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Injured cyclists with focus on single-bicycle crashes and differences in injury severity in Sweden

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A R T I C L E I N F O

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A B S T R A C T

While cycling is promoted as a clean, energy-efficient mode of transport generating physical activity, the number of injured cyclists must decrease to achieve traffic safety goals. The extent of the single bicycle crashes (SBCs) and crash causes are rather well studied. This study expands this knowledge by focusing on differences in injury severity. The aim of the study is to investigate the relationship between injury severity and characteristics of the crash and the cyclist with focus on SBCs. Furthermore, injury risk is calculated for different age classes and sexes, as well as for different purposes of the trip.

The results are based on injured cyclists in Sweden (N = 105,836) registered in STRADA, 2010–2019, by both the police and accident and emergency departments (A&Es), with a special focus on injury severity reported by the A&Es. Binary logistic regression was applied to analyse how the odds of being severely injured differed for different cyclists and situations. Results from of the National Travel Survey, 2011–2016, were used to study differences in distance travelled with respect to sex, age group and purpose of the trip.

Given that the cyclist is injured in an SBC, the results show a higher probability of being severely injured (maximal AIS 3 or more) for cyclists 45 years or older compared to younger cyclists, for males compared to females and for cyclists not wearing a helmet compared to cyclists wearing a helmet. A higher probability for severe injury was also found for crashes occurring during leisure trips compared to work/school trips, crashes occurring during weekdays compared to weekends and crashes at intersections and road stretches compared to pedestrian and cycle paths. Furthermore, the risk of being severely injured in an SBC per km travelled was higher for cyclists aged 45 and older and during a leisure trip.

1. Introduction

Cycling is promoted as a clean, energy-efficient mode of transport generating physical activity, helping to implement the 2030 Agenda for Sustainable Development (e.g., Stockholm Declaration, 2020). At the same time, the number of injured cyclists must decrease to achieve national traffic safety goals. Better knowledge of bicycle crashes is needed as it could aid in identifying effective measures to reduce the number of injured.

It is well known that police records, which are often the basis for official statistics, vastly underreport crashes involving cyclists, particularly single-bicycle crashes (SBCs) (e.g., Langley et al., 2003; Veisten et al., 2007). In Sweden, the SBCs reported by the police represent only about 10% of all crashes involving cyclists, whereas hospital records show that SBCs represent about 80% (Niska and Eriksson, 2013; Swedish Transport Agency, 2020). Kjeldgård et al. (2019) found an even higher share of 85%, based on in-patient and specialized out-patient healthcare data including accident and emergency departments (A&Es) in Sweden.

Several international studies have found that SBCs account for the largest share of injured cyclists reported by A&Es. For instance, an international review (Schepers et al., 2015) found that SBCs represented 60–95% of all crashes involving cyclists in 13 districts or countries (based on 150–37,563 victims at A&Es between 1985 and 2012). Later studies from Australia in which 129 cyclists were interviewed at trauma units in Melbourne showed an SBC share of 48% (Beck et al., 2019). Another Australian study (Meuleners et al., 2020) of 100 cyclists in Perth found that 39% of hospitalized cyclists had been injured in SBCs. Such studies analysing information from hospitals are valuable but are often based on few observations only.

Since road authorities often base their knowledge on police records, they have focused on reducing collisions between cyclists and motor vehicles, both now and in the past. However, to increase road safety for

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cyclists, actions are also needed to prevent SBCs, as they are the most common type of crash for this category of road user.

Aiming to find the areas with highest potential to reduce SBCs, a previous study (Niska and Eriksson, 2013) randomly selected and categorised crash descriptions. The data were collected from the Swedish national registry of road traffic crashes (STRADA) which includes data from cyclists visiting accident & emergency departments (A&Es) (see section 2.1.1 for more detailed information about STRADA). The crash descriptions are based mainly on the victims' recollections of their crashes. In total, 4,000 out of 34,112 SBC descriptions from the years 2007–2012 were randomly selected. After excluding cases with missing information and cases that were not eligible, 2,848 injured cyclists remained in the analysis. A main crash cause was selected for each crash and the results were weighted with respect to each cyclist's risk of getting a permanent medical impairment of 1% or more (see definition in Malm, et al., 2008). The crash causes were distributed as follows:

- road maintenance deficiencies (44%): slippery surfaces (e.g., snow/ice, grit, and leaves), uneven surfaces, temporary objects, and road edges
- bicycle–cyclist interaction (16%): something stuck in the wheel, falls when mounting/dismounting the bicycle, bicycle malfunctions, and braking mistakes
- road design (15%): kerbstones/edgings, permanent objects, and tram rails
- cyclist behaviour (14%): handling errors, high speed, stunting, distraction, alcohol influence, cycling with dog, windy conditions, and uphill riding
- interaction with other road users (10%): evasive actions to avoid collision.

