OLYCKS- OCH SKADEREDUCERANDE EFFEKTER AV ABS (ANTILOCK BRAKE SYSTEM) PÅ MOTORCYKLAR

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Utökad sammanfattning

Att åka motorcykel har de senaste åren ökat i popularitet och i dag finns i Sverige ca 300 000 motorcyklar i trafik. Tyvärr visar det sig också i olycksstatistiken. År 2008 omkom i Sverige 51 motorcyklister medan 60 omkom under 2007. Även om antalet omkomna och svårt skadade motorcyklister inte ökar med det ökade antalet motorcyklar i trafik, är risken att omkomma som motorcyklist redan idag relativt hög (20 gånger så stor att omkomma jämfört med personbilsförare). Dessutom är skaderisken för motorcyklister mer än dubbelt så hög än för personbilister, vilket i första hand beror på att man som relativt oskyddad trafikant färdas i höga hastigheter.

På senare tid har en rad nya säkerhetssystem för motorcyklar introducerats men få utvärderingar eller effektstudier har gjorts. Exempel på sådana system är passiva system som airbag men framförallt aktiva säkerhetssystem som bl a ABS vilka tros ha en stor olycksförebyggande betydelse. Med ABS riskerar inte föraren att låsa hjulen, vilket gör att man lättare kan utnyttja bromsarnas fulla potential och öka kontrollen över fordonet. I en stor del av de djupstudier av dödsolyckor med motorcyklister som Vägverket utför är dålig bromsteknik en avgörande faktor för olyckans uppkomst och utfall. I vissa fall använder man bakbromsen för kraftigt vilket gör att man går omkull, i andra fall vågar inte föraren använda frambromsen tillräckligt vilket gör att man inte utnyttjar bromsarna optimalt. Med ABS skulle olyckan i många fall helt kunnat undvikas, eller konsekvenserna lindras.

Marknadsbilden vad gäller ABS är väldigt varierande beroende på tillverkare och motorcykeltyp. Trots att en tillverkare sedan slutet av 90-talet i Sverige sålt nästan alla sina motorcyklar med ABS, är antalet modeller med ABS som standard eller tillval generellt sett ganska litet och förekommer främst i klasserna *sporttouring*, *touring*, *standard* och *offroad*. En annan tillverkare har dock under 2009 börjat sälja ABS som tillval på sina *supersport* modeller.

Syftet med denna studie var att undersöka de olycks- och skadereducerande effekterna av ABS på motorcyklar på verkliga olyckor. Den statistiska metoden baseras på oddskvoter och har tidigare använts för att beräkna effekten av andra fordonsäkerhetssystem som antisladdsystem (ESC) på personbilar men aldrig för ABS på motorcyklar. Sådana effektstudier är dock viktiga och borde utföras så fort som möjligt för att förstå den verkliga effekten av säkerhetssystem i trafiken och därmed skapa faktabaserade argument för införandet av effektiva åtgärder (t.ex. antisladdsystem på personbilar under de senaste åren). Lika viktigt är att dessa undersökningar genomföras internationellt för att kunna dra mer generella slutsatser.

Studien utfördes i två steg. I det första användes djupstudier av dödsolyckor med motorcyklar i Sverige mellan 2005 och 2008 för att förstå i vilka omfattningar ABS skulle (eller inte skulle) kunna ha en positiv inverkan på olyckans utfall. Analysen visade att ABS skulle ha varit minst avgörande i mötesolyckor och mest i korsningsrelaterade olyckor. I 75% av de analyserade dödsolyckorna bromsade mc-föraren innan kollisionen och i 18% bromsade man omkull, vilket påpekar bromsnings- och instabilitetsproblematiken. I det andra steget, analysen med oddskvoter, användes alla polisrapporterade trafikolyckor med personskador i Sverige mellan 2003 och 2008. Analysen jämförde olycksfrekvensen bland två grupper av motorcyklar där den enda avgörande skillnaden förutsattes vara ABS.

Slutsatserna i denna studie var att:

- **ABS beräknades ha en olycksreducerande effekt av 38% på alla olyckor med personskador i Sverige och 48% på svåra och dödliga olyckor.** Den lägsta effekten med 95% konfidensintervall beräknades vara 11% respektive 17%.
- Olycksreducerande effekten av ABS i alla korsningsrelaterade olyckor beräknades vara minst 42%.
- ABS på motorcyklar skulle inte ha varit avgörande, eller endast marginellt, i mötesolyckor med dödlig utgång under 2005-2008.
- Skadegraden i trafikolyckor med motorcyklar utrustade med ABS var markant lindrigare än i olyckor med motorcyklar utan ABS.

Slutliga rekommendationer utifrån studien är att tillverkare inför ABS på alla nya modeller inklusive i *supersport* klassen och att kunder endast köper motorcyklar utrustade med ABS.

Projektet har finansierats av Vägverkets Skyltfond. Professor Brian Fildes på Monash University Accident Research Centre har granskat dokumentationen. Ett speciellt tack till Anita Ramstedt, Mats Artebranth, Jörgen Persson och Ylva Berg på Vägverket, Jenny Eriksson på Vectura Consulting, Kristina Mattsson på Transportstyrelsen och de svenska filialerna av BMW, Honda, Suzuki, Kawasaki och Yamaha.

