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Research article

The safety effect of increased pedestrian protection, autonomous emergency braking for pedestrians and bicyclists on passenger cars, and speed management

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Abstract: This was the first retrospective study to estimate the effect of increased pedestrian protection, autonomous emergency braking, and speed management to reduce serious injuries among pedestrians and bicyclists. More specifically, the aim was to estimate the injury mitigating effects of the following interventions: AEB with pedestrian and bicyclist detection, Euro NCAP pedestrian test score, active bonnet, traffic calming at pedestrian and bicycle crossings, and additionally, the combined effect of the above-mentioned treatments. The main source of data was the Swedish traffic data acquisition system (Strada), where information of road traffic crashes between passenger cars and pedestrians or bicyclists for the period 1 January 2003–31 December 2022 was obtained. Cars with optional fitment of AEB systems were identified, and the license registration number was used to access individual car equipment lists to identify whether the vehicle was equipped with AEB with pedestrian and/or cyclist detection. Information about traffic calming at pedestrian and bicycle crossings was obtained from the Swedish Transport Administration. The injury metric used was risk of permanent medical impairment (RPMI) of at least one percent and ten percent. RPMI captures the risk of long-term medical impairment based on a diagnosed injury location and Abbreviated Injury Severity (AIS) score. The relative difference between the mean values of RPMI (mRPMI1%+ and mRPMI10%+) was calculated and tested using an independent two sample t-test which was conducted for unequal sample sizes and variance. Although many results were found to be statistically non-significant, the following results were found to be significant at least at 90% level. Pedestrian mRPMI10%+ was reduced by 44% in speed zones $\leq$ 50 km/h comparing the group struck by cars equipped with AEB with pedestrian detection compared to the group struck by cars without the system. For cyclists, the mRPMI10%+

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was reduced by 35% in speed zones $\leq$ 50 km/h. For crashes within ± 20 meters from a pedestrian or bicycle crossing, the AEB system reduced 60% of pedestrians mRPMI10%+ at crossings with good safety standard compared to crossings of poor safety standard. The comparison of cars with poor performance (1–9 points) in the NCAP pedestrian test and cars with a high score (28–36 points) showed that pedestrian mRPMI10%+ was reduced by 48% across all speed limits, and by 64% including only those aged $\leq$ 64 years. For bicyclists, a significant reduction of cyclist mRPMI10%+ was found comparing low scoring cars to high scoring cars in $\leq$ 30 km/h speed limit (-73%) and across all speed limits (-36%). Including only those aged $\leq$ 64 years, the reduction was 49%. For the active bonnet, a significant reduction of mRPMI1%+ by 24% was observed but given that the rate of helmet wearing was higher in the group struck by cars with active bonnet, this difference cannot be attributed to an effect of an active bonnet. The STA safety rating of pedestrian and bicycle crossings showed that overall pedestrian mRPMI1%+ was reduced by 15%, while cyclists mRPMI10%+ was reduced by 32% comparing crossings of high safety level to crossings of poor safety level. The analysis of combined interventions showed that the total reduction of pedestrians and cyclists mRPMI10%+ together was 69%, from 6.4% to 2%. This paper demonstrates that a road environment with adapted infrastructure and speed, combined with passenger car technologies that improve the safety for vulnerable road users, can create significant reductions of serious (long-term) injuries among pedestrians and bicyclists.

Keywords: AEB with cyclist detection, AEB with pedestrian detection, Euro NCAP, pedestrian protection, speed management

1 Introduction

Vision Zero, the policy framework for road safety introduced in 1995, builds on the aspiration to control kinetic energy and keep the amount of kinetic energy below the threshold of human biomechanical tolerance for serious injuries (Tingvall & Haworth, 1999). This principle comes from the fact that impact speed has been shown to be one of the factors with the highest influence on the risk of a fatal or serious injury outcome in crashes between vehicles and pedestrians and bicyclists (Rosen & Sander, 2009; Rosen et al., 2011).

Crashes involving passenger cars account for a significant proportion of trauma among vulnerable road users as pedestrians and bicyclists, worldwide and in Sweden (Naci et al., 2009; Cripton et al., 2015; Bil et al., 2016; Ohlin et al., 2019; Amin et al., 2022). A safe environment where passenger cars and vulnerable road users are sharing the road space is therefore of great importance. Not only when it comes to reducing road deaths and injuries, but also when it comes to increasing the proportion of active travel and sustainable transportation, especially in urban environments.

The Vision Zero design principles promote a maximum 30 km/h travel speed where vulnerable road users and motor vehicles interact (Johansson, 2009). Besides an appropriate speed limit, other traffic calming infrastructure treatments such as raised pedestrian crossings, speed bumps, road narrowing and chicanes are also used to manage vehicle travel speeds (Pucher et al., 2010; Lee et al., 2013; Agerholm et al., 2017). Accordingly, the Swedish Transport Administration (STA) has developed a tool to classify pedestrian crossings according to three safety levels; good safety standard (represented by a green colour), medium safety standard (yellow) and poor safety standard (red). Good safety standard means that a crossing is grade separated or has a speed bump or similar, or a 30 km/h speed limit combined with road narrowing, to ensure that at least 85% of vehicles travel at maximum 30 km/h (Lundberg & Ekman, 2016). The real-life safety benefits of the STA classification are, however, yet to be evaluated.

Apart from speed management, the vehicle itself can be designed and equipped with safety features to mitigate the injury severity in crashes with vulnerable road users. In 1997 Euro NCAP started evaluating pedestrian protection by testing leg form to bumper impact severity, upper leg form to bonnet leading edge and head form to bonnet top. In the test, a car can score between 0-36 points. From 1997-2008 the test score was given as a separate star rating, where 1 star was given to tests performing between 1 and 9 points, 2 stars between 10 and 18 points, 3 stars between 19 and 27 points, and 4 stars between 28 and 36 points. Previous studies have shown a correlation between the Euro NCAP pedestrian test score and injury outcome of pedestrians and to some extent bicyclists in real world crashes (Strandroth et al., 2011; Sternlund, 2011; Strandroth et al., 2014; Ohlin et al., 2017). However, due to a limited number of cases, it was not possible to differentiate between 3-star vehicles and 4-star vehicles, therefore it is unknown how a 4-star car compares to lower scoring car models.