Regarding all causes mentioned in the crash descriptions, without assessing the main cause, the five most common causes resulting in SBCs were: skidding due to ice/snow (20%), kerbstones/edgings (11%), grit, mainly from winter maintenance (10%), evasive action to avoid collision with other road users (9%), and making a turn/taking a curve (9%).

Thus, the extent of the SBCs and crash causes are rather well studied in Sweden. However, the injuries range from minor to severe or even fatal. More knowledge of what affects injury severity could help in prioritizing among safety measures to first address the most severe injuries. Two Danish studies that identify factors influencing injury severity have recently been published (Hosseinpour et al. 2021; Skyum Myhrmann et al. 2021). The study by Hosseinpour et al. (2021) is based on self-reported cycling injuries and classifies injuries requiring medical treatment as "severe". Myhrmann et al. (2021) studied hospital records from 1,720 cyclists involved in an SBC and visiting a specific A&E. The division into slight and severe injury mimicked the definition used by the police where a severe injury includes fractures, trunk injuries and burns (K. Hyldekær Janstrup, personal communication, September 28, 2021).

The present study can be viewed as a complement to the Danish studies since it is based on a larger data set ($n = 94{,}570$) that includes all A&Es in Sweden, and has a higher threshold for severe injury, using MAIS 3+ (see definition in 2.1). The aim of the study is to investigate the relationship between injury severity and characteristics of the crash and the cyclist with focus on SBCs. Furthermore, injury risk is calculated for different purposes of the trip.

2. Material and method

2.1. Data sources

2.1.1. Strada

The study is based on injured cyclists as registered by the Swedish national registry of road traffic crashes (Swedish Traffic Accident Data Acquisition, STRADA). STRADA contains data from two sources, police crash records and data collected at A&Es. The latter include self-reported data as well as data from medical records. The police report all crashes known to them, and the number of reporting A&Es has gradually increased from the start in 2003, covering all such units in Sweden from 2016 onwards (n = 51 in 2010 and n = 69 in 2016). The A&Es report injury severity according to the Abbreviated Injury Scale[1] (Gennarelli and Wodzin, 2008) and AIS-classification is performed by health care professionals. However, not all patients are registered since patients can choose to opt out of registration. Patients receive a questionnaire containing both closed-ended and open-ended questions designed to cover all types of traffic crashes. The closed-ended questions concern crash type, road state, place type, and trip purpose, and the open-ended question addresses the course of events before and during the crash. In this study, only the closed-ended questions have been analysed. Non-fatal injured cyclists ($n = 94{,}570$) were retrieved from data collected at A&Es and fatally injured cyclists (n = 222) were retrieved from police records since not all fatalities are reported by A&Es. Data from the years 2010 to 2019 are included.

2.1.2. The national travel survey

Results of the National Travel Survey (TS Sweden), 2011–2016, have been used to study differences in distance travelled between sexes, age groups and purposes of the trip. The target population of the survey was all Swedish residents aged 6–84 years and it was conducted daily during the years 2011–2016 through telephone interviews. In total, 48,000 persons participated, and the response rate was 31.3–47.5% over the six-year study period.