Olycks- och skadereducerande effekter av ABS på motorcyklar

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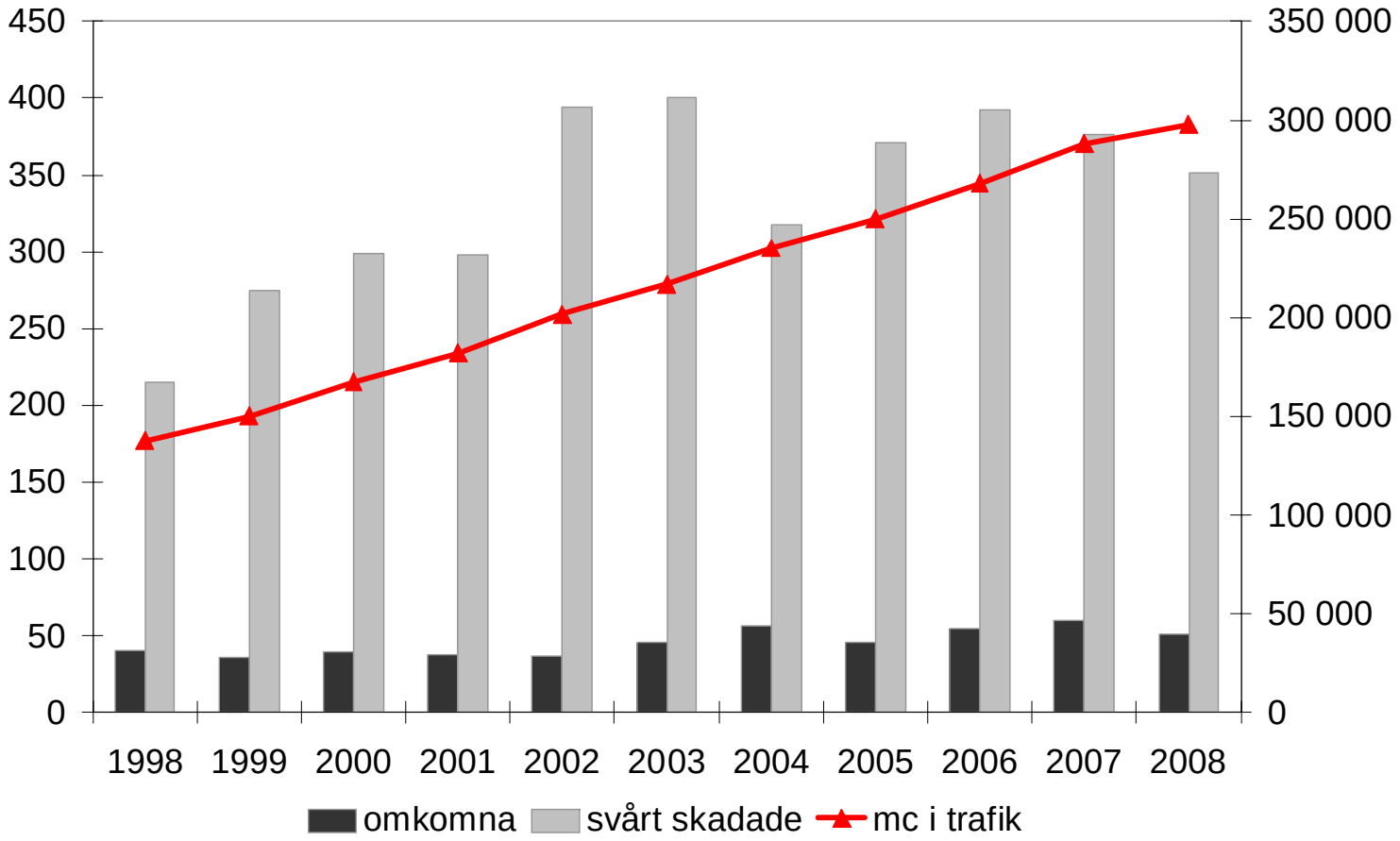
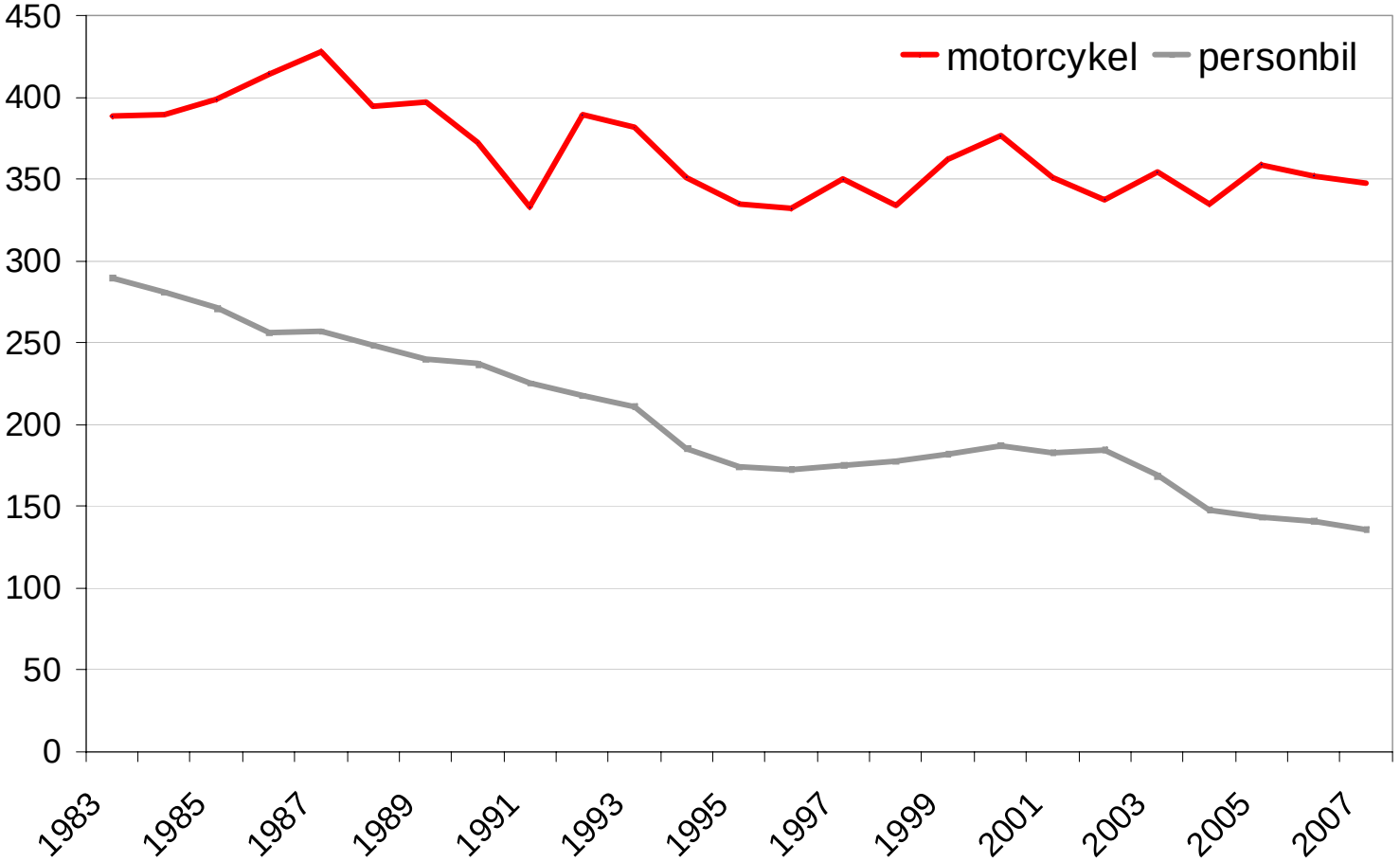
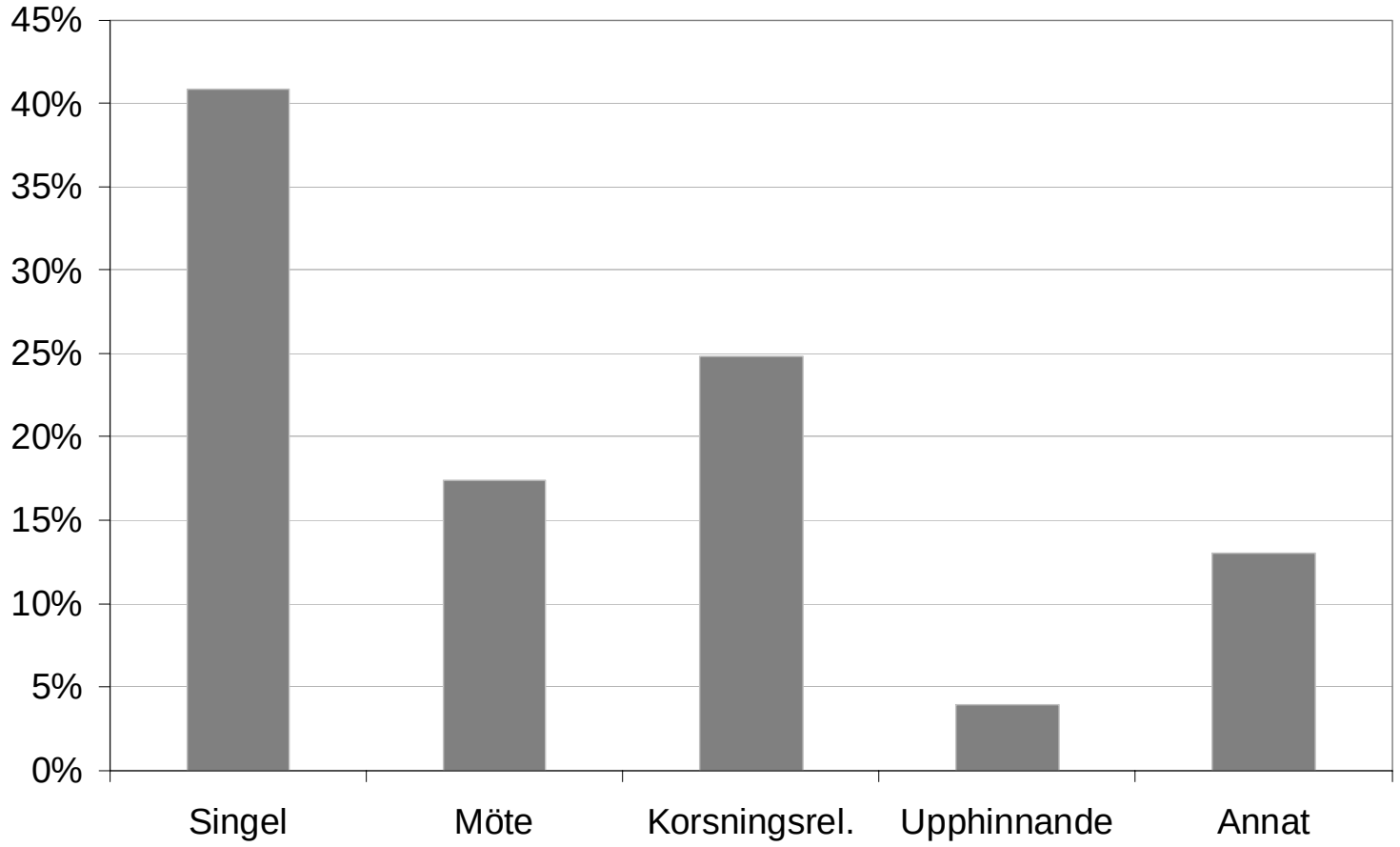
Dödade och svårt skadade på mc 1998-2008



Dödade och svårt skadade per 1000 olyckor



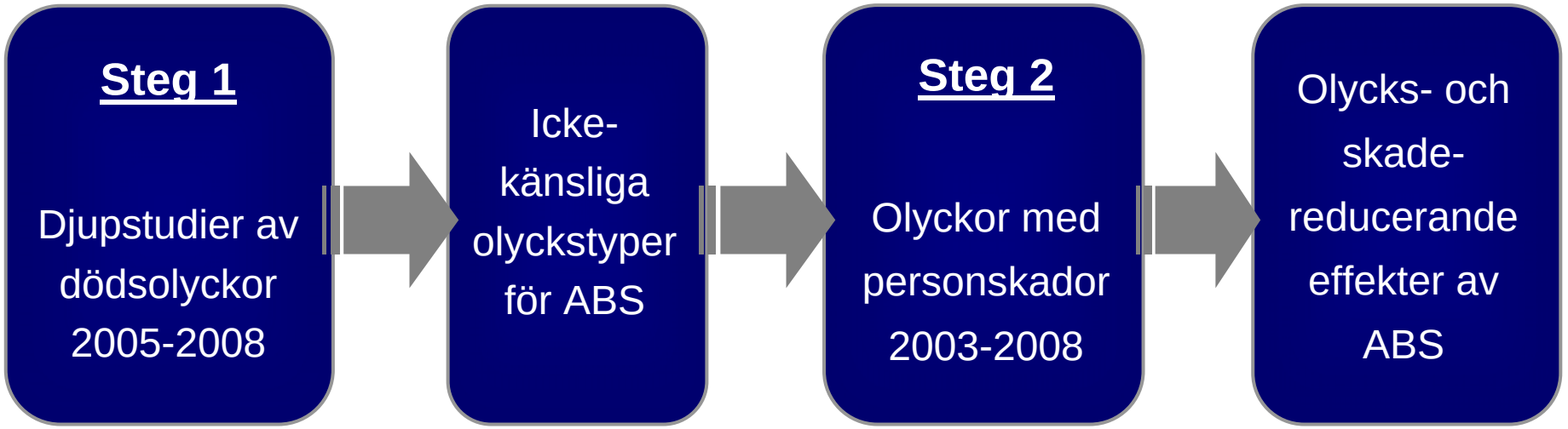
Olyckstyp i dödsolyckor 1998-2008



Syfte med studien:

1. **Undersöka potentialen av ABS på motorcyklar att förhindra olika olyckstyper**
2. **Beräkna effekten av ABS på motorcyklar i att reducera personskadeolyckor**
3. **Undersöka om ABS på motorcyklar påverkar skadegraden i olyckor**