The Euro NCAP pedestrian test has also led to car manufacturers introducing additional features to improve the test score. In 2006 the active bonnet safety system was introduced. This system was designed to improve pedestrian safety using front sensors so that, when detecting a collision, the rear part of the bonnet is raised to better absorb the impact with the pedestrian (Euro NCAP, 2023). As of today, no studies have evaluated this system in real-life conditions.

In later years an increasing number of passenger cars have been equipped with Autonomous Emergency Braking (AEB) systems that can detect and brake for pedestrians and bicyclists. In retrospective studies, 13%–30% reductions of police reported car-to-pedestrian crashes has been reported (Cicchino, 2022; Kullgren et al., 2023; Leslie et al., 2021, 2022; Spicer et al., 2021), while studies based on insurance claims in Sweden report between 6–36% depending on crash scenario (Isaksson-Hellman & Lindman, 2019, 2023). In a study from the US, the effect of AEB with pedestrian detection showed a 30% reduction of pedestrian injury crashes (Cicchino, 2022). A recent study from Sweden showed no significant reduction of police reported pedestrian injury crashes, but a 23% (± 19%) reduction of car to bicycle crashes in daylight and twilight (Kullgren et al., 2023). Similar to the study by Kullgren et al. (2023), another Swedish study based on insurance claims reported a small but not statistically significant reduction of car-to-pedestrian and car-to-bicycle crashes involving Volvo cars (Isaksson-Hellman & Lindman, 2023).

However, the effectiveness of an AEB system with pedestrian and cyclist detection is not limited to crash avoidance, but even more importantly to the influence of the system on the injury outcome in case of a crash. That is, even if the system cannot avoid a collision, the automated braking could lead to a lower impact speed compared to cars without the system. Also in this case, no evaluations have been undertaken to evaluate the injury mitigating effects of AEB for pedestrian and cyclist detection. It is clear from how AEB systems are designed and from previous real-life evaluations of pedestrian protection, that the effect of different injury mitigating countermeasures are likely to result in larger benefits combined rather as separate interventions. E.g. traffic calming could increase the safety effects of AEB by including more crashes in the effective envelop through reduced travel speed. Regardless of AEB systems, travelling at lower speeds could also help drivers anticipate pedestrian action and avoid the crash by themselves. Further, Strandroth et al. (2011) showed a greater effect of a high Euro NCAP score for pedestrian protection in lower speed zones. Ohlin et al. (2017) showed great reductions of serious injuries among pedestrians and bicyclists when combining different interventions targeting vulnerable road users, including helmet wearing, thus illustrating that different treatments and interventions can complement and enhance each other. This, together with the increased demand for more livable and place oriented urban areas, shows that the safety for vulnerable road users as pedestrians and bicyclists does not have one single solution. Instead, a holistic approach needs to be taken where everything from vehicle design, speed management, roads and street design as well and land use and transport planning needs to be considered.

Despite the promising results of combined safety interventions for pedestrians and cyclists, the present paper has listed a number of treatments that have not yet been evaluated; 4-star vehicles in the NCAP pedestrian test, traffic calming as per the STA classification, and injury mitigating effect of AEB with pedestrian and cyclist detection. Therefore, the overall objective of this paper was to estimate the effect of increased pedestrian protection and speed management to reduce serious injuries among pedestrians and bicyclists.

More specifically, the aim was to estimate the injury mitigating effects of the following interventions:

1. AEB with pedestrian and bicyclist detection
2. Euro NCAP pedestrian test score (high performing cars VS low performing cars) and active bonnet
3. Traffic calming at pedestrian and bicycle crossings
4. The combined effect of the above-mentioned treatments.

2 Material and methods

2.1 Material

The present paper included data from a number of sources. The main source of data was the Swedish traffic data acquisition system (STRADA), where information of road traffic crashes between passenger cars and pedestrians or bicyclists for the period January 2003–December 2022 was obtained. STRADA contains information of road traffic crashes reported by either the police and/or emergency care hospitals. STRADA contains a number of characteristics, such as information regarding sex, age, location, crash circumstances, weather conditions etc (Amin et al., 2022). When there is medical information about the crashes, such as injury severity, the reports from the two sources are linked together (Howard & Linder, 2014). The information contained in the register is pseudonymized (Transportstyrelsen, 2023).

AEB with pedestrian and/or cyclist detection is standard in some car models and optional on some others, depending on model and model year. To find this information, ethical approval was obtained in order to access individual vehicle information in form of the vehicle license registration number from STRADA. Cars with optional fitment of these systems were identified, and individual information in terms of manufacturer codes was identified through license registration numbers and individual car equipment lists via the website *biluppgifter.se*. Cars with uncertain or unknown AEB status were not included in the analysis.

To identify crashes that occurred on or near a traffic calming treatment, the coordinates for all crashes was sent to the STA, which provided a list of bicycle and pedestrian crossing facilities and any traffic calming infrastructure in connection to the crash sites. The data also included a report date of completion reported to STA. Crashes that had occurred before the report date of the treatment were identified, and for these, Google Street View was used to identify if the treatment was present at the time of the crash. This was, however only possible for crashes occurring after 2009 since that was the first year with available Street View.

Furthermore, crashes in which the AEB VRU would not be expected to be activated were excluded. Such crashes are when the pedestrian or cyclist had not been struck by the car front, for example if the passenger car was reversing, or if a cyclist had rear-ended a passenger car. Only crashes with available information from both the police and emergency care hospital, and where the vehicle identification number/license registration number was available were included. Fatalities as well as cases without fully diagnosed injuries were also excluded. The final sample consisted of 11 035 crashes involving 4 306 pedestrians and 6 902 cyclists.

2.2 Injury outcome measure

The injury measure used in this study was the Risk of Permanent Medical Impairment (RPMI), which is the basis for the Swedish national target for serious injuries and is included in the STRADA database (Berg et al., 2016). RPMI estimates the risk of long-term medical impairment based on the diagnosed injury location and severity and criteria of the Swedish Insurance Companies (Malm et al., 2008; Försäkringsförbundet, 2004). A medical impairment is considered permanent when no further improvement in physical and/or mental function is expected with additional treatment. The assessment impairment degree is independent of cause and without regard to occupation, hobbies or other special circumstances of the injured person. An injury is given a degree of medical impairment between 1% and 99%. Some general examples are as follows: limited motion of shoulder 1–20%, amputation of tibia is set to an impairment of 19%, total loss of hearing 60%. While permanent medical impairment of at least one percent includes all levels of impairments, a permanent medical impairment of at least ten percent results in persistent symptoms affecting activities of daily living of a person. The present study used the mean RPMI (mRPMI) of PMI of at least 1% (mRPMI1%+) and at least 10% (mRPMI10%+).