2.2. Analysis

To study how different attributes were related to injury severity, two different analyses were performed. In both analyses, binary logistic regression was applied with the response variable set to 1 if the injured cyclist had injuries classified as MAIS 3 or higher (i.e., severely injured) and 0 if MAIS was 1 or 2 (i.e., slightly injured). The first analysis (model 1) only included type of crash as explanatory variable, and the different types were: SBCs, bicycle–motor vehicle collisions (passenger cars, lorries, buses, vans, and motorcycles), and other bicycle collisions (collisions with other bicycles (most common), pedestrians, mopeds, quads, trains, tractors, game and other). This model was applied to two different data sets, Model 1a: Fatally injured cyclists were included in MAIS 3 or higher, and Model 1b: Fatally injured cyclists were excluded. The second analysis (model 2) focused only on SBCs and had the following explanatory variables: sex, age group (0–14, 15–24, 25–44, 45–64, and 65 + years), purpose of trip (leisure, work/school, other, and unknown), place type (intersection including roundabout, stretch, pedestrian and bicycle path, other, and unknown), road state (did not affect, ice/snow, grit from winter maintenance, other causes of slipperiness, uneven surface, other maintenance-related causes, and unknown), helmet usage (yes, no, and unknown), time of year (Jan–Mar, Apr–Jun, Jul–Sep, and Oct–Dec), day of week (weekdays and weekends), and time of day (06:00–08:59, 09:00–14:59, 15.00–17:59, 18:00–05:59, and unknown). The road state variables were ranked in the following order (starting with the top rank) if there was more than one cause: (1) did not affect, (2) ice/snow, (3) grit from winter maintenance, (4) other type of slipperiness, (5) uneven surface, (6) other maintenance-related causes, and (7) unknown. This model only includes non-fatally injured cyclists since fatalities are not always reported by the A&Es, and police records do not include all information needed for the explanatory variables. The results from the logistic regression analyses are presented as odds ratios. An odds ratio larger than 1 means that the

[1] MAIS = maximum abbreviated injury, with MAIS capturing the highest (i.e., most severe) AIS code that patient sustains; AIS 1 = minor and AIS 6 = maximum.

odds of being severely injured at the studied level of an explanatory variable is higher than the odds of being severely injured at the reference level, given the same values for the other explanatory variables.

Binary logistic regression was performed using SAS software v9.4 (SAS Institute, Cary, NC, USA).

The risk of being injured in an SBC was estimated by dividing the number of injured cyclists with the distance travelled. The variance and 95% confidence interval of the estimated ratio were calculated using Taylor Series Methods (Wolter, 2007).

A separate analysis was made for electric-assisted bicycles (EABs). This only included 2019, since that year offered higher-quality A&Es data due to an updated routine where EABs is reported separately. Chi-square tests were performed to test the hypotheses of independence between type of bicycle (EABs and other bicycles) and injury severity (MAIS 1–2 and MAIS 3 +), gender, age groups (0–14, 15–24, 25–44, 45–64, and 65 + years), and purpose of the trip (leisure, work/school, other, and unknown).

3. Results

3.1. Crash type

The most common types of fatal crashes among cyclists were collisions with a motor vehicle, followed by SBCs (Table 1). For injured cyclists, SBCs were the dominant crash type.

Odds ratios based on logistic regression analysis of the relationship between injury severity and crash type are presented in Table 2. Results from model 1a (fatally injured cyclists included) showed that cyclists were more likely to be severely injured in bicycle–motor vehicle collisions (OR 1.94; 95% CI 1.78–2.11) than in SBCs. No effect was found for other bicycle collisions (OR 1.06; 95% CI 0.95–1.20). When fatally injured cyclists were excluded (results from model 1b) cyclists were still more likely to be severely injured in bicycle–motor vehicle collisions, although the odds ratio was lower. In this case there was also a small but significant increase in odds for other bicycle collisions (OR 1.14; 95% CI 1.01–1.29).

3.2. Single-bicycle crashes

The results from model 2, i.e., injury severity as a function of different explanatory variables of SBCs are presented in Table 3, together with the number and proportion of injured in different categories.

3.2.1. Sex and age

More men than women were injured in SBCs among those registered by the A&Es, and the odds ratio shows that men also were more likely to be severely injured than women (Table 3). The average age of cyclists having injuries rated as MAIS 1–2 was 37.3 years (SD 22.0) and for injuries rated MAIS 3 or more it was 59.3 years (SD 19.3). The 65 + year age group had the highest number and proportion of severely injured (MAIS 3 +). The probability of being severely injured in an SBC increased with age. For example, the odds of being severely injured for the age group 65 + was 6.35 times higher than for the 25–44-year group.

Table 1
Fatally injured cyclists registered in STRADA by the police and injured (MAIS 3 + and MAIS 1–2) cyclists registered by A&Es, divided by crash type. Year 2010–2019.

