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The combined effect of vehicle frontal design, speed reduction, autonomous emergency braking and helmet use in reducing real life bicycle injuries

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ABSTRACT

Vulnerable road users as bicyclists and pedestrians account for a significant share of fatalities and serious injuries in the road transport system. Traditionally, the protection for bicyclists has been addressed by speed management and separating vulnerable road users from motorized traffic. Also, the use of bicycle helmet has been prompted and regulated in some countries. Pedestrian protection by improving the car fontal design has been around since the late 1990s and has proven to be effective in reducing injury risk on pedestrians (Strandroth et al., 2011) as well as on bicyclists (Strandroth et al., 2014). Pedestrian detection with Autonomous Emergency Braking (AEB) has also been introduced on the market to prevent and mitigate pedestrian and bicyclist injuries. The purpose of this study was to evaluate the effect of the different interventions promoting safety for vulnerable road users, and an additional purpose was to look at the combined effect of the interventions. Swedish emergency hospital reports from approximately 2000 bicyclists and 1200 pedestrians between Jan 1st 2003 and March 2014 were included in the study. Hospital reports including injury diagnosis were combined with police data and the vehicle registry in order to obtain detailed vehicle information. Euro NCAP pedestrian test score, speed limit restriction and helmet use was correlated with real-life pedestrian and bicyclist injuries. The results showed that on pedestrians, large injury reductions were found comparing low scoring cars (1–9 p) in the Euro NCAP pedestrian test to high scoring cars (>18 p). Also for bicyclists significant injury reductions were found. Focusing on bicyclist's injury level, large reductions were found on all body regions, with the highest reduction on head injuries. The effect of speed limit restriction showed few statistically significant results, although across both pedestrian and bicyclist injuries the trends showed overall small but positive effects. The effect of helmet use on bicyclist injuries was investigated both on individual level and on head injury level. Helmet showed to significantly reduce the risk of head injuries. However, on individual level, the results were quiet conflicting, and only on mRPMI10+ level a positive and statistically significant reduction was found. The calculated combined effect of speed-reduction, helmet-use and car frontal design was 79%. Also, preliminary calculations, based on a limited number of cases, and including both bicyclists and pedestrians, showed that when adding the effect of AEB, the risk of long-term impairment decreased by more than 90%.

1. Introduction

Vulnerable road users as bicyclists and pedestrians account for a significant share of fatalities and serious injuries in the road transport system (Naci et al., 2009). In Sweden, compared to other road users, bicyclists account for the highest proportion of hospital reported injuries (Swedish Transport Administration, 2011). Traditionally, the protection for bicyclists has been addressed by speed management, based on risk curves. The impact of speed on fatality risk in pedestrians hit by cars was estimated by Rosén and Sander (2009) who found that the fatality risk at 50 km/h was more than twice as high as the risk at 40 km/h, and more than five times higher than the risk at 30 km/h. In Sweden, lowering of speed

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restriction is most often combined with other traffic-calming countermeasures, such as smaller roundabouts and speed bumps (Swedish Transport Administration, 2013). Separating vulnerable road users from motorized traffic is also a way to make the road environment safer (Pucher et al., 2010). The use of separate bicycling lanes is in Sweden estimated to reduce injuries by 20–30% (Swedish Transport Administration, 2013).

Also, the use of bicycle helmet has been prompted and regulated in some countries. The effect of bicycle helmets in Sweden was evaluated by Rizzi et al. (2013) who found that a helmet could reduce all impairing head injuries by at least 58% and severe impairing head injuries by 64%. Helmet use in Sweden is on average 30–35%, but with great variations between different regions. In 2005 helmet use amongst children <15 years was legislated and helmet use amongst this group is now around 60% (Swedish Transport Administration, 2013).

Pedestrian protection by improving the car fontal design was introduced in the late 1990s and has proven to be effective in reducing injury risk on pedestrians (Strandroth et al., 2011) as well as on bicyclists (Strandroth et al., 2014). Interestingly, in a study by Fredriksson et al. (2012), it was found that bicyclists injury locations on the car compared to pedestrians were located further backwards on the car front. The same relationship was also found when including non-fatal injuries, where Fredriksson and Rosén (2012) found that bicyclists head impact locations more commonly were from higher impact locations.