Risk of permanent medical impairment of at least 1% and 10% can be found in the Supplements (Table S1, published separately), and these values are used to calculate an overall RPMI according to Equation (1):

$$RPMI = 1 - \prod_{i=1}^{n}(1 - \text{risk}_i) \tag{1}$$

See Malm et al. (2008) for a more detailed description of the method.

2.3 Statistical tests

The relative difference between the mean values of RPMI (mRPMI1% and mRPMI10%+) was calculated and tested using an independent two sample t-test which was conducted for unequal sample sizes and variance, the same approach as used in Strandroth et al. (2011); Rizzi et al. (2016); Ohlin et al. (2017). *p*-

values are displayed to indicate significance level at 99%, 95% and 90%. Following are descriptions of the comparisons made and how comparison groups were created.

2.4 Effect of AEB

The data was analysed in order to match case and control groups of cars with and without AEB with pedestrian/cyclist detection with regards to car sizes, model years and pedestrian protection score according to the Euro NCAP tests. This meant that the following conditions were set and applied to both pedestrians and cyclists:

- NCAP pedestrian protection score ≥ 10
- Small family car, mid size car, large car, small / large SUVs
- Model Year (MY) ≥ 2014.

For injured pedestrians, this resulted in 135 cases involving AEB with pedestrian detection and 188 cars without. For injured cyclist the result was 169 cases involving AEB with cyclist detection and 500 without. This means that a variety of manufacturers, with various different AEB systems, are included. Hence, this study mirrors the variety of AEB systems, with different technical specifications and performance, present in the modern Swedish car fleet. A list of all car models and sizes included in the analysis can be found in the Supplements (Table S2).

2.5 Effect of pedestrian protection

The Euro NCAP pedestrian test score (i.e. without the score for AEB system) was used to estimate the effect of pedestrian protection. All car models and model years with a pedestrian test score were included, although cars with AEB with pedestrian and/or cyclist detection were excluded as this could potentially confound the results. Four groups of cars were created, based on the star rating previously used by Euro NCAP, where:

- 3-Star = 1–9 points
- 4-Stars = 10–18 points
- 5-Stars = 19–27 points
- 6-Stars = 28–36 points.

For this analysis, the impact of age of the struck pedestrian or cyclist was considered by estimating the effect of pedestrian protection for those aged ≤ 64 years in addition to all age groups. The cut-off at 65 years has been done in similar studies, e.g. Lubbe et al. (2022); Wisch et al. (2017).

2.6 Active bonnet

A separate analysis was undertaken to understand if the active bonnet influences the injury severity compared to cars without active bonnet, but with a similar (high) score in the Euro NCAP pedestrian protection test. Included in the analysis was all car models with Model Year ≥ 2009, scoring 19–36 points, without AEB with pedestrian/cyclist detection.

A list of cars equipped with active bonnet included in the analysis can be found in the Supplements (Table S2).

2.7 Traffic calming

A cut-off of at ± 20 meters from the collision point was set, which meant that any traffic calming treatment within 20 meters distance from the crash site assumed the crash to have occurred in a treated area. The STA classification of pedestrian and bicyclist crossings was used (Lundberg & Ekman, 2016), and is defined as:

Good safety standard (green):

- Grade separated crossings[1]
- Other crossing at level and including a traffic calming measure (speed bump/raised intersection within 15 meters of the crossing
- Other crossing at level with max 30 km/h speed limit including some type of road narrowing or lateral displacement.

Medium safety standard (yellow):

- Crossing at level with max 30 km/h speed limit
- Signalized crossing at level and 40 km/h speed limit
- Other crossing at level and 40 km/h speed limit including road narrowing within 15 meters from crossing
- Other crossing at level within 15 meters from a roundabout.

Poor safety standard (red):

- If none of the above-mentioned conditions are met.

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[1] For this analysis, grade separated crossings were excluded.

2.8 Combined effect of different measures

The empirical combined effect was calculated, where a crash population with different treatments included at the same time was compared to another crash population without the treatments. Specifically, the following groups were created and compared:

- Pedestrians and helmeted bicyclists struck by cars with $\geq$ 19 points in the Euro NCAP test, with AEB with pedestrian/cyclist detection, on crossings with good safety standard
- Pedestrians and non-helmeted bicyclists struck by cars with 1–9 points in the Euro NCAP test, without AEB with pedestrian/cyclist detection, on crossings with poor safety standard.

As reference, the theoretical combined effect of the above-mentioned treatments was also calculated according to the method of common residuals (Elvik, 2009):

$$\text{Combined effect} = 1 - \textstyle\prod_{i=1}^{n}(1 - E_i) \tag{2}$$

This approach assumes independence between treatments. The effect of helmet to reduce mRPMI10%+ among bicyclists was derived from Rizzi et al. (2013), where the effect of helmet to reduce serious head injuries (64%) was multiplied by the proportion of serious head injuries (42%).

2.9 Handling of confounding factors

The effect of AEB and the Euro NCAP pedestrian test score are confounding factors for one another, thereby, as described earlier, the effect the Euro NCAP pedestrian test score is calculated only for cars without AEB. Vice versa, the effect of AEB can be influenced by the proportion of cars with a high score in the Euro NCAP pedestrian test. The proportion between different groups of points split by AEB fitment can be fount in the Supplements (Table S4).

Another obvious confounder is speed. As we do not have information of involved vehicles travel speeds, the speed limit as well as the level of traffic calming is regarded as a proxy for speed, and results are calculated for different speed limits and levels of traffic calming (STA safety rating of crossings).

Another confounding factor is helmet wearing among cyclists and the rate of helmet wearing is presented in the text throughout the result section. Other factors related to the individuals such as age and gender are presented in the Supplements.

The characteristics of the comparison groups are shown in the Supplements (Tables S6–E11), along with the injury distributions (Tables S12–S13).