Crash type	Fatal, N (%)	MAIS 3+, n (%)	MAIS 1–2, n (%)
Total	222 (1 0 0)	3374 (1 0 0)	91,196 (1 0 0)
SBCs	70 (32)	2499 (74)	72,193 (79)
Bicycle–motor vehicle collisions	141 (64)	548 (16)	10,079 (11)
Other bicycle collisions	11 (5)	327 (10)	8924 (10)

Table 2
Logistic regression analysis of injury severity. The models estimate the probability of a severe injury (MAIS 3 +), compared to a slight injury (MAIS 1–2) of cyclists in Sweden. Year 2010–2019. Model 1a includes fatally injured cyclists in MAIS 3 + and model 1b excludes fatally injured cyclists.

	OR (95% CI)	
Crash type	Model 1a	Model 1b
SBCs	1	1
Bicycle–motor vehicle collisions	1.94 (1.78–2.11)	1.52 (1.36–1.70)
Other bicycle collisions	1.06 (0.95–1.20)	1.14 (1.01–1.29)

3.2.2. Trip purpose

SBCs occurred more often during leisure trips than during work/school trips or trips for other purposes. SBCs occurring during leisure trips were also more likely to result in severe injury than those occurring during work and school trips (OR 1.47; 95% CI 1.27–1.69).

3.2.3. Place type and road state

SBCs leading to slightly injured cyclists most often occurred on pedestrian and bicycle paths (46.3%), while road stretches were the most common place type for severe injuries (45.8%). The place types intersection and road stretch were associated with higher risks of severe injuries than were pedestrian and bicycle paths.

Between 50% and 55% of all SBCs had at least one maintenance-related known cause (i.e., unknown not included), but those causes did not correlate with a higher risk of severe injury (ORs were not statistically significant from 1, except for unknown causes).

3.2.4. Helmet use

Helmet use among cyclists involved in SBCs was 41% for the slightly injured and 29% for the severely injured. Cyclists not wearing a helmet had a higher risk of being severely injured than did those wearing a helmet (OR 1.29; 95% CI 1.17–1.42). Note that the logistic regression model does not consider what part of the body that was injured, i.e., whether or not it was a head injury.

3.2.5. Time of crash

Most SBCs occurred from July to September (35%) closely followed by April to June (33%), with the lowest share during the winter, from January to March (12%). According to the ORs, the quarterly periods did not affect the injury severity. About 71% of SBCs occurred on weekdays, corresponding to the proportion of weekdays (5/7 = 71.4%). On weekends, there was somewhat lower risk of being severely injured than on weekdays (OR 0.89; 95% CI 0.81–0.98). The highest share of slightly injured due to an SBC was found in the evening or at night, 18:00–05:59 (31%), and of severely injured in the daytime, 09:00–14:59 (37%), but the time of day was not significantly associated with injury severity.

3.2.6. Crash risk by travelled distance

Travelled distance and crash risk was investigated for sex, age group, and purpose of the trip. As estimated from the travel survey, the yearly average cycled distance in Sweden was 1,868 million km and the risk of being slightly injured was 3.9 per 1,000 million km. The risk of being severely injured was 0.13 per 1,000 million km (Table 4). The total distance travelled by men was longer than the total distance travelled by women, but the risk of being injured was at the same level (not significantly different). The risk of being slightly injured was higher for age groups 6–14, 15–24, and 65–84 compared to 25–44 years (statistically significant difference). Among severely injured the risk was higher for the groups 45–64 years and 65–84 years, compared to 25–44 years (statistically significant difference). The total distances travelled to work/school was about the same as the total distance devoted to leisure trips. However, the risk of being injured was higher during a leisure trip (statistically significant difference).

Table 3
Rash characteristics (number and proportion of SCBs) divided into MAIS 1–2 (slightly injured), MAIS 3+ (severely injured), and logistic regression analysis of factors contributing to the severity of injury of cyclists involved in an SBC (MAIS 1–2 vs MAIS 3 +), 2010–2019.