Metod – Arbetsgång



Metod – Steg 1

Djupstudier av dödsolyckor

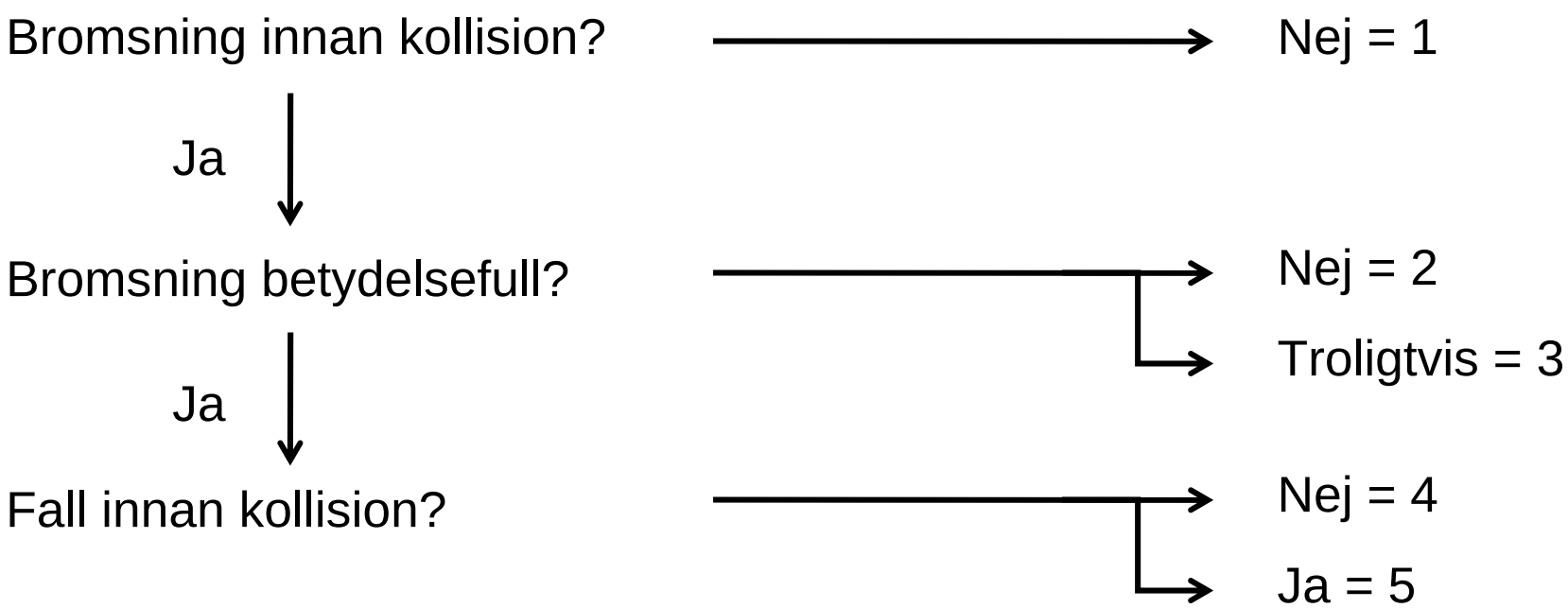
Potentialskala för analys av dödsolyckor:

1. ABS skulle absolut inte ha påverkat olyckan
2. ABS skulle möjligtvis ha påverkat olyckan
3. ABS skulle sannolikt ha påverkat olyckan
4. ABS skulle absolut ha påverkat olyckan
5. ABS kunde definitivt ha undvikit olyckan

Metod – Step 1

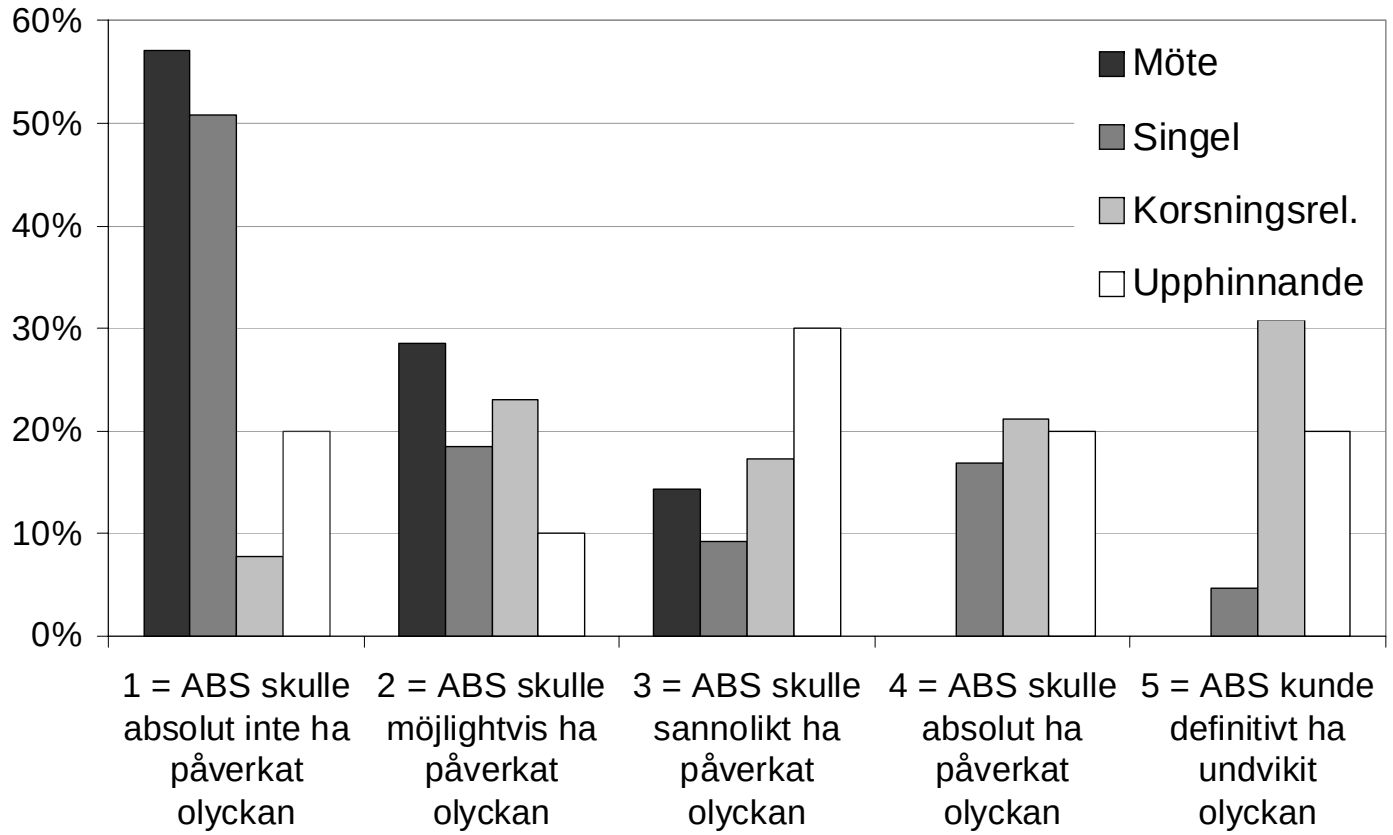
Djupstudier av dödsolyckor

Beslutsträd för analys av dödsolyckor:



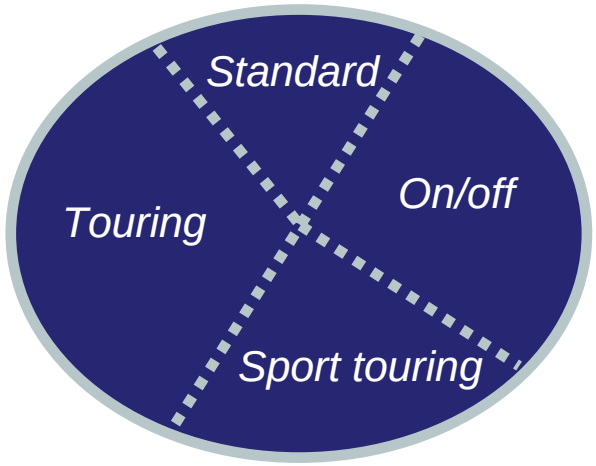
Resultat – Steg 1

Potentialen av ABS i olika olyckstyper

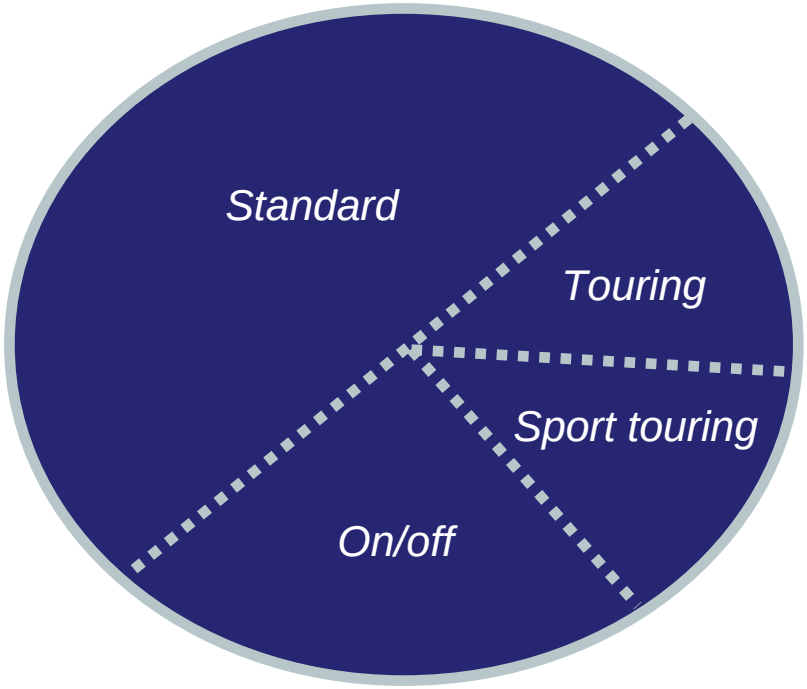


Metod – Steg 2

Effektberäkning baserad på oddskvoter



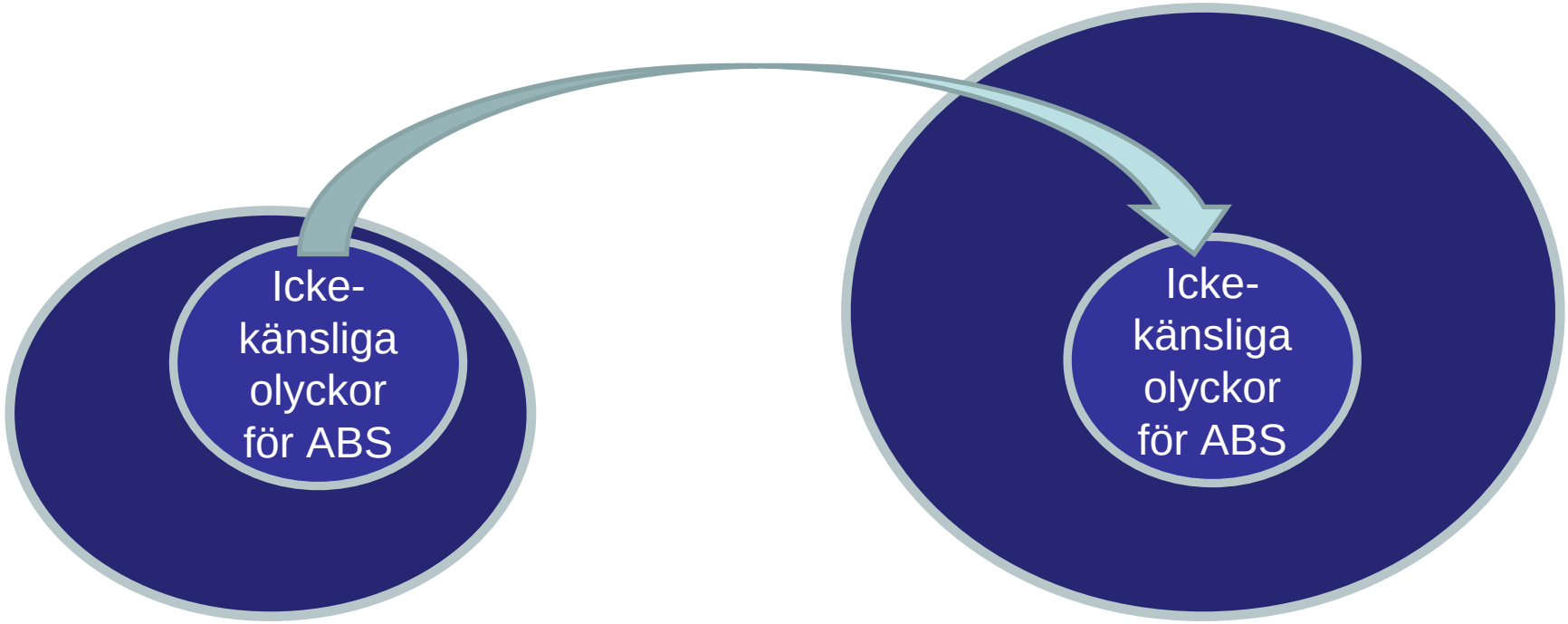
Olyckor i ABS-gruppen (n=187)



Olyckor i icke-ABS gruppen (n=985)

