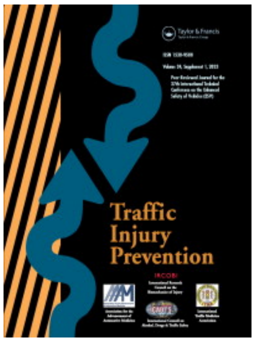
Effects on crash risk of automatic emergency braking systems for pedestrians and bicyclists



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Effects on crash risk of automatic emergency braking systems for pedestrians and bicyclists

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ABSTRACT

Objective: The first automatic emergency braking (AEB) system was presented in 2003 and aimed to mitigate or reduce rear-end crashes. Since then, several AEB systems aimed to reduce other collision types have been introduced and studies have shown that they reduce crash risks. The aim with this study was to evaluate crash reductions of cars fitted with AEB systems with pedestrian detection and those with bicyclist detection.

Methods: The study is based on the Swedish Traffic Accident Data Acquisition that includes road traffic accidents reported by the police and by emergency hospitals. Crashes occurring between 2015 and 2020 and with cars from model years 2015 to 2020 were included. The statistical analysis used odds ratio calculations with an induced exposure approach where the outcomes of sensitive and nonsensitive crashes were studied. The sensitive crashes were hit pedestrians and bicyclists, respectively. The nonsensitive crash type in both comparisons was struck vehicles in rear-end crashes. Evaluations were also made for different light and weather conditions and for high and low speed roads.

Results: Seven hundred and twelve hit pedestrians and 1,105 hit bicyclists were included, and the nonsensitive crashes consisted of 1,978 vehicles. The overall reduction on crash risk for AEB with pedestrian detection was 8% (±15%; ns) and for AEB with bicyclist detection it was 21% (±17%). When separating for light conditions, no reduction in crash risk for AEB with pedestrian detection nor for AEB with bicyclist detection could be seen in darkness. However, in daylight and twilight conditions, AEB with pedestrian detection reduced pedestrian crash risk by 18% (±19%; ns) and AEB with bicyclist detection reduced bicyclist crash risk by 23% (±19%). No significant reductions could be seen when separating for weather conditions except for a 53% (±31%) reduction for bicyclists in rain, fog, and snowfall. A larger reduction on high-speed roads (50–120 km/h) compared with low-speed roads (10–40 km/h) was also found.

Conclusions: AEB systems with bicyclist detection were found to reduce the numbers of hit bicyclists, especially in daylight and twilight conditions. In darkness, no reduction for hit pedestrians or bicyclists was found.

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Automatic emergency braking; AEB; pedestrian; bicyclist; crash reduction; effectiveness

Introduction

Worldwide, fatalities in the road transport system are dominated by car occupants, but the second largest group is pedestrians struck by motor vehicles (Naci et al. 2009; World Health Organization 2018). Road traffic fatalities are decreasing in Europe, especially regarding car occupants. However, fatalities among pedestrians and bicyclists do not follow the same positive trend (ETSC 2015; STA 2019). In the European Union, 21% of all fatalities in the road transport system are pedestrians (European Union 2019), and bicyclists account for approximately 8% (ETSC 2015). In Sweden, 18% of fatalities were pedestrians and 10% were bicyclists when fall injuries were included (Amin et al. 2022), and in terms of serious injuries, pedestrians are the most frequently injured road user group, followed by bicyclists (Amin et al. 2022).

In the line with the United Nation's global goals on sustainability, several initiatives promote walking and cycling. However, if effective countermeasures are not implemented, an increased number of pedestrians and bicyclists will lead to an increased number of road casualties. Therefore, further initiatives aimed at reducing the number of killed pedestrians and bicyclists are needed.

Several countermeasures aimed to prevent serious injuries and deaths among vulnerable road users have shown

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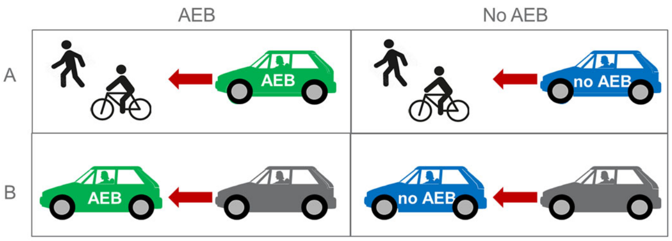

Figure 1. Matrix used for the induced exposure analyses: (A) Sensitive crashes: cars with and without AEB hitting a pedestrian or bicyclist and (B) nonsensitive crashes: struck vehicle in rear-end crashes.