3 Results

3.1 Effect of AEB with pedestrian and cyclist detection

Table 1 shows the effect of AEB with pedestrian detection on pedestrians mRPMI10%+ and mRPMI1%+ by speed limit and STA safety rating of pedestrian and bicycle crossings. For mRPMI10%+ a reduction of 44% can be observed for speed zones $\leq$ 50 km/h, as well as speed zones 40–50 km/h, between the group struck by cars equipped with AEB with pedestrian detection compared with the group struck by cars without the system. However, the reductions are only significant at 90% level. In speed zones of $\geq$ 60 km/h no reduction can be observed. For mRPMI1%+ only the reduction of 21% in speed zones 40–50 km/h is statistically significant of at least 90%.

For pedestrian crossings, the effect of AEB with pedestrian detection shows a significant reduction of 60% for mRPMI10%+ ($p = 0.05$) and 34% for mRPMI1%+ ($p = 0.02$) at crossings of less good or poor quality. At crossings of good quality, no significant reductions can be observed either for mRPMI10%+ or mRPMI1%+.

Table 2 shows the effect of AEB with cyclist detection on mRPMI10%+ and mRPMI1%+ divided by speed limit and STA safety rating of pedestrian/bicycle crossings. In $\leq$ 50 km/h speed zones, a reduction of 35% ($p = 0.05$) is observed comparing the group struck by cars equipped with AEB with pedestrian detection compared with the group struck by cars without the system. In $\leq$ 50 km/h speed limit, the rate of helmet wearing was 45% in the group of cyclists struck by cars with AEB with cyclist detection and 46% in the group struck by cars without the system (Table 3). In speed zones of $\geq$ 60 km/h no reduction can be observed.

As regards the effect of AEB across the TS safety rating of pedestrian/bicycle crossings, no significant reduction of bicyclists mRPMI10%+ or mRPMI1%+ was observed. The rate of helmet wearing was lower or the same for cyclists struck by cars with or without

Table 1 Effect of AEB with pedestrian detection on pedestrians mRPMI10%+ and mRPMI1%+ by speed limit and STA traffic safety rating of pedestrian and bicycle crossings

Speed limit	With AEB pedestrian mRPMI10+ (n)	Without AEB pedestrian mRPMI10+ (n)	Rel. diff mRPMI10+	*p*-value	With AEB pedestrian mRPMI1+ (n)	Without AEB pedestrian mRPMI1+ (n)	Rel. diff mRPMI1+	*p*-value
≤ 30 km/h	2.8% (33)	4.3% (32)	-34%	n.s.	21% (33)	17% (32)	+19%	n.s.
40–50 km/h	4.1% (70)	7.2% (118)	-44%	0.09*	25% (70)	32% (118)	-21%	0.08*
≤ 50 km/h	3.4% (103)	5.7% (150)	-44%	0.06*	24% (103)	29% (150)	-18%	n.s.
≥ 60 km/h	16% (11)	7.5% (11)	+112%	n.s.	42% (11)	38% (11)	-18%	n.s.
STA safety rating of crossings								
Green	1.7% (7)	1.8% (11)	-8%	n.s.	23% (7)	13% (11)	+71%	n.s.
Yellow	1.2% (24)	5.7% (29)	-79%	n.s.	16% (24)	25% (29)	-34%	n.s.
Red	4.4% (32)	8.7% (51)	-49%	n.s.	25% (32)	36% (51)	-32%	0.08*
Yellow + Red	3.0% (56)	7.6% (80)	-60%	0.05**	21% (56)	32% (80)	-34%	0.02**

* Statistically significant at 90% level

** Statistically significant at 95% level

Table 2 Effect of AEB with cyclist detection on mRPMI10%+ and mRPMI1%+ by speed limit and STA safety rating of pedestrian/bicycle crossings

Speed limit	With AEB cyclist mRPMI10+ (n)	Without AEB cyclist mRPMI10+ (n)	Rel. diff mRPMI10+	*p*-value	With AEB cyclist mRPMI1+ (n)	Without AEB cyclist mRPMI1+ (n)	Rel. diff mRPMI1+	*p*-value
≤ 30 km/h	2.3% (31)	3.4% (82)	-31%	n.s.	17% (31)	19% (82)	-13%	n.s.
40–50 km/h	2.2% (104)	3.3% (293)	-35%	n.s.	20% (104)	20% (293)	-4%	n.s.
≤ 50 km/h	2.2% (135)	3.4% (375)	-35%	0.05**	19% (135)	20% (375)	-6%	n.s.
≥ 60 km/h	9.5% (9)	4.7% (11)	+102%	n.s.	31% (9)	29% (11)	+5%	n.s.
STA safety rating of crossings								
Green	2.5% (32)	2.8% (53)	-12%	n.s.	19% (32)	25% (53)	-23%	n.s.
Yellow	3.8% (36)	4.3% (114)	-12%	n.s.	17% (36)	21% (114)	-23%	n.s.
Red	3.8% (29)	2.7% (97)	+40%	n.s.	28% (29)	19% (97)	+43%	n.s.
Yellow + Red	3.8% (65)	3.6% (211)	+6%	n.s.	21% (65)	18% (211)	+20%	n.s.

** Statistically significant at 95% level

Table 3 Bicyclists helmet wearing rate

Speed limit	% cyclists with helmet (AEB with cyclist detection)	% cyclists with helmet (AEB without cyclist detection)
≤ 30 km/h	44%	59%
40–50 km/h	47%	41%
≤ 50 km/h	45%	46%
≥ 60 km/h	33%	74%
TS safety rating of crossings		
Green	19%	49%
Yellow	44%	47%
Red	52%	52%

AEB with cyclist detection (Table 3).

3.2 Effect of pedestrian protection

The effect of Euro NCAP pedestrian protection score on pedestrians mPRMI1%+ and mRPMI10%+, divided by speed limit is shown in Table 4. Only cars not equipped with AEB with pedestrian detection are included. Comparing pedestrians struck by cars with a low score (1–9 points) or a high score (28–36 points) the total reduction in all speed limits is 48% on mRPMI10%+ ($p = 0.01$). In low speeds (≤ 30 km/h) the reduction is 98% ($p < 0.01$), however, there are only six pedestrians struck by a 28–36 point car in ≤ 30 km/h speed zones. Looking only at pedestrians aged ≤ 64 years, the reduction between low scoring cars and high scoring cars is 64% ($p < 0.01$). For mRPMI1%+ similar reductions, but smaller, are observed with 67% reduction in ≤ 30 km/h ($p < 0.01$) and 23% reduction across all speed limits ($p = 0.07$).