	MAIS 1–2	MAIS 3+	Log. regr. model
Attributes	*n* (%)	*n* (%)	OR (95% CI)
Total	72,193 (100.0)	2499 (100.0)	
Sex			
Male	39,953 (55.3)	1580 (63.2)	1.65 (1.51–1.80) [c]
Female[a]	32,240 (44.7)	919 (36.8)	1
Age group, years			
0–14	16,255 (22.5)	101 (4.0)	0.36 (0.29–0.46) [c]
15–24	10,005 (13.9)	85 (3.4)	0.46 (0.36–0.58) [c]
25–44[a]	16,566 (22.9)	283 (11.3)	1
45–64	20,246 (28.0)	879 (35.2)	2.53 (2.21–2.90) [c]
65+	9121 (12.6)	1151 (46.1)	6.35 (5.51–7.31) [c]
Purpose of the trip			
Leisure	43,678 (60.5)	1766 (70.7)	1.47 (1.27–1.69) [c]
Work/school[a]	19,850 (27.5)	363 (14.5)	1
Other purpose	660 (0.9)	44 (1.8)	1.82 (1.29–2.55) [c]
Unknown	8005 (11.1)	326 (13.0)	1.58 (1.31–1.89) [c]
Place type			
Intersection	5770 (8.0)	228 (9.1)	1.20 (1.03–1.40) [c]
Road stretch	27,666 (38.3)	1144 (45.8)	1.29 (1.18–1.42) [c]
Pedestrian and bicycle path[a]	33,437 (46.3)	987 (39.5)	1
Other place type	1578 (2.2)	73 (2.9)	1.27 (0.99–1.63)
Unknown	3742 (5.2)	67 (2.7)	0.52 (0.39–0.69) [c]
Road state			
Did not affect[a]	29,052 (40.2)	1048 (41.9)	1
Ice/snow	9767 (13.5)	330 (13.2)	0.99 (0.85–1.16)
Grit from winter maintenance	9018 (12.5)	233 (9.3)	0.90 (0.78–1.04)
Other type of slipperiness	3696 (5.1)	106 (4.2)	1.06 (0.85–1.30)
Uneven surface	5669 (7.9)	175 (7.0)	0.88 (0.74–1.03)
Other maintenance-related causes	5448 (7.5)	202 (8.1)	0.99 (0.85–1.16)
Unknown	9543 (13.2)	405 (16.2)	1.43 (1.25–1.63) [c]
Helmet usage			
Yes[a]	29,318 (40.6)	725 (29.0)	1
No	31,821 (44.1)	1343 (53.7)	1.30 (1.18–1.43) [c]
Unknown	11,054 (15.3)	431 (17.2)	1.25 (1.09–1.43) [c]
Over the year			
Jan–Mar	8493 (11.8)	333 (13.3)	1.03 (0.89–1.20)
Apr–Jun[a]	23,634 (32.7)	790 (31.6)	1
Jul–Sep	25,446 (35.3)	889 (35.6)	1.03 (0.93–1.14)
Oct–Dec	14,620 (20.3)	487 (19.5)	0.99 (0.87–1.13)
Day of week[b]			
Weekdays[a]	51,065 (70.7)	1779 (71.2)	1
Weekends	21,128 (29.3)	720 (28.8)	0.90 (0.82–0.99) [c]
Time of day			
06:00–08:59[a]	10,266 (14.2)	257 (10.3)	1
09:00–14:59	18,885 (26.2)	917 (36.7)	1.09 (0.93–1.28)
15:00–17:59	15,836 (21.9)	531 (21.2)	0.97 (0.82–1.14)
18:00–05:59	22,280 (30.9)	654 (26.2)	0.86 (0.72–1.02)
Unknown	4926 (6.8)	140 (5.6)	0.79 (0.63–1.00)

a Reference category.
b No consideration has been given to public holidays if these occur on weekdays.
c The odds of the current category is statistically significant from the odds of the reference category.

Table 4
Total distance travelled by bicycle (million km) in Sweden, yearly average 2011–2016 including 95% CI, and risk for injury in an SBC per 1000 million km travelled (95% CI), MAIS 1–2 (slightly injured) compared to MAIS 3+ (severely injured).