positive effects. In crashes between vehicles and vulnerable road users, impact speed is one of the parameters with the highest influence on the risk of fatality and serious injury (Rosén and Sander 2009; Rosén et al. 2011). Therefore, in areas where vulnerable road users and vehicles are mixed in a planned and frequent manner, a maximum speed limit of 30 km/h should be applied (Stockholm Declaration 2020). In addition to speed limits, vehicle speed can be controlled and reduced by infrastructure countermeasures, such as speed bumps and chicanes (Pucher et al. 2010; Lee et al. 2013; Agerholm et al. 2017), and physical separation in the form of separated paths for pedestrians and bicyclists, as well as safety barriers (Kullgren et al. 2017) or tunnels and footbridges (Höye 2017). In studies that have identified the potential of many countermeasures aimed at reducing accidents with pedestrians and bicyclists, automatic emergency braking (AEB) systems with detection of vulnerable road users was found to have the greatest potential (Rosén et al. 2010; Kullgren et al. 2017, 2019).

The first AEB system was presented in 2003 and aimed at reducing the risk of rear-end crashes at low speed (Kodaka et al. 2003). Since then, many AEB systems aimed at reducing other collision types have been introduced, such as AEB for collisions at higher speed into other vehicles or stationary objects, crossings, pedestrians, bicyclists, and large animals and rear AEB for crashes during reversing, some of which have been shown to be effective in reducing crashes (Rizzi et al. 2014; Fildes et al. 2015; Cicchino 2017; Ydenius et al. 2017; Decker et al. 2021). A recent U.S. study has also investigated the effectiveness of the AEB with detection of pedestrians (Cicchino 2022). However, so far, studies of the effectiveness of AEB with the detection of bicyclists have not been presented.

The aim of this study was therefore to evaluate crash reductions of cars fitted with AEB systems with pedestrian detection and those with bicyclist detection.

Methods

Data were retrieved from the Swedish Traffic Accident Data Acquisition (STRADA), a register that includes road traffic accidents reported by the police and by emergency hospitals where at least one person was injured (Transportstyrelsen 2022). Crashes occurring between 2015 and 2020 and with cars of model years 2015 to 2020 were included. The process for the evaluation is described in a flow chart (Figure A1, online supplement). The statistical analysis used odds ratio calculations with an induced exposure approach where the outcomes of sensitive and nonsensitive crashes were studied. The method can be used when true exposure is not available (Evans 1998). With this approach, the key point is to identify at least one crash type in which the countermeasure to be analyzed could be reasonably assumed (or known) not to be effective.

The sensitive crashes were hit pedestrians and bicyclists. The nonsensitive crash type used was struck vehicles in rear-end crashes. Fitment of AEB for detection of vulnerable road users in frontal impacts should not influence the risk of being struck in the rear. Figure 1 shows the matrix describing the groups. Evaluations were also made for different lighting conditions, weather conditions, and speed limits.

$$R_{\text{pedestrians}} = \frac{A_{\text{AEB-ped}}}{B_{\text{AEB-ped}}} \div \frac{A_{\text{no AEB-ped}}}{B_{\text{no AEB-ped}}} \quad (1)$$

$$R_{\text{bicyclists}} = \frac{A_{\text{AEB-bicycle}}}{B_{\text{AEB-bicycle}}} \div \frac{A_{\text{no AEB-bicycle}}}{B_{\text{no AEB-bicycle}}}, \quad (2)$$

where $A_{\text{AEB-ped}}$ is the number of hit pedestrians, involving cars with AEB for pedestrians; $A_{\text{no AEB-ped}}$ is the number of hit pedestrians, involving cars without AEB for pedestrians; $B_{\text{AEB-ped}}$ is the number of struck cars with AEB for pedestrians in rear-end crashes; $B_{\text{no AEB-ped}}$ is the number of struck cars without AEB for pedestrians in rear-end crashes; $A_{\text{AEB-bicycle}}$ is the number of hit bicyclists, involving cars with AEB for bicyclists; $A_{\text{no AEB-bicycle}}$ is the number of hit bicyclists, involving cars without AEB for bicyclists; $B_{\text{AEB-bicycle}}$ is the number of struck cars with AEB for bicyclists in rear-end crashes; and $B_{\text{no AEB-bicycle}}$ is the number of struck cars without AEB for bicyclists in rear-end crashes.