A significant reduction of pedestrian mRPMI10%+ comparing cars with 1–9 points and cars with 26–38 points was found at crossings with medium safety level according to the STA classification, -58% ($p < 0.01$). For mRPMI1%+, a significant reduction was observed at crossings with good safety level (green), -67% ($p < 0.01$).

Table 5 shows the effect of Euro NCAP pedestrian protection score on cyclists mRPMI10%+ and mRPMI1%+. Only cars without AEB with cyclist detection are included. A significant reduction of cyclist mRPMI10%+ can be seen comparing low scoring cars to high scoring cars in ≤ 30 km/h speed limit (-73%, $p = 0.02$) and across all speed limits (-36%, $p = 0.06$). Including only those aged ≤ 64 years, the reduction is 49% ($p < 0.01$). However, these results are irrespective of helmet wearing. The proportion of helmet wearing was higher in the group with cars 28–36 points, 46% compared with 33% in car group 1–9 points (Table 6). Looking at helmeted and non-helmeted cyclists separately, the difference between cars in group 1–9 and 28–36 points was not statistically significant for all age groups. However, looking at age groups ≤ 64 years, the relative difference in mRPMI10%+ between the cars in group 1–9 and 28–36 was 45% ($p = 0.04$) for helmeted cyclists and 44.2% ($p = 0.09$) for non-helmeted cyclists. A corresponding difference was not found for mRPMI1%+.

A significant reduction of cyclists mRPMI10%+ comparing cars with 1–9 points and cars with 26–38 points was found at crossings with good safety level (green) and medium safety level according to the STA classification, -67% ($p < 0.01$) and -55% ($p = 0.02$) respectively. This observed difference could, however, be a result of helmet wearing, as the proportion of helmet wearing was higher in the groups with high scoring cars (28–36 points) (Table 6). In difference to speed limit, it was not possible to divide between helmeted/non helmeted cyclists or older/younger age groups due to the limited size of the material.

3.2.1 Effect of active bonnet

The effect of active bonnet on pedestrians and bicyclists mRPMI10%+ is shown in Table 7. Only cars without AEB with pedestrian/cyclist detection is included. Reductions between 12–54% were observed, however, no results were significant at 95% confidence level. For mRPMI1%+, there was a difference observed across all speed limits with a 24% reduction ($p = 0.01$). However, the rate of helmet wearing was higher in the group with active bonnet (Table 8).

Table 4 Effect of Euro NCAP pedestrian protection on pedestrian mRPMI10%+ and mRPMI1%+, by speed limit

Speed limit	1–9 points mRPMI10+ (n)	10–18 points mRPMI10+ (n)	19–27 points mRPMI10+ (n)	28–36 points mRPMI10+ (n)	Rel. diff 1–9 points / 28–36 points	*p*-value
mRPMI10%+						
≤ 30 km/h	4.7% (57)	3.0% (179)	3.1% (88)	0.1% (6)	-98%	< 0.01***
40–50 km/h	5.6% (416)	5.5% (1108)	5.6% (379)	4.1% (28)	-27%	n.s.
≥ 60–km/h	12.8% (52)	5.7% (126)	10.6% (29)	5.5% (1)	-58%	n.s.
All speed limits (include unknown speed limit)	6.3% (592)	5.1% (1650)	5.4% (586)	3.2% (42)	-48%	0.01***
All speed limits (include unknown speed limit) ages ≤ 64 years	5.8% (466)	4.1% (1261)	4.5% (470)	2.1% (37)	-64%	< 0.01***
STA rating of crossings						
Green	6.7% (21)	6.3% (60)	1.7% (27)	2.1% (4)	-68%	n.s.
Yellow	3.6% (112)	4.1% (288)	4.7% (117)	1.5% (6)	-58%	0.01***
Red	7.5% (145)	6.1% (371)	5.8% (155)	6.4% (13)	-14%	n.s.
mRPMI1%+						
≤ 30 km/h	23% (57)	22% (179)	19% (88)	8% (6)	-67%	< 0.01***
40–50 km/h	30% (416)	28% (1108)	26% (379)	26% (28)	-13%	n.s.
≥ 60 km/h	41% (52)	33% (126)	40% (29)	56% (1)	+36%	n.s.
All speed limits (include unknown speed limit)	30% (592)	28% (1650)	26% (586)	24% (42)	-23%	0.07*
All speed limits (include unknown speed limit) ages ≤ 64 years	27% (466)	24% (1261)	27% (470)	22% (37)	-19%	n.s.
STA rating of crossings						
Green	30% (21)	26% (60)	16% (27)	10% (4)	-68%	0.01***
Yellow	27% (112)	24% (288)	24% (117)	20% (6)	-28%	n.s.
Red	31% (145)	29% (371)	26% (155)	31% (13)	0%	n.s.

***Statistically significant at 99% level

Table 5 Effect of Euro NCAP pedestrian protection on cyclist mRPMI10%+ and mRPMI1%+, by speed limit

Speed limit	1–9 points mRPMI10+ (n)	10–18 points mRPMI10+ (n)	19–27 points mRPMI10+ (n)	28–36 points mRPMI10+ (n)	Rel. diff 1–9 points / 28–36 points	*p*-value
mRPMI10%+						
≤ 30 km/h	3.7% (105)	3.7% (326)	2.4% (168)	1.0% (19)	-73%	0.02**
40–50 km/h	4.1% (603)	3.8% (1985)	3.7% (780)	3.3% (73)	-18%	n.s.
≥ 60 km/h	10.6% (54)	6.9% (180)	4.4% (54)	7.6% (6)	-28%	n.s.
All speed limits (include unknown speed limit)	4.3% (876)	4.0% (2852)	3.4% (1153)	2.8% (117)	-36%	0.06*
All speed limits (include unknown speed limit) ages ≤64 years	3.7% (753)	3.5% (2497)	3.1% (992)	1.9% (105)	-49%	< 0.01***
STA rating of crossings						
Green	3.1% (68)	3.3% (185)	2.9% (119)	1.6% (12)	-49%	n.s.
Yellow	4.6% (194)	3.4% (609)	2.9% (268)	1.5% (28)	-67%	< 0.01***
Red	3.9% (157)	4.2% (599)	4.9% (257)	1.7% (24)	-55%	0.02**
mRPMI1%+						
≤ 30 km/h	18% (105)	18% (326)	18% (168)	13% (19)	-28%	n.s.
40–50 km/h	21% (603)	20% (1985)	21% (780)	18% (73)	-11%	n.s.
≥ 60 km/h	33% (54)	30% (180)	28% (54)	47% (6)	+43%	n.s.
All speed limits (include unknown speed limit)	20% (876)	21% (2852)	20% (1153)	18% (117)	-11%	n.s.
All speed limits (include unknown speed limit) ages ≤64 years	19% (753)	19% (2497)	19% (992)	16% (105)	-17%	n.s.
STA rating of crossings						
Green	17% (68)	16% (185)	23% (119)	15% (12)	-16%	n.s.
Yellow	20% (194)	20% (609)	19% (268)	17% (28)	-18%	n.s.
Red	20% (157)	21% (599)	22% (257)	15% (24)	-24%	n.s.