		Risk of an SBC per 1000 million km travelled (95% CI)	
	Million km travelled (95% CI)	Being slightly injured (MAIS 1–2)	Being severely injured (MAIS 3 +)
Total	1,868 (1,748–1,987)	3.9 (3.6–4.1)	0.13 (0.11–0.15)
Sex			
Male	1,080 (978–1181)	3.7 (3.3–4.1)	0.15 (0.12–0.17)
Female	788 (724–852)	4.1 (3.7–4.5)	0.12 (0.09–0.14)
Age groups, years			
6–14 [a]	175 (152–198)	8.1 (7.0–9.3) [d]	0.05 (0.02–0.08)
15–24	264 (228–300)	3.8 (3.2–4.4) [d]	0.03 (0.01–0.05)
25–44	574 (501–647)	2.9 (2.5–3.3)	0.05 (0.03–0.07)
45–64	655 (576–734)	3.1 (2.7–3.5)	0.13 (0.10–0.17) [d]
65–84[b]	199 (167–231)	4.3 (3.6–5.1) [d]	0.52 (0.39–0.65) [d]
Purpose of the trip			
Leisure [c]	964 (870–1058)	4.6 (4.1–5.1) [e]	0.19 (0.15–0.22) [e]
Work/ school	902 (831–973)	2.2 (2.0–2.4)	0.04 (0.03–0.05)
Unknown	*1.2 (0.0–2.5)*		

a The number of injured cyclists in this age group is 14,203 (MAIS 1–2) and 87 (MAIS 3 +).
b The number of injured cyclists in this age group is 8,601 (MAIS 1–2) and 1,031 (MAIS 3 +).
c Defined as all trips other than work, school or unknown trips.
d Statistically significant compared to age group 25–44 years.
e Statistically significant compared to work/school.

3.3. *Electric-assisted bicycles in SBCs*

According to the definition in Sweden, electric-assisted bicycles (EABs) have pedal assistance up to 25 km/h; “bicycles” assisted to higher speeds are classified as mopeds.[2]

Table 5 shows that women represented a slightly higher share of those who sought medical care due to SBCs when riding EABs (56.5%), while men represented a slightly higher share when riding other bicycles (56.6%). Cyclists in the age groups 25 years and older had higher shares of SBCs with EABs than with other types of bicycles, while younger cyclists had lower shares of SBCs with EABs. For SBCs with EABs, more crashes occurred during trips to school/work and fewer during leisure trips compared to SBCs without EABs. A Chi-square test showed a significant difference between type of bicycle (EABs and other bicycles) and the variables sex, age groups, and purpose of trip ($p < 0.0001$ for all comparisons), while the variable injury severity did not show any significant difference ($p < 0.624$).

4. Discussion

This study investigated the relationship between injury severity and characteristics of the crash and the cyclist, with focus on SBCs. The logistic regression performed showed the most sizeable effect for age; in general, the older the cyclist the higher the risk of a severe injury.

[2] https://www.transportstyrelsen.se/sv/Nyhetsarkiv/2018/elcykel-eller-moped—vad-*ar*-skillnaden/

Table 5
SBCs with electric-assisted bicycles (EABs) versus other bicycles, year 2019.

Attributes	EABs n (%)	Other bicycles [a] n (%)
Total	437 (100.0%)	6702 (100.0%)
Injury severity		
MAIS 1–2	423 (96.8)	6457 (96.3)
MAIS 3+	14 (3.2)	245 (3.7)
Sex		
Male	190 (43.5)	3795 (56.6)
Female	247 (56.5)	2907 (43.4)
Age groups, years		
0–14	10 (2.3)	1506 (22.5)
15–24	38 (8.7)	812 (12.1)
25–44	124 (28.4)	1528 (22.8)
45–64	168 (38.4)	1912 (28.5)
65+	97 (22.2)	944 (14.1)
Purpose of trip		
Leisure	219 (50.1)	4230 (63.1)
Work/school	199 (45.5)	2111 (31.5)
Other	2 (0.5)	40 (0.6)
Unknown	17 (3.9)	321 (4.8)

aThere might be some EABs in this group as well.

Almost half of the severely injured cyclists (46.1%) were 65 years or older and the risk calculations showed that this age group also had a higher risk of being involved in an SBC in the first place. The odds ratio of a severe accident was as high as 6.35 (95% CI 5.51–7.31) for this age group compared with the reference group (25–44), given that the values of the other explanatory variables were the same. The age group 45–64 also had a higher risk with 2.53 (95% CI 2.21–2.90) times higher odds of being severely injured than the reference group. These results are in line with findings from a Danish study (Hosseinpour et al., 2021) showing that cyclists in the age group 45–64 were overinvolved in severe SBCs compared with other age groups. Cyclists older than 65 years were rather few and not presented separately in that study.