Metod – Steg 2

Effektberäkning baserad på oddskvoter

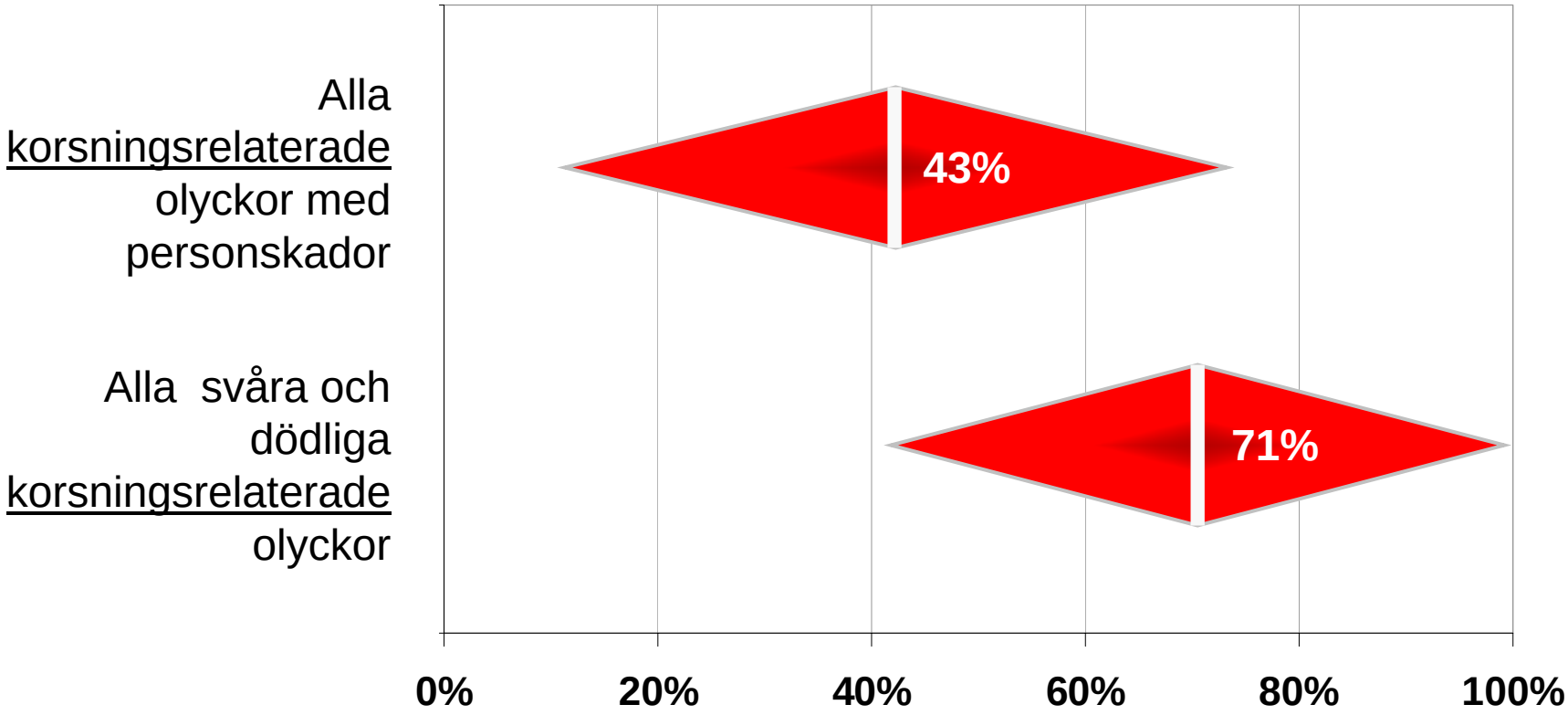


Olyckor i ABS-gruppen

Olyckor i icke-ABS gruppen

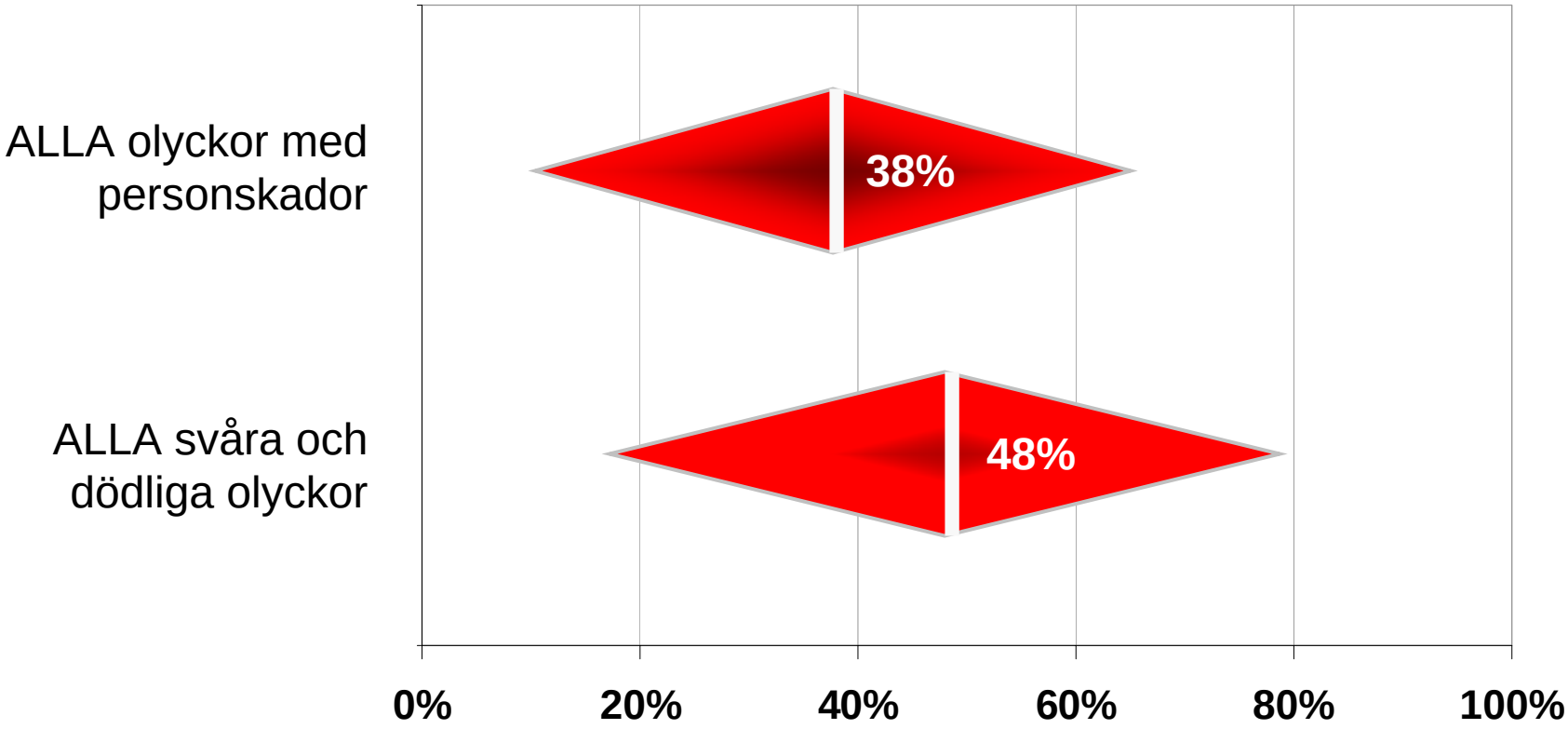
Resultat – Steg 2

Olycksreducerande effekt av ABS i korsningsrelaterade olyckor



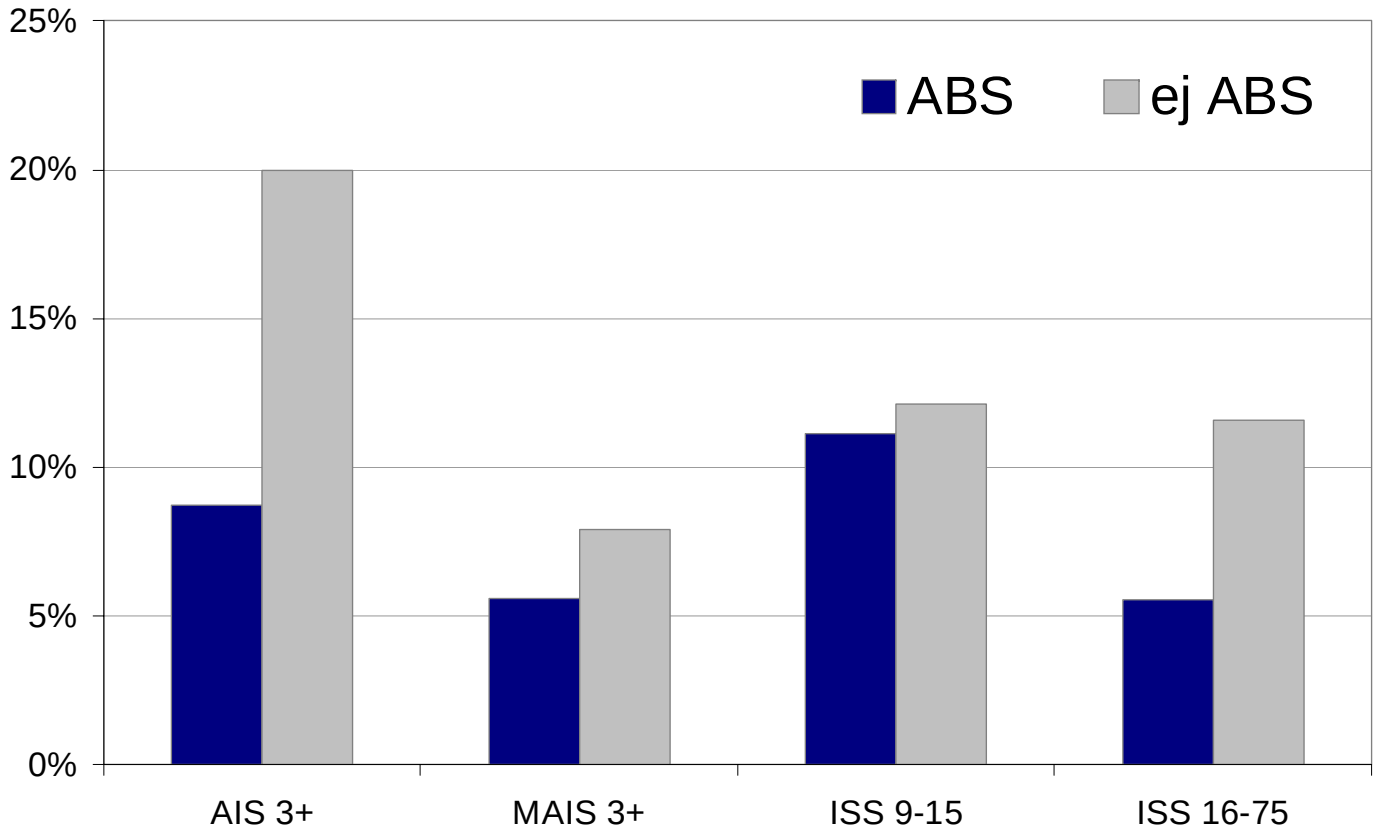
Resultat – Step 2

Olycksreducerande effekt av ABS i alla olyckor



Resultat – Steg 2

Skadereduktion i olyckor med ABS



Slutsatser

- Den totala effekten av ABS på motorcyklar i Sverige var:
  - **38% på alla olyckor med personskador**
  - **48% på alla svåra och dödliga olyckor**
  - Den minsta effekten var mellan 11% och 17%
  - 43% på alla korsningsrelaterade olyckor
  - 71% på alla svåra och dödliga korsningsrelaterade olyckor

- Skadegraden i olyckor med ABS-försedda motorcyklar var markant lägre än i liknande olyckor med icke ABS-försedda motorcyklar

THE EFFECTIVENESS OF ANTILOCK BRAKE SYSTEMS (ABS) ON MOTORCYCLES IN REDUCING REAL LIFE CRASHES AND INJURIES

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ABSTRACT

This study set out to evaluate the effectiveness of ABS technology on motorcycles in reducing real life injury crashes and to mitigate injury severity. The study comprised an analysis of in-depth fatal crash data in Sweden during 2005-2008 to investigate the potential of ABS as well an estimate of the effectiveness of ABS in crash reduction in Sweden between 2003 and 2008 using induced exposure methods. Findings show that head-on collisions were the least ABS-affected crash types and collisions at intersections the most influenced. Induced exposure analysis showed that the overall effectiveness of ABS was 38% on all crashes with injuries and 48% on all severe and fatal crashes, with a minimum effectiveness of 11% and 17% respectively. The study recommends the fitment of ABS on all new motorcycles as soon as possible and that customers only purchase motorcycles with ABS.

INTRODUCTION

The risk of being killed on a motorcycle per passenger mileage is approximately twenty times higher than for a passenger car occupant (1). The risk of being killed or severely injured in a crash has been the same since the 1980s for motorcycle riders, while the risk for passenger car occupants has systematically reduced by almost 75% (2). Figure 1 shows the number of persons killed or seriously injured per 1000 casualty crashes.

During the last ten years the number of motorcycles in Sweden has more than doubled while the number of KSI has been relatively stable over this period. Consequently, this has lead to a reduction in the risk of KSI per 100,000 motorcycles as seen in Figure 2. While this can be explained by a number of reasons, it is also conceivable that it may be due to an improvement in the likelihood of crashing a motorcycle over this time period.

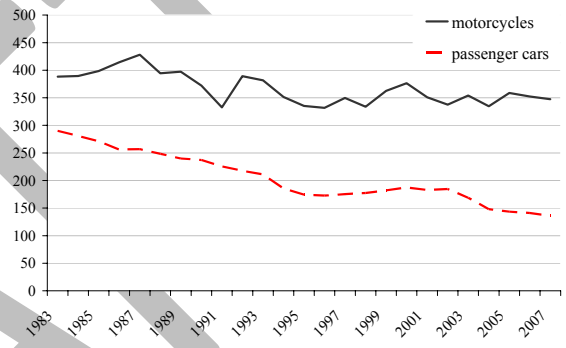

Figure 1.
Number of persons killed or seriously injured in Sweden per 1000 casualty crashes in passenger cars and motorcycles.

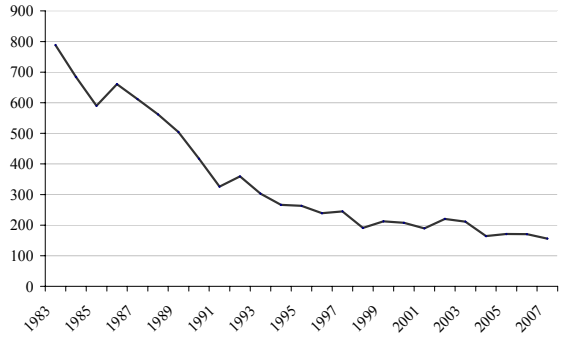

Figure 2.
Number of persons killed or seriously injured in Sweden per 100 000 motorcycles, 1983 to 2007.

The chain of events that eventually lead to a crash is described in Figure 3. With regards to passenger cars, systems have been developed to warn or support drivers (i.e. Intelligent Speed Assistance), to intervene in driving (i.e. Lane Departure Warning), or to immediately correct poor driving manoeuvres (i.e. Electronic Stability Control - ESC).

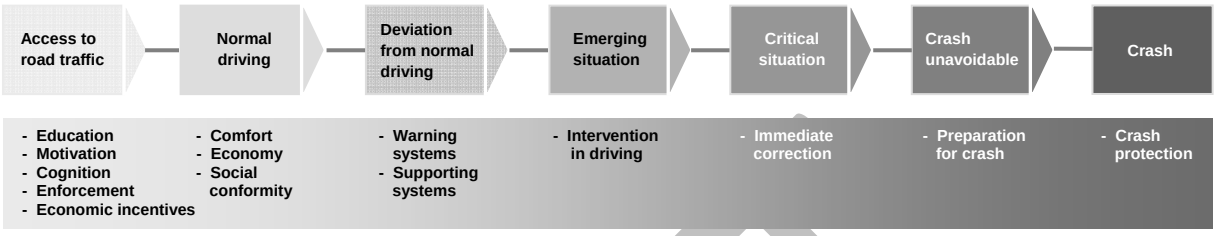

Figure 3.
Chain of events from access to road traffic to crash. An integrated safety approach.

In-depth studies have showed that the majority of motorcycles crashes with other motor vehicles involve braking and that injury severity increase when motorcycle riders fall prior to collision (3, 4). Antilock Braking Systems (ABS) on motorcycles uses electronic controls to maintain wheel rotation under hard braking (6). In a situation that would normally lock the wheel, ABS increases the motorcycle's stability preventing it from falling to the ground. The system also provides the motorcyclist with the necessary confidence to apply the brakes up to the limit of the friction available (7), therefore possibly increasing deceleration (15). This is especially the case when ABS is combined with Combined Brake Systems (CBS), which makes it easier for the rider to distribute the brake force between the back and front wheel more optimally (8).