* Statistically significant at 90% level
** Statistically significant at 95% level
*** Statistically significant at 99% level

Table 6 Proportion of helmet wearing

	%with helmet	%with helmet ≤64 years	%with helmet Green STA safety rating	%with helmet Yellow STA safety rating	%with helmet Red STA safety rating
1-9 points	33%	34%	26%	29%	33%
10-18 points	34%	35%	29%	34%	32%
19-27 points	42%	44%	43%	38%	39%
28-36 points	46%	43%	30%	39%	61%
Total	36%	37%	33%	35%	35%

3.3 Effect of traffic calming

The effect of traffic calming (TS rating) on pedestrians and cyclists mRPMI1%+ and mRPMI10%+ is shown in Table 9. Only cars without AEB with pedestrian/cyclist detection are included. Results show that pedestrians mRPMI1%+ is reduced by 15% comparing crossings of good quality (green) with poor quality (red) ($p = 0.06$) and cyclists mRPMI10%+ is reduced by 32% ($p = 0.01$). Cyclist helmet wearing rate was 30% in the group with good quality crossings and 34% in the group with poor quality crossings.

3.4 Combined effect of pedestrian protection, traffic calming, AEB and helmet use among cyclists

The empirical combined effect of pedestrian protection, traffic calming (STA safety rating of crossings), AEB with pedestrian/cyclist detection and helmet use among cyclists is shown in Table 10. Comparisons are made between groups of low scoring cars (1–9 points), poor quality (red) crossings, and non-helmeted cyclists and groups of high scoring cars (≥ 19 points) with AEB for pedestrian/cyclist, good quality (green) crossings, and helmeted cyclists. For pedestrians, a reduction of mRPMI10%+ by 69% ($p < 0.01$) is observed, and a corresponding reduction of 64% ($p = 0.02$) of cyclists mRPMI10%+. The total reduction for pedestrians and cyclists mRPMI10%+ together is 69% ($p < 0.01$). No significant reductions of mRPMI1%+ were found.

The corresponding theoretical effect of the individual treatments were estimated to a 48% reduction of pedestrian mRPMI10%+, and 63% reduction of bicyclists mRPMI10%+ (Table 11).

4 Discussion

This study set out to calculate the individual and combined effect of several treatments aiming to mitigate injury severity for vulnerable road users. This is the first retrospective study that calculate the effect of AEB with pedestrian and cyclist detection to mitigate injuries among pedestrians and bicyclists. It was found that the mean RPMI10%+ was reduced from 5.7% to 3.4% (-44%) in speed zones ≤ 50 km/h, however this was only significant on 90% confidence level. No significant reductions at higher speeds (≥ 60 km/h) were observed, in line with Cicchino (2022). The functionality of these systems is designed mainly to work in lower speeds, and the Euro NCAP test protocol include speeds up to 60 km/h. Therefore, this result is not too surprising. However, as the risk of fatal and serious injury increases with higher speed (Lubbe et al., 2022; Rosen & Sander, 2009; Rosen et al., 2011) further development of AEB functionality to perform even in higher speeds should be encouraged.

For bicyclists, a reduction of 35% ($p = 0.05$) of mRPMI10%+ was observed at ≤ 50 km/h speed limit. The reduction was smaller compared to the reduction of pedestrian mRPMI10%+, but the overall mRPMI10%+ in ≤ 50 km/h speed zones was lower for bicyclists compared to pedestrians. For crashes within ± 20 meters from a pedestrian or bicycle crossing of less good or poor quality, the AEB system reduced 60% ($p = 0.05$) of pedestrians mRPMI10%+. In areas with good safety standard, where 85% of vehicles travel at maximum 30 km/h, there was no effect of AEB on pedestrian mRPMI10%+. This result suggests that when operating speeds are 30 km/h or less there is no extra benefit of the AEB system, but our result does not take into account the possible crashes avoided with the AEB technology. However, Kullgren et al. (2023) showed no significant reduction of pedestrian or bicyclist injury crashes at low speed. An explanation

Table 7 Effect of Active bonnet on pedestrians and bicyclists mRPMI10%+ and mRPMI1%+

Speed limit	with active bonnet mRPMI10+ (n)	without active bonnet mRPMI10+ (n)	Rel. diff w/without	*p*-value	with active bonnet mRPMI1+ (n)	without active bonnet mRPMI1+ (n)	Rel. diff w/without	*p*-value
Pedestrians								
≤ 30 km/h	1.4% (13)	3.1% (64)	-54%	n.s.	12% (13)	17% (64)	-32%	n.s.
40–50 km/h	7.1% (30)	6.1% (281)	+17%	n.s.	34% (30)	27% (281)	+26%	n.s.
≥ 60 km/h	7.2% (3)	12.6% (21)	-43%	n.s.	48% (3)	41% (21)	+15%	n.s.
All speed limits (include unknown speed limit)	5.0% (55)	6.0% (433)	-16%	n.s.	28% (55)	26% (433)	+8%	n.s.
Bicyclists								
≤ 30 km/h	1.3% (23)	2.3% (146)	-45%	n.s.	13% (23)	18% (146)	-27%	n.s.
40–50 km/h	4.0% (79)	3.7% (609)	+9%	n.s.	17% (79)	21% (609)	-18%	n.s.
≥ 60 km/h	2.1% (6)	5.4% (47)	-61%	0.06*	19% (6)	33% (47)	-42%	n.s.
All speed limits (includes unknown speed limit)	3.0% (124)	6.0% (928)	-12%	n.s.	16% (124)	21% (928)	-24%	0.01***

* Statistically significant at 90% level

*** Statistically significant at 99% level

Table 8 Cyclists helmet wearing rate with/without active bonnet

Speed limit	% with helmet with Active bonnet	% with helmet without Active bonnet
≤ 30 km/h	65%	51%
40–50 km/h	42%	38%
≥ 60 km/h	100%	62%
TOTAL	51%	42%

