3 databases. With this method, the overall effectiveness of motorcycle ABS in the 3 countries can still be compared, as $F_{\text{sens}}$ is multiplied with the total share of sensitive crashes in each country; see Eq. (7). In fact, this aspect would imply a more robust analysis: positive results were found by using slightly different induced exposures (nonsensitive crash types), which suggested that motorcycle ABS does have the calculated benefits.

Research Strengths and Limitations

The research presented here used an induced exposure approach, as has been used in several previous studies (Evans and Winkelbauer 2004). Tests of avoidance maneuvers performed on gravel roads by a Swedish motorcycle magazine (Solli and Sjöström 2011) also reported similar results. Roll et al. (2009) suggested that ABS may increase riders' confidence when applying full brakes, although stability improvements per se could also explain the large benefits of ABS.

In addition, though these findings help to explain the effectiveness of motorcycle ABS in avoiding crashes, it can also be argued that motorcycle ABS is relevant for mitigating injuries when a crash does occur. Little research is available on this issue now for motorcycles, although some insights were noted in the previous study (Rizzi et al. 2009). An increased deceleration during hard braking, as reported earlier, would logically decrease the impact speed if a crash occurs, thus mitigating injuries. Other studies also suggest that injury severity is reduced in crashes in which the rider was an upright position, compared to similar crashes involving prone riders (Rizzi et al. 2012; Sporner et al. 2003). Though it is important to stress that this study (Rizzi et al. 2012) was based on a limited material and only analyzed crashes into road barriers, these findings could raise the question of whether the reduction of injury crashes with ABS is due to crash avoidance only. The possibility that a system that was designed to avoid crashes, such as ABS, might also have injury-mitigating effects is intriguing and could have great safety implications.

Data quality represents a limitation of the present study that needs to be discussed. Police-reported crashes from different time periods were used, and these are well known to suffer from a number of quality issues. Injury severity measures relied on police assessments, which have been previously shown to have clear limitations (Farmer 2003). However, it was assumed that these limitations would equally affect both the ABS and non-ABS group and therefore it was not expected to affect the overall results to any large degree. A possible way of addressing the injury assessment issue would be to analyze fatal crashes separately. Though the number of fatal crashes in the present material was too limited to do that, future research should investigate this issue.

A further limitation is that VINs were not available for the Spanish and Swedish materials. It should be noted, however, that a misclassification between ABS and non-ABS motorcycles would give a conservative estimation of the actual benefit of ABS.

In the present study, the material was too limited to be broken into the categories: ABS with CBS, ABS alone, and CBS alone. Previous research (HLDI 2013) has reported greater reductions of collision claims with ABS and CBS, compared to ABS alone, which may suggest that part of the calculated benefits of ABS could be due to CBS as well. On the other hand, CBS and non-ABS scooters included in the analysis had similar distributions of CBS. The results for scooters, however, were generally in line with the overall results for all motorcycles, thus suggesting that the influence of CBS on the present material was probably quite limited.

Though improved stability in critical situations is probably the greatest benefit of motorcycle ABS, its implementation with CBS and TCS raises the possibility of combined effects that could enhance the total effectiveness of these systems. This aspect should also be further investigated as soon as possible.

A recent study (Fildes et al. 2013) used a multinational meta-analysis approach to evaluate the effectiveness of ESC on passenger cars where separate analyses from 6 different countries were individually conducted using a common analytic approach and then merged in a meta-analysis. Though the main goal of that study was to obtain an overall result, rather than comparing the benefits in separate countries, the same approach could be applied to the present material. Future research should also consider the possibility of using logistic regression for this kind of multinational studies.
Motorcycle Antilock Braking Systems

Recommendations

Based on the findings of the present study as well as previous research, there is more than sufficient scientific-based evidence to support the mandatory implementation of ABS on all motorcycles, even light ones. Manufacturers should immediately work toward a wide fitment of ABS on light scooters as well to meet the European deadline of fitment of ABS on all motorcycles before 2016 and in other regions of the world. Further strategies need to be developed to encourage consumers to purchase only ABS-equipped motorcycles. This could include insurance discounts and other economic incentives like scrapping programs. There is also a need for consumer testing so that the demand for effective ABS increases in future motorcycles.

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Supplemental Materials

Supplemental data for this article can be accessed on the publisher’s website.

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