In passenger cars, it has been shown that ABS has had only a minor effect in reducing the number of crashes (6) while ESC has decreased crash involvement and injury severity markedly (9,11). The effect of ABS on motorcycles might be expected to be greater than for passenger cars because of possible instability problems from locked wheels. One study comparing fatal crash involvements by total registered vehicle years for ABS and non-ABS motorcycles showed that motorcycles equipped with ABS had a 38% lower crash involvement rate, although these results were not statistically significant (5).

While ABS was first introduced on the market twenty years ago, nowadays only a minority of new motorcycles in Sweden sold by major manufacturers in the region are equipped with ABS as standard. On other models, ABS is offered as optional equipment. Only one manufacturer has equipped almost the entire range of motorcycle models with ABS since the late 1990s.

The challenge is yet to find, evaluate and introduce corresponding safety equipment for motorcycles. One technology, Antilock Brake Systems (ABS) has been introduced on a range of motorcycles since the late 1980s and could be considered similar to ESC on passenger cars, as they both act by immediate correction when a critical situation is detected.

STUDY OBJECTIVES

The main objectives of this study were to:

1. investigate the potential of ABS to reduce fatal motorcycle crashes in Sweden;
2. find out which crash types are most influenced by ABS;
3. estimate the effectiveness of ABS on motorcycles in reducing crashes with injuries in Sweden; and
4. examine whether ABS on motorcycles affects injury severity in crashes.

METHOD

This project was divided into two parts. Study 1 used in-depth studies of fatal crashes in order to investigate the potential of ABS to reduce crashes and injuries and to find out in which type of crashes ABS would be of relevance. Such findings were then used in Study 2 to estimate the effectiveness of ABS in crash reduction using an induced exposure approach. A comparison of injury severity in crashes with, and without, ABS was also undertaken.

Study 1

Sferco and his colleagues (10) used a decision-tree approach to judge the potential of ESC to reduce real life crashes. A similar approach was adopted here using a scale from 1-5 to rank the likely influence of ABS on fatal crashes and to determine which types of events are most influenced by ABS. The decision-tree scale was defined as follows:

1 ABS would definitely not have influenced the crash
2 ABS would perhaps have influenced the crash
3 ABS would probably have influenced the crash
4 ABS would definitely have influenced the crash
5 ABS could definitely have avoided the crash

The sequence of events was analyzed for each crash in the database in order to ensure objective results. A fatal accident involving an ABS-equipped motorcycle would automatically get a score 1.

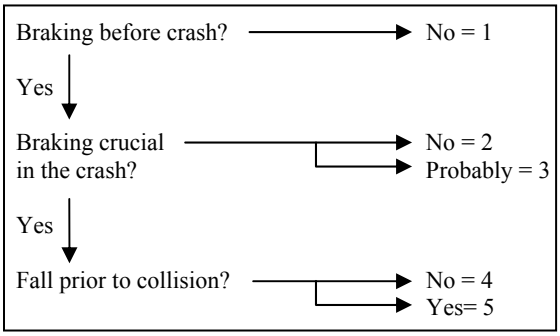

Figure 4.
Decision-tree method for analyzing in-depth studies.

While braking before the crash, as well as a fall prior to collision, are normally simple to detect, it was more complex to determine whether braking was a crucial event or not. Factors such as driving speed, assumed reaction time, actual braking distance (i.e. from skid marks), road condition, and so on were taken into account in making these judgments. By examining the distribution of scores 1-5 for different crash types, it was then possible to determine under which circumstances ABS would have (or not have) affected the outcome of the crash. The least ABS-affected crash type was thus considered to be non-sensitive to ABS in the follow-up analysis in Study 2.

Study 2

An analysis using induced exposure can be used when true exposure is not available, (6, 11). Using this approach, it is assumed that the ratio between the number of crashes in sensitive and non-sensitive situations to ABS should not differ between two groups of vehicles with the same risk of crash involvement. If the ratio is different for two groups, where the only noteworthy difference is ABS, it is assumed that the difference is due to ABS. The effect of ABS is considered to be zero if R in the equation below is equal to 1.

$$R = \frac{A_{ABS}}{N_{ABS}} \div \frac{A_{non-ABS}}{N_{non-ABS}} \qquad \text{(Eq.1)}$$

Where:

A_{ABS} = number of crashes sensitive to ABS, involving motorcycles with ABS

$A_{non-ABS}$ = number of crashes sensitive to ABS, involving motorcycles without ABS

N_{ABS} = number of crashes non-sensitive to ABS, involving motorcycles with ABS

$N_{non-ABS}$ = number of crashes non-sensitive to ABS, involving motorcycles without ABS

Thus, the effectiveness in crash reduction can be expressed as:

$$E = 100 \times (1 - R)\% \qquad \text{(Eq. 2)}$$

The standard deviation of the effectiveness was calculated on the basis of a simplified odds ratio variance, according to Eq.3. This method gives symmetric confidence limits but the effectiveness is not overestimated.

$$Sd = R \times \sqrt{\sum_{i=1}^{4} \frac{1}{n_i}} \qquad \text{(Eq. 3)}$$

Where n is the number of crashes of each type. The 95% confidence limits are given in eq.4.

$$\Delta E = 100 \times R \times Sd \times 1{,}96 \qquad \text{(Eq. 4)}$$

Motorcycles are generally divided into a number of different types or categories, such as *standard* (also knows as naked), *off-road*, *touring, sport touring*, *sport*, *on/off* (also known as dual-sport) and *cruiser*. Crash data involving motorcycles with ABS were only available for the categories touring, sport touring, on/off and standard in this analysis. This is because there are very few ABS-equipped models among sport and cruiser models which were only introduced in Sweden from 2008 and 2009 and not represented in Swedish crash records yet.

As the number of crashes involving the same models, with and without ABS, was too small to compare directly, case and control motorcycles were divided according to the category-criteria. Motorcycles within each category were expected to have approximately the same characteristics regarding performance, seating position, brake and frame construction, etcetera, and were therefore estimated to have comparable crash rates. Checks were also carried out to ensure that both ABS and non-ABS groups were representative of the population at large.

Some motorcycles have ABS as standard equipment while others have it as an option. In such cases a number of manufacturers were contacted in order to retrieve information about ABS through the chassis number of those motorcycles. During this process the crash data were handled according to confidentiality restrictions.

Finally, an attempt was made to investigate whether crashing with an ABS-equipped motorcycle might influence injury severity, compared to a non ABS-equipped motorcycle. Personal injuries in ABS and non-ABS groups were compared using ISS (Injury Severity Score), AIS (Abbreviated Injury Scale) and MAIS (Maximum Abbreviated Injury Scale). Crash type distributions were also taken into account to determine whether any difference might relate to ABS or to other confounders.

MATERIAL

Study 1

The Swedish Road Administration has been carrying out in-depth studies for each fatal road crash since 1997. This

study was based on 164 in-depth fatal motorcycle crashes in Sweden between 2005 and 2008.
Crashes with any category of motorcycles with engine displacement over 125cc were included in the analysis.

Study 2

Data for Study 2 was taken from STRADA (Swedish TRaffic Accident Data Acquisition) which includes police reported crashes with at least one injured person. Motorcycle crashes between 2003 and 2008 were analyzed where the case group contained motorcycles manufactured from 1997 to 2008, with a nominal engine power of at least 25 kW. As mentioned earlier, all case and control motorcycles belonged to categories including touring, sport touring, on/off and standard, and manufactured during the same time period and with an engine developing at least 25 kW.

Table 1.
Number of motorcycles used for the calculations per category (see appendix for motorcycle models in each category).

Motorcycle category	Number of case motorcycles	Number of control motorcycles	**Sum**
Touring	61 (33%)	104 (11%)	**165**
Sport touring	45 (24%)	145 (15%)	**190**
On/off	52 (28%)	250 (25%)	**302**
Standard	29 (16%)	486 (49%)	**515**
Sum	**187** (100%)	**985** (100%)	**1172**

Police reported crash data are generally known to suffer from a number of data quality problems. As it was assumed that this limitation would equally affect both categories, it was not expected to affect this analysis.

Hospital reported data were also used to compare injuries in crashes involving motorcycles with and without ABS. Again, crash data from 2003 to 2008 were acquired through STRADA. Since hospital reported crash data do not include any technical specifications about vehicles, case and control groups could only be compared by matching police reported crashes with hospital reported ones. In total 72 cases and 354 control motorcycles were identified from this process.

RESULTS

Study 1

Analysis of 164 in-depth studies of fatal motorcycle crashes showed that 14% of crashes could have been avoided with ABS and further 16% would have definitely been influenced by ABS. It was unclear at which degree ABS could have influenced the outcome of 22% of the crashes. These results are illustrated in Figure 5 below.

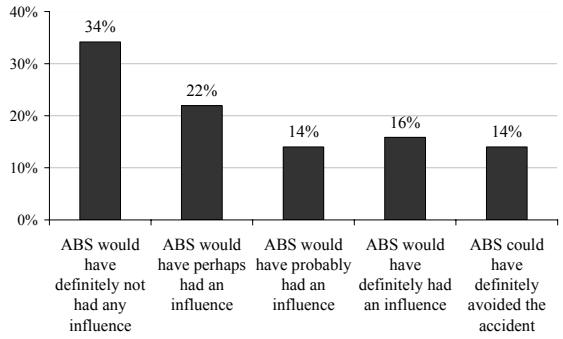

Figure 5.
The potential of ABS on fatal motorcycle crashes in Sweden between 2005 and 2008.

In 66% of the cases, the motorcycle rider did brake before the crash. In a further 18% of crashes, the rider fell prior to the collision. When motorcycle-motor vehicle collisions were analyzed separately, braking before crash was found in 75% of cases, while falls prior to collision occurred in 27% of cases. Crash type was then taken into account to determine in which circumstances ABS would have affected the outcome of a crash. Results are shown in Table 2 below.

Table 2.
The potential of ABS on fatal motorcycle crashes in Sweden between 2005 and 2008, per crash type.