Table 9 Effect of traffic calming (TS rating) on pedestrians and cyclists mRPMI1%+ and mRPMI10%+

mRPMI	Red	Yellow	Green	Rel. diff green/red	*p*-value
Pedestrians					
mRPMI1%+	29% (864)	25% (638)	25% (150)	-15%	0.06*
mRPMI10%+	6.4% (864)	4.4% (638)	5.3% (150)	-17%	n.s.
Cyclists					
mRPMI1%+	21% (1311)	20% (1385)	19% (459)	-10%	n.s.
mRPMI10%+	4.2% (1311)	3.7% (1385)	3.1% (459)	-32%	0.01***

* Statistically significant at 90% level
*** Statistically significant at 99% level

Table 10 Empirical combined effect of pedestrian protection, traffic calming (TS rating), AEB with pedestrian/cyclist detection and helmet use among cyclists.

	1–9 points NCAP score red TS-rating non-helmeted cyclist (n)	≥ 19 points NCAP score green TS rating helmeted cyclist, with AEB VRU (n)	Rel. diff	*p*-value
mRPMI10%+				
Cyclists	4.6% (89)	1.6% (5)	-64%	0.02*
Pedestrians	7.5% (145)	2.3% (5)	-69%	< 0.01***
Pedestrians+ Cyclists	6.4% (234)	2.0% (10)	-69%	< 0.01***
mRPMI1%+				
Cyclists	21% (89)	15% (5)	-31%	n.s.
Pedestrians	31% (145)	31% (5)	0%	n.s.
Pedestrians + Cyclists	27% (234)	23% (10)	-16%	n.s.

*Statistically significant at 90% level; ***Statistically significant at 99% level

Table 11 Theoretical combined effect of individual treatments on pedestrians and cyclists mRPMI10%+

	Pedestrians	Cyclists
Red TS rating	6.4%	4.2%
Green TS rating	5.3%	3.1%
Rel. diff Red TS rating and Green TS rating	**-17%**	**-32%**
1–9 points	6.3%	4.3%
≥ 19 points	5%	3.4%
Rel. diff 1–9 points and ≥ 19 points	**-16%**	**-21%**
Without AEB VRU	6%	3.4%
With AEB VRU	4.5%	3.2%
Rel. diff with AEB VRU and without AEB VRU	**-25%**	**-5%**
Effect of helmet use	-	-27%
Theoretical combined effect	**-48%**	**-63%**

for this might be that in lower speeds, drivers are able to brake before AEB is activated. On the other hand, other studies have reported reductions in car-to-pedestrian/bicyclist crashes (e.g. Cicchino (2022) and), suggesting that there could be an even greater combined benefit of avoided injuries as well as mitigated injuries. Therefore, we see a need for additional studies that can evaluate this possible combined benefit. A possible design for such a study could be to use induced exposure to calculate the number of expected injured pedestrians and bicyclists reported to emergency care hospitals, combined with the effect on injury severity, as demonstrated in Rizzi et al. (2016).

The comparison of cars with poor performance (1–9 points) in the NCAP pedestrian test and cars with a high score (28–36 points) showed that pedestrian mRPMI10%+ was reduced by 48% ($p < 0.01$) across all speed limits, and by 64% including only those aged $\leq$64 years. For bicyclists, a significant reduction of cyclist mRPMI10%+ was found comparing low scoring cars to high scoring cars in $\leq$ 30 km/h speed limit (-73%, $p = 0.02$) and across all speed limits (-36%, $p = 0.06$). Including only those aged $\leq$ 64 years, the reduction was 49% ($p < 0.01$). The helmet wearing rate was higher in the group with cars 28–36 points, 46% compared with 33% in car group 1–9 points. Thus, the overall results for the Euro NCAP pedestrian protection score should be treated with caution for the bicyclists, as the helmet wearing has an impact on the injury outcome. However, significant reductions between low and high scoring cars could be observed when controlling for helmet use, with a reduction of 45% ($p = 0.04$) for helmeted cyclists and 44% ($p = 0.09$) for non-helmeted cyclists. A significant reduction of cyclists mRPMI10%+ comparing cars with 1–9 points and cars with 26–38 points was found at crossings with good safety level (green) and medium safety level according to the STA classification, but as the rate of helmet wearing was significantly higher in the group struck by high scoring cars it cannot be concluded that the observed difference was a result of high scoring cars and not a result of helmet wearing. In difference to speed limit, it was not possible to divide between helmeted and non-helmeted cyclists or older/younger age groups for the crashes at crossings, due to the limited size of the material.

For the active bonnet, a significant reduction of mRPMI1%+ by 24% was observed but given that the rate of helmet wearing was higher in the group struck by cars with active bonnet, this difference cannot be attributed to an effect of the active bonnet. This indicate that the Euro NCAP pedestrian protection test score is valid, irrespective of the type of design used by car manufacturers to achieve a higher score.

In general, the relative reductions comparing low to high scoring cars is similar to reductions previously reported by Ohlin et al. (2017) and Strandroth et al. (2011, 2014), but a difference is that overall, the mRPMI10%+ is lower in the present study, both for pedestrians and bicyclists. This is likely explained by the fact that the present study includes more recent crashes, and thereby a larger number of newer and better performing cars. Another circumstance related to bicyclists is that the rate of helmet wearing has significantly increased in Sweden, from around 35% in 2013 to 46% in 2021 (Hurtig et al., 2022).

Overall, pedestrians showed higher reductions of mRPMI10%+ compared to bicyclists. This result could possibly be explained by the fact that bicyclists compared to pedestrians are traveling faster and thereby gives the AEB system (and also the drivers) less time for detection and braking before impact.

Pedestrian mRPMI10%+ was higher compared to the bicyclists. A reason for this could be that pedestrians had a larger proportion of elderly (65+ years). Age has previously been shown to correlate with RPMI (Stigson et al., 2012). The comparison group for pedestrian protection had 23% of pedestrians at 65 years or older, while the corresponding number for bicyclists was 13%. The mRPMI10%+ was 6% for the pedestrians and 4% for the bicyclists in the pedestrian protection comparison groups.