For each equation, the effectiveness (%) in terms of crash reduction can be expressed as

$$E_{\text{pedestrians, bicyclists}} = 1 - R_{\text{pedestrians, bicyclists}}. \quad (3)$$

The standard deviation of each effectiveness was calculated based on a simplified odds ratio variance according to Eq. (4):

$$SD = \sqrt{\sum_{i=1}^{4} \frac{1}{m_i}}, \quad (4)$$

where m is the number of crashes of each type. The 95% confidence limits for each effectiveness are given in Eq. (5):

$$E \pm \Delta E = E \pm 1.96 * R * SD. \quad (5)$$

Results

A total of 712 hit pedestrians and 1,105 hit bicyclists were included. The nonsensitive crashes consisted of 1,978 struck vehicles in rear-end collisions. The existence of AEB was identified in most vehicles except those noted as unknown (Table 1).

Table 1. Number of hit pedestrians, number of rear-end crashes, and injury crash reduction for cars with AEB for pedestrians and bicyclists.

		AEB pedestrian		AEB bicycle		Injury crash reduction	
	AEB fitment	Rear-end (*n*)	Pedestrian (*n*)	Rear-end (*n*)	Bicycle (*n*)	AEB pedestrian (%)	AEB bicyclist (%)
Total	Yes	598	209	288	133	8	21
	Unknown	76	14	38	12	±15	±17
	No	1,283	489	1,652	960		
	Total	1,957	712	1,978	1,105		
Daylight	Yes	474	103	237	100	19	20
	Unknown	66	7	33	9	±21	±19
	No	1,001	267	1,289	719		
	Total	1,541	377	1,559	828		
Day- and twilight	Yes	512	119	253	107	18	23
	Unknown	67	10	33	10	±19	±19
	No	1,096	312	1,412	776		
	Total	1,675	441	1,698	893		
Darkness	Yes	124	77	51	20	−8	−9
	Unknown	12	3	9	1	±37	±61
	No	273	157	356	128		
	Total	409	237	416	149		
Good visibility	Yes	520	145	241	111	11	11
	Unknown	65	7	33	8	±20	±21
	No	1,115	350	1,449	752		
	Total	1,700	502	1,723	871		
Rain, fog, snow	Yes	104	36	54	12	28	53
	Unknown	11	3	6	2	±33	±31
	No	194	93	254	119		
	Total	309	132	314	133		
Low-speed, 10–40 km/h	Yes	81	112	41	80	−9	15
	Unknown	5	6	3	5	±37	±35
	No	197	251	243	556		
	Total	283	369	287	641		
High-speed, 50–120 km/h	Yes	523	91	250	53	21	26
	Unknown	74	7	37	7	±21	±24
	No	1,061	235	1,395	397		
	Total	1,658	333	1,682	457		

The overall reduction in crash risk for AEB with pedestrian detection was 8% (±15%; not significant) and for AEB with bicyclist detection it was 21% (±17%; significant; Table 1). When separating for lighting conditions, no reduction in crash risk for AEB with pedestrian detection or for AEB with bicyclist detection could be verified in darkness (−8% ± 37% for pedestrians and −9% ± 61% for bicyclists). However, in daylight and twilight conditions, AEB with pedestrian detection was found to reduce pedestrian crash risk by 18% (±19%) and AEB with bicyclist detection was found to reduce bicyclist crash risk by 23% (±19%). With the data available, no significant reductions were observed when separating for weather conditions except for a 53% (±31%) reduction for bicyclists in rain, fog, and snowfall. A larger reduction on high-speed roads (50–120 km/h) compared to low-speed roads (10–40 km/h) was also found (Table 1).

Discussion

From both public health and environmental perspectives, the ambition is to increase the number of pedestrians and bicyclists, and it has been shown that the positive effects of cycling outweigh the increased risks (de Hartog et al. 2010). However, increased protection of vulnerable road users is essential and desirable to be able to increase the number of pedestrian and bicyclist trips, especially in urban areas.

Studies have shown that the potential of AEB with detection of pedestrians and bicyclists to avoid crashes is high, meaning that AEB can address many of the accidents (Kullgren et al. 2017, 2019). Although AEB systems with both pedestrian and bicyclist detection show a crash reduction, this study shows a relatively low reduction compared to AEB aimed at avoiding or mitigating collisions with other vehicles. Another study has shown a slightly higher injury crash reduction for AEB for pedestrians (29%–30%) and a higher reduction at lower speeds (up to 56 km/h; Cicchino 2022).

Clearly, to be able to reach the full potential of AEB, the effectiveness needs to increase, and it appears that AEB alone will not be enough to protect vulnerable road users. To ensure protection of vulnerable road users in cities and other low-speed areas, a combination of maintaining speed below 30 km/h (for example, by geofencing) and AEB and good passive protection on car fronts in case of an accident could be used, as proposed by others (Lubbe et al. 2022).