Pedestrian detection with Autonomous Emergency Braking (AEB) has also been introduced on the market in order to prevent and mitigate pedestrian and bicyclist injuries. In a prospective study by Hannawald (2011) it was estimated that Brake Assist, in combination with a pedestrian protection system could reduce the number of seriously injured persons by 14.3% and fatalities by 11.1%. In another prospective study Rosén et al. (2010) estimated autonomous braking to reduce fatalities by 40% and severely injured by 27%. In 2010 autonomous emergency braking with pedestrian detection (AEB) was launched by Volvo Cars on the S/V60 models as optional equipment. Lindman et al. (2010) estimated the system to have a projected potential to reduce 24% of the pedestrian fatalities.

In 1997 the Euro NCAP started evaluating pedestrian protection by testing legform to bumper, upper legform to bonnet leading edge and headform to bonnet top. In the test, a car can score between 0 and 36 points. From 1997–2008 the test score was given as a separate star rating, where 1 star = 1–9 points, 2 stars = 10–18 points, 3 stars = 19–27 points, and 4 stars = 28–36 points. Since 2009 the pedestrian test score is included in the overall rating and a minimum of 21 points is required to achieve an overall five star rating (European New Car Assessment Programme, 2009).

1.1. Aim

The purpose of this study was to evaluate the effect of the different interventions promoting safety for vulnerable road users, using the same population of real life crashes. An additional purpose was to estimate the combined effect of the interventions. Regarding the specific intervention of friendlier car fronts, a special interest was to look specifically at bicyclist injuries to further understand if and how safety designed for pedestrians can also benefit bicyclists, because in modern day city-planning interventions usually relate to vulnerable road users as a whole.

2. Material

Swedish real-life crash data was obtained from the data acquisition system STRADA, which contains police records and hospital admission data. Police data should include all reported road crashes with personal injuries and is the basis for the national statistics. The police data is linked to the national vehicle register, making it possible to identify every specific car model involved in a car to pedestrian crash. Car make, model and model year was linked to their respective Euro NCAP test score. The hospital records in STRADA are collected from emergency hospitals in Sweden (since 2011, all but one). From STRADA injury severity classed according to the Abbreviated Injury Scale (AIS) was obtained. AIS is a globally used severity scoring system that classifies injuries by body region according to its relative importance on a 1–6 point ordinal scale, where 1 = minimum and 6 = maximum. MAIS represents the highest injury severity classification given to the individual (AAAM, Abbreviated Injury Scale, 2005).

All crashes between cars and pedestrians and bicyclists included in police records and hospital admission data in STRADA during the period January 1st 2003 to March 2014 were selected. This selection only included pedestrians submitted to hospital, thus pedestrians declared dead at the crash scene were not included in this study. Cases where the patient was hit by parts of the car other than the front was excluded from the study. Only cars tested by Euro NCAP were included. In the end, 1184 pedestrians with 2297 injuries and 2029 bicyclists with 3651 injuries were included in the study. Tables 1 and 2 below further describes the characteristics of the material.

3. Method

The correlation between pedestrian score and real-life injuries was estimated by comparing three groups of cars (group 1 = 1–9 points, group 2 = 10–18 points, group 3 = >18 points) by the relative difference in injury severity. In this study the injury severity was defined as the proportion of MAIS2+ and MAIS3+ injuries as well as mean risk of permanent medical impairment (mRPMI) on the 1%+ (mRPMI1+), 5%+ (mRPMI5+) level, and 10%+ (mRPMI10+) level. Also bicyclist's injury severity level was investigated comparing the proportion of AIS2+, AIS3+ as well as mRPMI for different body regions (Head, Lower extremities and pelvis, and Others).

In addition to AIS and MAIS, which are intended to capture the risk of life threatening injuries, this study used the risk of permanent medical impairment (RPMI), which estimates risk of long term impairment. RPMI was developed to estimate the risk for a patient to suffer from a certain level of impairment based on the diagnosed injury location and criteria of the Swedish Insurance Companies (Malm et al., 2008; Försäkringsförbundet, 2004). The RPMI matrix is based on approximately 35,000 diagnoses from 20,000 injured car occupants who reported an injury to an insurance company. The injured car occupants were followed for

Table 1
Mean age and sex of the studied population of injured pedestrians and bicyclists.

	Male	Female	Unknown	Mean age
Pedestrians (*n* = 1184)	781	355	48	46
Bicyclists (*n* = 2029)	1209	784	36	50

Table 2
Number of injuries by injury severity level grouped by pedestrians and bicyclists.

Injury severity	No. of pedestrians	%	No. of bicyclists	%
MAIS 1	625	53	1347	66
MAIS 2	387	33	499	25
MAIS 3	131	11	151	7
MAIS 4	30	3	24	1
MAIS 5	11	1	8	0
Sum	1184	100	2029	100

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