The STA safety rating of pedestrian and bicycle crossings showed that overall pedestrian mRPMI1%+ was reduced by 15% ($p = 0.06$), while cyclists mRPMI10%+ was reduced by 32% ($p = 0.01$) comparing crossings of high safety level to crossings of poor safety level. In a meta-analysis of the installation of speed bumps, it was concluded that the installation of speed bumps results in an overall reduction of crashes as well as reduced speeds (Quigley, 2017). However, when pedestrian and cyclist crashes was studied separately, only non-significant reductions of crashes were found. In a recent before-and after study of speed bumps in 50 km/h speed zones in Ghana, an overall reduction of 77% of police reported injury crashes was observed (Gyaase et al., 2023). The present study observed significant reductions in injury severity for both bicyclists and pedestrians, results that add new knowledge to this field of research. However, it should be noted that the present study not only included speed bumps, but the definition of traffic calming was according to the STA safety level classification.

The analysis of combined interventions showed that the total reduction of pedestrians and cyclists mRPMI10%+ together was 69% ($p < 0.01$), from 6.4% to 2%. When the interventions were calculated separately according to the method for common residuals, the theoretical combined effect was lower (48% and 63%, respectively). In other words, the overall empirically derived impact of combined treatments was larger than the individual effects multiplicatively combined. The value of this comparison is to show that when the infrastructure and speed management create conditions that allow for vehicle technologies to work, synergetic results are achieved. This result is an encouragement for road authorities to continue working with speed management and traffic calming treatments in areas where vehicles and VRUs interact. Another implication from the present study was that the effect of increased pedestrian protection was larger compared to the effect of AEB with pedestrian/cyclist detection, a result that highlight the significance of car frontal designs. With that said, the present study could only account for crashes that has happened, and the crashes avoided with AEB are not included. If combining the two, the total effect of AEB should be greater. AEB with pedestrian and bicyclist detection was introduced around ten years after passive pedestrian protection, so it is likely that AEB when developed to address more scenarios and environmental conditions will increase its protection effect towards the levels of passive pedestrian protection. Even after this development it is most likely that the protection effect of AEB will be both avoiding and mitigating, since e.g. obstructed scenarios and false positive limitations will limit the possibility of completely avoiding crashes. Therefore, it is still the belief of the authors that both passive (pedestrian protection) and active (AEB) protection is needed and will give the highest protection when combined also in the future.

Finally, some limitations in the present study should be raised. Firstly, significant reductions for different treatments were observed, but some of these involve rather small numbers (e.g. the effect of combined interventions). The statistical method was chosen because it can handle small numbers, but still this should be kept in mind when interpreting the results. Obviously, the treatments included in the present study can all be regarded as confounders for each other, for example, AEB and pedestrian protection score. In order to control for these factors, the analysis of the effect of increased pedestrian protection excluded cars with AEB with pedestrian/cyclist detection. Similarly, the analysis of the effect of AEB could also be influenced by the pedestrian protection score. In fact, there was a slightly higher proportion of cars with 28–36 points as well as a slightly lower proportion of cars with 10–18 points in the group with AEB with pedestrian detection (Table S4 in the Supplements). This was not the case for the group with AEB with cyclist detection. Naturally, the AEB technology will be fitted on newer car models that simultaneously increases the performance in the protection test as well, as also indicated by the average MY of cars displayed in Tables S7 and S10 in the Supplements. However, the difference in proportion was not significant enough to have impact on the results, especially considering that the largest difference in mRPMI10%+ between cars with and without pedestrian detection was found for cars with 19–27 points, which was also the largest group (see Table S5 in the Supplements). This group (19–27 points) was also similar in proportion between the groups with and without pedestrian detection. However, the influence of passive protection is clearly something to consider in future studies of AEB technologies. Another confounding factor is of course helmet use among bicyclists, especially for mRPMI10%+. There was most often no significant difference in the proportion of helmet use in the different effect groups, with the exception for the analysis of pedestrian protection, where the proportion of helmet wearing was significantly higher among cyclists injured by high scoring cars. As mentioned previously, this can be related to the fact that the rate of helmet wearing has significantly increased in Sweden, from around 35% in 2013 to 46% in 2021.

It could also be mentioned that the functionality of AEB systems with pedestrian/bicyclist detection differ between different car models included in the study. Therefore, this study does not evaluate the performance of individual systems, but rather how this technology in general impacts the injury severity of pedestrians and bicyclists in real-life conditions. Additional studies are encouraged, including additional statistical methods and injury metrics. A way forward for future studies could be to include aggregated data from different countries, with similar infrastructure, in order to increase the size of the material.

5 Conclusions

This is the first retrospective study on injury mitigation from AEB with pedestrian/cyclist detection. It concludes that:

- Results indicated long-term injury reductions of 35–44% of mRPMI10%+ at speed zones of $\leq$ 50 km/h for bicyclists and pedestrians from to AEB fitment. For crashes within ± 20 meters from a pedestrian or bicycle crossing, the AEB system reduced 60% ($p = 0.05$) of pedestrians mRPMI10%+ in areas with good safety standard compared to crossings of poor safety standard.
- No effects of AEB with pedestrian/cyclist detection was observed at higher speeds (60 km/h or higher). An implication for consumer organizations is to start testing AEB at higher speeds, where the risk of fatal and serious injuries is higher.
- High performing cars in the Euro NCAP pedestrian test (28–36 points) showed significantly lower mRPMI10%+ compared to low performing cars (1–9 points), with a reduction of 36%–64%.
- It could not be concluded that the active bonnet differed in terms of pedestrian protection, compared to other cars with a high score in the Euro NCAP pedestrian test.
- Injury severity was reduced by 15%–32% comparing crossings with a good level of safety to crossings with poor level of safety according to the STA classification.
- A road environment with adapted infrastructure and speed, combined with passenger car technologies that improve the safety for vulnerable road users, can create high and synergetic reductions of serious injuries among pedestrians and bicyclists.

CRediT contribution statement

Maria C. Rizzi: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing—original draft, Writing—review & editing. **Khabat Amin:** Conceptualization, Data curation, Investigation, Methodology, Writing—review & editing. **Johan Strandroth:** Conceptualization, Writing—review & editing. **Simon Sternlund:** Conceptualization, Methodology, Writing—review & editing. **Rikard Fredriksson:** Conceptualization, Methodology, Writing—review & editing. **Anders Kullgren:** Conceptualization, Data curation, Methodology, Writing—review & editing.

Declaration of competing interests

The authors report no competing interests.

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