ABS scale	**Head on** n=28	**Single** n=65	**Inter-section** n=52	**Rear end** n=10
1 ABS would have definitely not influenced the crash	57%	51%	8%	20%
2 ABS would have perhaps influenced the crash	29%	18%	23%	10%
3 ABS would have probably influenced the crash	14%	9%	17%	30%
4 ABS would have definitely influenced the crash	0%	17%	21%	20%
5 ABS could have definitely avoided the crash	0%	5%	31%	20%

These results show that 31% of crashes at intersections could have been avoided entirely with ABS, while in another 21% of the cases, ABS would have been expected to have definitely influenced the outcome. Alternatively, ABS was considered not to have had any significant influence on the outcome in 57% of head-on collisions and 51% of single-vehicle crashes. In only 14% of the head-on collisions analyzed could ABS have probably influenced the outcome. Instead, the outcome of 31% of single-vehicle crashes was judged to have been influenced to some degree.

Study 2

Based on the results of Study 1, head-on collisions were the least ABS-affected crash type among the analyzed fatal crashes. The effectiveness of ABS was therefore estimated by considering head-on collisions as non-sensitive events (crash types) in the Study 2 analysis. Comparisons were carried out to ensure that case and control groups had similar distributions of crash types among the motorcycle population involved in road crashes in Sweden. This ensured that the ABS and non-ABS groups were representative samples of the motorcycle population and the effectiveness of ABS would not be compromised.

Calculations showed similar distributions (if not identical) for almost all crash types. With regard to non-ABS sensitive crashes in particular, the sharing of head-on collisions in the case group (13%) was slightly greater than in control group (8%). According to official crash records, head-on collisions amounted for 7% of all crashes with injuries between 2003 and 2008, which means that both case and control groups have greater distributions of non ABS-sensitive crashes. This suggested that the effectiveness would not be over-stated.

Further calculations were made within the control group to verify that the only noticeable difference was ABS. This was done by analyzing the variation of the ratio, $\frac{A_{non-ABS}}{N_{non-ABS}}$ (see Eq.1), depending on a number of factors such as speed limit, road condition, driver age and driver gender, vehicle age, weight to power ratio and motorcycle category. No substantial variations from the overall results were found except for riders aged 20 to 24 years and for older drivers, which showed a greater sensitive to non-sensitive ratio.

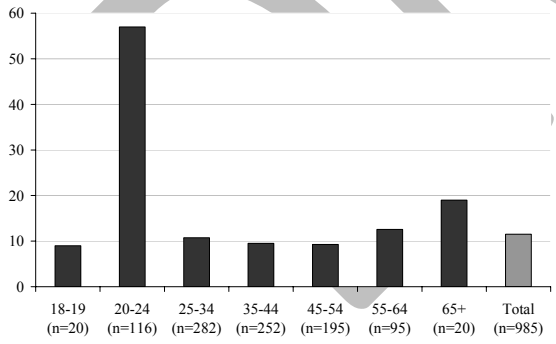

Figure 6.
Sensitive (all crashes excl. head-on collisions) to non-sensitive (head-on collisions) ratios in the control group, per driver age.

Logically, this difference could harm the analysis as riders between 20 and 24 were involved in more ABS-sensitive crashes than the rest of the control group.

However, as they amount for only 12% of the population within the control group, it was calculated that this variation was only likely to have a minor affect on the results. The findings are shown in Table 3.

Table 3.
The effectiveness of ABS in crashes in mitigating injury (with 95% confidence limits) relative to head-on collisions.

All crashes with injury excl. head-on collisions	41% +/- 29%
Crashes in intersections	43% +/- 32%
All severe and fatal crashes excl. head-on collisions	54% +/- 35%
Severe and fatal crashes in intersections	71% +/- 29%

All results are statistically significant. The reduction on crash involvement for ABS was estimated to be 41% for all crashes relative to head-on collisions and 43% for crashes at intersections. The lower 95% confidence limit is quite similar for both these comparisons. The effectiveness of ABS on severe and fatal crashes compared with head-on collisions was even greater, with a 54% estimated reduction on crash involvement. The lower 95% confidence limit was 19%. The effectiveness on severe and fatal crashes in intersections again was higher at 71%, with a lower 95% confidence limit of 42%.

Head-on collisions in these data amount to 8% of all crashes with injuries and 12% of all severe and fatal crashes. The results in Table 4 show that the overall effectiveness for ABS including head-on collisions was 38% for all casualty crashes and 48% for all severe and fatal crashes. The lower confidence limit was 11% for all casualty crashes and 17% for severe and fatal injuries, while the upper limits were 65% and 79%, respectively.

Table 4.
The overall effectiveness of ABS on all casualty crashes as well as severe and fatal crashes.

All casualty crashes	38% +/- 27%
All severe and fatal crashes	48% +/- 31%

Table 5 shows the injury severity outcome in all casualty crashes involving ABS and non-ABS equipped motorcycles. Comparisons were made in order to comprehend whether any possible difference could have been related to ABS. Again, the sharing of head-on collisions in the case group was greater than in the control group (9% and 5%, respectively).

Table 5.
Injury severity in crashes involving motorcycles with and without ABS.

Injury	Case motorcycles n=72	Control motorcycles n=354
AIS 3+	8,7%	20,0%
MAIS 3+	5,6 %	7,9%
ISS 9-15	11,1%	12,1%
ISS 16-75	5,6%	11,6%

As seen in Table 5, crashes involving ABS motorcycles generally resulted in fewer severe injuries. While the distribution of most severe injury (MAIS 3+) does not differ substantially, the injury severity score is about 100% greater for controls than cases for the more severe injuries (ISS 16 or greater) and 130% greater for AIS 3+ injuries.

DISCUSSION

Two different analyses were presented in this paper and these will be discussed separately. However, it should be noted that, while the scale of potential (3) and induced exposure (6, 9) has been used before to estimate the benefits of other safety systems, this was the first attempt to combine both methods. Caution should be taken in drawing general conclusions from these findings due to the limited number of crashes. Since Study 2 is based on the results of Study 1, it should also be noted that the result from the analysis of the in-depth studies can directly affect the analysis with induced exposure. It is therefore important that further studies using even greater numbers of in-depth cases are carried out in the future when more motorcycles with ABS will be represented in fatal crash records. While the figures seem very promising, more research is needed.

Study 1 Findings

From the analysis of the SRA in-depth fatal crash data, it was found that head-on collisions were the only crash type for which ABS seemed to be ineffective. For the others, analysis revealed likely effectiveness figures from 17% to 21% for definite influence by ABS and possible crash avoidance for ABS in 31% of intersection, 20% of rear-end, and 5% of single vehicle collisions.

The analysis with the in-depth fatal crash data showed that in 75% of the motorcycle-other motor vehicle collisions, the motorcycle rider did apply the brakes before the crash, suggesting that braking is relevant and important in motorcycle crashes. Furthermore, in 27% of crashes the rider fell prior to the collision which highlights the instability problem. These figures are somewhat greater, but still in the same magnitude, as other values shown in a German study (3), where 65% of collisions between motorcycles and other motor vehicle involved braking and around 12% for a fall before the collision.

It was found by analysing the in-depth studies that head-on collisions were the least ABS-affected crash type and therefore assumed to be non-sensitive to ABS. Such results are reasonable. Motorcycle riders are rather unprotected compared to passenger car occupants. It is logical that braking prior to head-on collisions may not be the most efficient crash avoidance maneuver to perform. While it might be expected that ABS would generally improve stability during braking and perhaps provide those split seconds needed to avoid the collision, it did not seem to show such potential in these head-on collisions.

It should also be noted that the scale of potential was not a subjective judgment but related to a number of objective facts such as brake marks, road condition, driving speed etcetera.

Study 2 Findings

The results using the STRADA 2003 to 2008 data showed impressive reductions in crash involvement for ABS technology on motorcycles. The overall effectiveness for ABS including head-on collisions was 38% for all casualty crashes and 48% for all severe and fatal crash outcomes. The reductions in crash involvement were even more impressive using head-on crashes as a control, estimated to be 41% for all other crashes, and up to 43% for crashes at intersections alone. The effectiveness on severe and fatal crashes at intersections was even higher at 71%.

A critical assumption for Study 2 was that different motorcycle models and riders within the same category were assumed to have similar crash risks. While the concept of crashworthiness does not apply to motorcycles, no evidence of relation between crash risk and engine size or power has been found (12).

The induced exposure method employed here was based on the category-criteria, due to the lack of sufficient crash data and should be therefore regarded as only a first step using this new approach. Even though it may be reasonable to compare similar motorcycle models with similar properties, it is still important to ensure that the only relevant difference is ABS and not other confounding factors. Of some comfort, an analysis conducted to verify if showed no considerable variation between case and control riders except for rider age as mentioned before.

Compared to other studies which have evaluated ABS on motorcycles and that are based on true exposure like vehicle mileage, number of vehicles in traffic (5) or insurance data (14), induced exposure is more robust. When using true exposure, many confounders can affect the results. The only critical issue with induced exposure is to make sure that there is no decisive anomaly between the case and control cases.

The only major deviation found in this study concerned riders of ages between 20 and 24 which had a higher proportion of non ABS-sensitive crashes, although it was argued that as they only represent 12% of the control group, this factor would have only had a minor influence if any on the results.

While these results seem extraordinary, they are in line with other recent reports regarding ABS on motorcycles, albeit of greater magnitude. A study in Germany estimated that introducing ABS on all motorcycles would reduce crashes by around 10%, thus with a "theoretical presupposition for positive influence by ABS in more than 50% of all crashes" (3). Other studies in the US show a 19% reduction in frequency of insurance claims with ABS-equipped motorcycles (14). Furthermore ABS has been found to reduce fatal motorcycle crashes per 10,000 registered vehicles by 38% (5). Other studies have also reported a reduction of MAIS 4+ injuries if the motorcycle rider is sitting on an upright position when a crash occurs (3).

Explanations for the effects on both crash reduction and injury severity can speculatively be related to the dual function of ABS. Earlier studies have showed that ABS not only increases the achievable deceleration (18) but also improves stability in an emerging situation. Both functions may reduce injury severity because improved stability during braking would reduce the risk of fall prior to collision and increased deceleration would reduce collision speed. However, stability improvements might be the biggest advantage of ABS. The possibility of full braking and changing trajectory at the same time in a critical situation could allow riders to totally avoid the crash. At the moment though, very little is known regarding the possible dual effect of ABS on motorcycles.