The findings also show clear gender differences. Overall, men travel longer distances by bicycle than women, and even though the risk per distance of being injured in an SBC is about the same for men and women, once in a SBC leading to an A&E visit, male cyclists are severely injured to a greater extent than female cyclists (OR 1.65; 95% CI 1.51–1.80). This is in accordance with findings in Hosseinpour et al., 2021. A Belgian study also showed that male cyclists travelled longer distances than female cyclists (de Geus et al., 2012). No statistically significant differences were found in crash rate in that study, possibly because it was based on relatively few crashes.

Other than mileage, this present study did not explicitly explore the factors contributing to the higher injury risk for men in SBC crashes. Previous studies on such factors suggest that male riders take more risks (Félonneau, et al., 2013; Cobey, et al., 2013) and travel at higher speeds (Boufous et al., 2018; Flügel et al., 2019). Another possible explanation may be that men are less inclined to seek emergency care when slightly injured. Note though that a higher speed may not be directly related to a higher crash and injury risk. Speed is a requirement for cyclists to keep their balance, and Reijne et al. (2021) found that when the handlebars were disturbed the higher the speed the lower chance to fall. Studies show that at low speeds and while mounting or dismounting, the injury risk is reversed, with higher risks for women than for men (Ormel et al., 2008, in Schepers and Klein Wolt, 2012; Scheiman et al., 2010; Thulin and Niska, 2009).

A study from the Netherlands indicates that the effect of gender depends on age (Ormel et al., 2008, in Schepers and Klein Wolt, 2012). Women aged 55 + years had a higher risk, per million km travelled, of being treated at an emergency care department than did men in the same age group. However, in the younger groups (<55 years old), men had a higher risk than did women. Future studies should therefore include the interaction effects of gender and age.

A variable that did not show any relationship with injury severity was road state. This means that although SBCs due to ice/snow or grit are frequent, they do not lead to severe injuries to a higher extent than SBCs where the road state did not affect the crash.

The results showed that the risk of being severely injured in an SBC is higher on road stretches than on pedestrian and bicycle paths, although the odds ratio is small (1.29). This difference might be related to higher cycling speeds on road stretches. Unfortunately, there is no information in the travel survey TS Sweden on what infrastructure the cyclist travelled. In the Netherlands, cycling in built-up areas was most common in mixed traffic (approx. 45%), followed by separate cycle paths (just over 40%) and cycle lanes (just over 10%), with the accidents having about the same distribution as the number of kilometres travelled by bicycle (Schepers, 2008, in Schepers and Klein Wolt, 2012). This indicates that most accidents occur where the most kilometres are travelled (at an overall level). Like the present study, Myhrmann et al. (2021) showed an increased probability of severe injury for SBCs occurring on road sections compared with bicycle lanes. However, no similar findings were obtained in the study by Hosseinpour et al. (2021). Hence, the road infrastructure impact on injury severity needs to be further studied.

The results show a higher probability of being severely injured for cyclists not wearing a helmet compared to helmet-wearing cyclists. A systematic review found that bicycle helmet use reduced the risk of head injuries by at least 50% (Olivier and Creighton, 2017). The helmet use of cyclists involved in SBCs in Sweden is comparable to that of the general helmet use on the national level, where the helmet use varied between 27% and 47% during 2010 to 2019 (Swedish Transport Administration, 2020).

A higher probability for severe injury was found for SBCs occurring during leisure trips compared with work/school trips. This was also the case when accounting for distance travelled. One possible explanation is that routes to work/school are well-known by the cyclists, who are therefore more prepared to avoid risky situations. Another possible explanation is that many leisure trips are for exercise and recreation (Eriksson et al., 2019), and such trips might entail higher speeds leading to higher injury severity in the case of a crash, and more commonly occur on rural roads without separate bicycle infrastructure. Beck et al. (2019) found that of 62 SBC injured cyclists, 79% occurred during non-commuting trips, versus 21% when commuting. Yet another possible explanation is that alcohol and darkness are contributing factors, which are more common during leisure trips. Niska and Eriksson (2013) found that about 3% of the categorised injured cyclists were under the influence of alcohol (2% stated this, and 1% had cycled home from a party, i.e., suspicion of alcohol). Darkness was reported in 1% of the cases. Both alcohol and darkness are probably underreported since it is optional to report these variables in STRADA. However, Myhrmann et al. (2021) found an increased probability of severe injury of SBCs after dark and suggests that proper illumination is important. In the present study, darkness has not been studied and this subject needs to be further investigated.