The findings regarding the performance of AEB for pedestrians in various lighting conditions are in line with those of another recent study (Cicchino 2022). Bad performance in darkness is critical because studies have shown that, to a large extent, pedestrians are hit in darkness. The same poor performance in darkness was also found for AEB with bicyclist detection, thereby showing the importance of improving detection in darkness.

Furthermore, in poor light there may be too little time for the system to be able to detect and activate. Many bicyclists enter the road less than 1 s before impact, which makes it difficult for the AEB system to react, assuming that 1 s is needed for the system to be able to detect and react (Haus et al. 2021). It is proposed that in areas where vulnerable road users and vehicles are mixed in a planned and frequent manner, a maximum speed limit of 30 km/h should be applied (Stockholm Declaration 2020). This would probably increase the possibility for the AEB systems to detect vulnerable road users, which would increase their effectiveness.

The reductions for both AEB systems evaluated were higher under bad weather condition (rain, fog, or snowfall) compared with good visibility, which could seem unlikely at a first glance. However, this could be due to the relationship between car and driver; that is, the car may be better a driver at detecting vulnerable road users in bad weather. However, this needs to be further evaluated.

Another finding was that the reduction on low-speed roads (10–40 km/h) was lower than that on high-speed roads (50–120 km/h). This somewhat contradicts the results found by Cicchino (2022). However, this study involved many accidents on parking lots, walking and cycling paths, and other low-speed areas. The reduction in these areas may be lower because the driver has time to react and steer or brake, meaning that the AEB may not be activated. This should be further evaluated with larger data sets.

The effect of AEB on injury severity for vulnerable road users was not evaluated in this study and should be further studied.

Research strength and limitations

This study is based on real-world crashes that occurred in the Swedish traffic environment and were registered in STRADA. The register offers a unique opportunity to study this problem using accident data reported by the police and injury data from every emergency hospital in Sweden. The register data contain detailed information about characteristics from many crashes in Sweden, such as how the accident occurred and which road users were involved. STRADA includes vehicle data such as make, model, model year, and vehicle identification number. Based on this information, it was possible to identify whether AEB for pedestrians and bicyclists was fitted for each involved vehicle.

The present research used an induced exposure approach, as in several previous studies (Evans 1998; Strandroth et al. 2012; Rizzi et al. 2014). Other exposures could also be used for this kind of evaluation; for instance, the number of registered vehicles with and without the analyzed technology. However, these may include confounding factors for which an induced exposure approach would normally compensate, because the result is given by the relative differences within the AEB and non-AEB groups. The present method, however, is based on some assumptions that are important to discuss. The most critical step in the analysis is to determine the nonsensitive crash type. In the present study, struck rear-end crashes were considered nonsensitive. There is no reason to believe that AEB for detection of vulnerable road users in frontal impacts would influence the risk of being struck in the rear.

Data quality is also a limitation that needs to be discussed. Police-reported crashes were used, and these are well known to suffer from quality issues. This aspect was especially important in the case of defining the striking and struck cars for the calculations using the induced exposure technique. To improve quality, this classification was done manually, based on the description of the crashes made by the police officer at the crash scene.

Most of the vehicles included (both study group and control group) were fitted with AEB City systems aimed to avoid or mitigate low speed rear-end crashes. Under certain circumstances, AEB City may also detect pedestrians and bicyclists. A crude analysis of the reduction in hit pedestrians was conducted and indicated no reduction. However, this should be further investigated. If AEB City has a small effect on vulnerable road users, the true reduction with detection of vulnerable road users would be somewhat larger than what was found in this study.

Furthermore, during the model year period 2015 to 2020, there have been improvements of pedestrian AEB performance, which can be seen in the performance in the European New Car Assessment Programme assessments. When more data are available, further research should be conducted including shorter time spans; for example, model years 2018 to 2020 and later intervals.

Lastly, the Swedish car fleet has a larger proportion of Volvo models than other countries, which should be considered in comparisons with studies using data sets from other countries.

In conclusion, even though there are several factors that could influence the findings of the present study, AEB systems with bicyclist detection were found to reduce the number of hit bicyclists, especially in daylight and twilight conditions. No reduction in hit pedestrians or bicyclists in darkness was observed. Generally, the more noise in the data, the lower the effectiveness that will be found (Kullgren and Lie 1998); therefore, there is reason to believe that the true effect of AEB systems may be larger than those presented.

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