While ABS has shown disappointing results for passenger cars (6), ESC has been proved to have such a dual effect (11). Based on the results of this study, it could be appropriate to compare the importance of ESC for passenger car with ABS for motorcycles, as they both act on vehicle stability when a critical situation emerges (see Figure 3 earlier) and provide more favorable conditions during the crash. Clearly, such a comparison may be difficult to demonstrate since ABS relates to stability while braking only. The possible effect of ABS in reducing falls prior to collision, however, can be of relevance to the implementation of other crash protection systems on motorcycles. While the introduction of airbags on the market is still very limited, a possible interaction between ABS and airbags seems promising and needs to be further investigated. Unfortunately the limited number of models with airbags and ABS makes such task impossible at the moment. Furthermore the increased deceleration and possible decreased impact speed with ABS can favor the effectiveness of other crash protection systems, such as helmets, protective clothing and motorcycle friendly barriers.

It is possible that riders on ABS-equipped motorcycles in Sweden may have adopted a more risky behavior by driving faster or braking later, if they believed that ABS would help them manage dangerous braking situations. It is believed that this may motivate the rider to compensate for the safety system advantages and push the safety level back to the same as before the safety system was introduced. In any case in this study, it would have lead to underestimating the effectiveness and the results would be conservative. As when all new safety systems are introduced risk compensation is possible, this effect cannot be ignored. Such behavior has been suspected on passenger cars with ABS (6).

Evaluation of safety systems that seek to prevent injuries should always be conducted as soon as possible after its implementation. It is a key factor in understanding the advantages and disadvantages and also to be able to push for a broader and more rapid penetration of promising safety systems. However, it is important to stress that the results were based on crashes in Sweden only, which is a rather small country with limited numbers of crashes. Therefore the possibility to draw general robust conclusions from these results also is quite limited. That shows the need of these studies being more broad and multinational, possibly by joining many countries as proposed in other studies (11).

With respect to ABS on motorcycles, this would allow analysis on a broader set of crash data involving other types of motorcycles (i.e. scooters) and different motorcycling cultures. Weather conditions in Sweden are different from other countries, which makes motorcycling some of a seasonal activity. This is apparent in crash statistics too, as the majority of motorcycle crashes occur under favorable weather conditions. Besides, motorcycles involved in crashes in Sweden are mainly heavier vehicles, ridden outside urban areas during free time. This is not the case in other parts of the world. In Southern Europe, for instance, more fatal crashes are reported inside urban areas than outside (13). It would be of major interest to investigate the effectiveness of ABS in other countries where lighter motorcycles are widely used too, possibly throughout the year, with various road conditions and in different traffic environments. Such investigations could then validate the results of this study as well as others. In the meanwhile, there is reason to believe that ABS provides that very much needed help in managing critical situations, thus avoiding crashes and saving lives. The motorcycle industry should therefore be encouraged to implement ABS on all categories of motorcycles, as well as customers should preferably purchase ABS-equipped models.

CONCLUSIONS

There were a number of important major findings from this research:

- The potential of ABS in reducing fatal motorcycle crashes in Sweden is approximately 30%.
- The overall effectiveness of ABS in Sweden was 38% on all crashes with personal injuries and 48% on severe and fatal crashes. The minimum effectiveness ranged from 11% to 17%, respectively. The effectiveness on severe and fatal crashes in intersections was estimated to be at least 42%.
- Injury severity in crashes with ABS-equipped motorcycles is markedly lower than in similar one with non ABS-equipped motorcycles.
- Head-on motorcycle collisions are not, or only slightly, affected by ABS.

RECOMMENDATIONS

- Manufactures should work towards introducing ABS equipment on new motorcycles in each category in Sweden.
- Customers should be encouraged to only purchase motorcycles fitted with ABS technology.
- Further studies on a larger scale should be made in order to validate the results of this study and to investigate possible risk compensation behaviors.

ACKNOWLEDGMENTS

This study has been financed by the Skyltfonden project at SRA. Many thanks to Brian Fildes at MUARC for reviewing and improving the manuscript. Many thanks also to Anita Ramstedt, Mats Artebranth, Jörgen Persson and Ylva Berg at SRA, Jenny Eriksson at Vectura Consulting AB, Kristina Mattsson at Swedish Transport Agency and the Swedish branches of BMW, Honda, Suzuki, Kawasaki and Yamaha for valuable support in providing data on ABS equipment.

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APPENDIX

The tables below show the motorcycle models included in the induced exposure analysis.

Standard category

Case motorcycles n=29	Control motorcycles n=486
BMW R 1100 R BMW R 1150 R BMW R 850 R HONDA CB 1300 SA HONDA CB 600 FA HONDA CBF 1000 A HONDA CBF 600 SA KAWASAKI ER-6 N ABS KAWASAKI Z 750 ABS SUZUKI GSF 1200 SA YAMAHA FZ6 N ABS YAMAHA FZ6 S ABS	BMW R 850 R BUELL M2 CYCLONE BUELL S1 LIGHTNING BUELL X1 MILLENUIM BUELL XB12 X BUELL XB9 S CAGIVA V-RAPTOR DUCATI GT 1000 DUCATI MONSTER DUCATI MONSTER 1000 S DUCATI MONSTER 600-620 DUCATI MONSTER 750 DUCATI MONSTER 800 DUCATI MONSTER 900 DUCATI MONSTER S2 DUCATI MONSTER S4 DUCATI PAULSMART 1000 HONDA CB 1000 R HONDA CB 1100 SF HONDA CB 1300 F HONDA CB 500 HONDA CB 600 F HONDA CB 900 F HYOSUNG GT 650 KAWASAKI EJ 650 A KAWASAKI EN 500 KAWASAKI ER 500 KAWASAKI ER-5 KAWASAKI ER-6 N KAWASAKI Z 1000 KAWASAKI Z 750 KAWASAKI ZR 7 S KTM 640 DUKE KTM 990 DUKE MOTO GUZZI BREVA 1100 MOTO GUZZI GRISO V1100 MOTO GUZZI V11 SPORT SUZUKI GS 500 SUZUKI GSF 1200 SUZUKI GSF 600 SUZUKI GSF 650 SUZUKI GSR 600 SUZUKI GSX 1400 SUZUKI SV 1000 SUZUKI SV 650 TRIUMPH ADVENTURER TRIUMPH BONNEVILLE TRIUMPH LEGEND TT TRIUMPH SCRAMBLER TRIUMPH SPEED FOUR TRIUMPH SPEED TRIPLE TRIUMPH THRUXTON 900 TRIUMPH THUNDERBIRD YAMAHA BT 1100 YAMAHA FZ1 YAMAHA FZS 1000 YAMAHA FZS 600 YAMAHA MT01 YAMAHA MT03 YAMAHA XC 1100 YAMAHA XJ 600 YAMAHA XJ 900 S YAMAHA XJR 1300

On/off category

Case motorcycles n=52	Control motorcycles n=250
BMW F 650 CS BMW F 650 GS BMW F 800 GS BMW R 1100 GS BMW R 1150 GS BMW R 1200 GS BMW R 850 GS HONDA XL 1000 VA TRIUMPH TIGER 1050 ABS	APRILIA ETV 1000 APRILIA PEGASO 650 BMW F 650 GS BMW F 650 ST CAGIVA GRAN CANYON 900 CAGIVA NAVIGATOR M5 DUCATI MULTISTRADA 1000 HONDA FMX 650 HONDA FX 650 HONDA NX 650 HONDA SLR 650 HONDA XL 1000 V HONDA XL 600 V HONDA XL 650 HONDA XRV 750 KAWASAKI KL 650 C KAWASAKI KLE 500 A KAWASAKI KLV 1000 KAWASAKI VERSYS KTM 640 ADV KTM 660 ADV KTM 950 ADV SUZUKI DL 1000 SUZUKI DL 650 SUZUKI DR 650 SUZUKI DR 800 SUZUKI XF 650 TRIUMPH TIGER TRIUMPH TIGER 1050 YAMAHA TDM 850 YAMAHA TDM 900 YAMAHA TT 600 E YAMAHA XT 600 E YAMAHA XT 660 R YAMAHA XT 660 X YAMAHA XTZ 660

Touring category

Case motorcycles n=61	Control motorcycles n=104
BMW R 1100 RT BMW K 1100 LT BMW K 1200 GT BMW K 1200 LT BMW R 1100 RT BMW R 1150 RT BMW R 1200 CL BMW R 1200 RT HONDA GL 1800 A HONDA NT 700 VA HONDA ST 1100 HONDA ST 1300 A MOTO GUZZI NORGE 1200 TRIUMPH SPRINT ST ABS YAMAHA FJR 1300 A	HARLEY DAVIDSON FLHR HARLEY DAVIDSON FLHRCI HARLEY DAVIDSON FLHT HARLEY DAVIDSON FLHTCU HARLEY DAVIDSON FLHX HONDA GL 1500 HONDA NT 650 V HONDA NT 700 HONDA ST 1300 TRIUMPH SPRINT ST TRIUMPH TROPHY 1200 YAMAHA FJR 1300

Sport touring category

Case motorcycles n=45	Control motorcycles n=145
BMW F 800 S BMW F 800 ST BMW K 1200 RS BMW R 1100 S BMW R 1200 ST DUCATI ST4 ABS HONDA VFR 800 A KAWASAKI ER-6 F ABS	APRILIA RST 1000 BMW R 1100 S BUELL S3 THUNDERBOLT DUCATI ST2 DUCATI ST4 HONDA VFR 750 F HONDA VFR 800 FI HONDA VTR 1000 F KAWASAKI ER-6 F KAWASAKI GPZ 500 MOTO GUZZI 1100 SPORT SUZUKI GSX 600 F SUZUKI GSX 750 F SUZUKI RF 600 R SUZUKI RF 900 R SUZUKI TL 1000 S TRIUMPH SPRINT RS YAMAHA TRX 850