Rather small differences in odds were found for place type and day of week and there was no relationship found between injury severity and quarter of the year or time of day. Most cyclists injured in SBCs in Sweden are injured from April to September, with no differences between the slightly and severely injured. Utriainen (2020) found that among Finnish commuters almost as many injured cyclists were reported to insurance companies in the October–March period as in the April–September period, indicating that there might be different types of cyclists during the year, week, and day, but in this present study there was no indication that this affected the injury severity.

The number of EABs in Sweden has increased since the Swedish government introduced a premium subsidizing the private purchase of EABs by 25% during the year 2018. An evaluation of this action showed that men and women used the subsidy to buy EABs to a similar extent (Swedish Environmental Protection Agency, 2019). It also showed that the subsidy was more commonly used among the 45–74-year age groups than among younger people (18–34 years). The SBCs of EAB riders involved a higher proportion of women and of trips to work/school, which could be explained by the EAB usage, but the evaluation of the subsidy does not support this assumption for women. Furthermore, Schepers et al. (2014) found that EAB users were more likely to be involved in crashes that require treatment at A&Es. A traffic safety concern regarding EAB is that the higher average speeds and the higher mass' of EABs could lead to increased injury severity. However, when comparing injury severity for EAB cyclists with that of other cyclists in this present study no significant differences were found.

The present study has focused on SBCs, but a comparison between SBCs and bicycle-motor vehicle collisions was also performed. This showed that there is a higher risk of being severely injured in a bicycle–motor vehicle collision than in an SBC. Such a result was expected considering the large difference in weight and usually also in speed between a bicycle and a motor vehicle. If fatally injured cyclists are included in the group of severely injured cyclists in the model the odds will be higher, 1.94 (95% CI 1.78–2.11) compared to the odds if excluded, 1.52 (95% CI 1.36–1.70). This is not entirely in line with Hosseinpour et al. (2021) who found a higher risk of severely injured cyclist in SBCs compared to multiparty crashes. However, that study also included pedestrians and other cyclists in multiparty crashes, which may partly explain the difference. The fact that the total number of those severely injured in SBCs in Sweden is four times higher than in bicycle–motor vehicle collision still emphasises the importance of a greater attention towards SBCs, when choosing between various measures to enhance traffic safety.

The major strength of the present study is its large number of records with injured cyclists and the fact that the injuries have been classified by healthcare professionals. A potential issue is the underreporting of injuries by the A&Es. However, this has no correlation to injury severity according to the Swedish Transport Agency (2018). The study has some limitations though, that should be kept in mind when studying the results; a few questionnaires being incorrect or incomplete, travel mileage from the National Travel Survey might not be fully representative due to decreasing response rates, and the potential problem that the tendency to visit A&Es may differ between groups and, hence, so may the probability that that the injury accident is recorded. Nevertheless, the results can be very useful for traffic safety engineers, planners, researchers and decisionmakers when choosing between different measures to increase traffic safety for cyclists.

5. Conclusions

This study has increased the knowledge of which attributes that are related to the risk of being severely injured. Such information could be used to prioritize among safety measures to first address the most severe injuries. Overall, we found a higher risk of being severely injured in a bicycle–motor vehicle collision than in an SBC. Hence, measures that are directed towards separation of cyclists from motor vehicles are of interest. However, since the total number of those injured in SBCs was much higher than those injured in collisions, SBC crashes also deserve attention. Among those, we found a higher risk of being severely injured for males and for cyclists not wearing a helmet. A higher probability for severe injury was also found for SBCs occurring during leisure trips, weekdays, and crashes at intersections and road stretches. Moreover, the risk of being involved in an SBC per kilometre travelled was higher for leisure trips than for trips to work and school. There are several plausible explanations for this, but further investigation is recommended.

Last but not least, the risk of severe injuries among cyclists increased with age: the older the cyclist, the higher the risk. In fact, being elderly was the most predominant risk factor of all the attributes analysed in this study, and measures should hence be directed towards this vulnerable group.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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