UPPER EXTREMITY INJURIES AMONG VULNERABLE ROAD USERS STRUCK BY PASSENGER CARS

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ABSTRACT

Upper extremity injuries are common among vulnerable road users (VRUs) and often result in long-term consequences for the injured VRU. As a first step towards prediction and mitigation of these injuries, this study sought to identify -in what situations upper extremity injuries occur, what parts of the upper extremity are most often injured and potential patterns in the prevalence of upper extremity injuries. By analyzing Swedish insurance data from the years 2020-2024, this study found that in general, accidents resulting in upper extremity injuries follow the general distribution of car to VRU crashes. Pedestrians were more likely to sustain upper extremity injuries given a collision with a car compared to bicyclists and e-scooter riders. The most injured area of the upper extremity was the wrist among bicyclists (31%), the shoulder among pedestrians (37%) and the hand among e-scooter riders (29%). Older (65 years old or older) females were overrepresented, both when considering upper extremity injuries in general and those sustaining multiple upper extremity injuries. Being struck by a new vehicle resulted in similar upper extremity injury risks as colliding with older vehicles and most injuries occurred when impacting both the vehicle and the ground. This study recommends focusing future studies on injuries to the wrist and shoulder and investigate the underlying injury mechanisms.

Keywords: Upper extremity injuries, Vulnerable road users, VRUs, Bicyclists, Pedestrians, E-scooter rider, Insurance data, Traffic analysis.

INTRODUCTION

Each year, 20-50 million people are injured in traffic accidents worldwide [1]. Most of these injuries are of lower severity, not posing a serious threat to life. However, studies show that many minor or moderate injuries can result in long-term consequences and negatively affect the quality of life for the injured occupant [2]. Addressing injuries with long-term consequences is important, not only to minimize suffering for affected individuals, but also to reduce societal costs [3]. When addressing injuries with long-term consequences it becomes important to consider body regions and injury types that may be overlooked if targeting severe and fatal injuries.

There are several different methods of measuring long-term consequences, for example permanent medical impairment (PMI) [2] and functional capacity index (FCI) [4], with their prediction measures, risk of PMI (RPMI) and predicted FCI (pFCI) respectively. Each of these metrics takes different factors into consideration in their judgement of what is a disability and how impactful the given disability is to everyday life. Regardless of the method, the upper extremities stand out as being prone to long term disability, already at injuries with little threat to life [2], [5], [6].

Not only do upper extremity injuries often result in long-term consequences for the injured person, but they are also very common. Among vulnerable road users (VRUs), such as bicyclists, pedestrians and e-scooter riders, the upper extremities have consistently been reported to be among the most commonly injured body regions, both in single accidents, in collisions with passenger cars, and in collisions between VRUs and commercial vehicles [6]-[11].

Despite the frequency of upper extremity injuries and their tendency to lead to long term impairment, there are limited means and methods to evaluate the risk of upper extremity injuries, something that is crucial to enable

injury mitigation. To develop such a method, it is important to understand the injury mechanisms at play. A first step towards that is to know what injuries are most common, in what situations they occur and to whom. Although several studies have investigated the frequency of upper extremity injuries in general among different road users, few have investigated what areas of the arm are most often injured and what types of injuries occur most often. Therefore, the objective of this study was to use insurance data to identify in what situation upper extremity injuries occur to VRUs. This study also sought to investigate what part of the upper extremity is most often injured and potential trends in injury distribution over the arm, to help guide future predictive and mitigative efforts.

METHODS

This analysis was based on data from If P&C Insurance's (from now on referred to as If) database People Around the Vehicle (PAV). The PAV database contains extensive information about crashes between cars and VRUs such as bicyclists, pedestrians and e-scooter riders, among others. The data was collected by If through third-party liability insurance claims. This type of insurance is mandatory in Sweden and If insures about 25% of all Swedish vehicles. The database includes detailed information on the accident scenarios as well as of the sustained injuries and information may be provided to the database from a vehicle crash claim report; a VRU claim report; a police report, including a sketch of the crash scene; and interviews with the driver, VRU and other eyewitnesses. Further information about the crash scene, such as road geometry and road-side objects, is added to the database from map data and medical records of the VRU involved are collected through an informed consent procedure and injuries are coded according to the Abbreviated Injury Scale (AIS), version 2015 [5]. Information on impact characteristics in PAV was based on two sources of information. Statements from the road users involved, regardless of whether the car was damaged or not, and evidence of vehicle damage based on photographs taken to support the insurance assessment process. The car damage locations were coded according to the SAE Collision deformation classification [12].

The data sample used for this study covered 1784 accidents, including 1838 VRUs in collisions with cars between the years 2020 and 2024. Near-crash cases, where the vehicle caused the VRU to fall but without an actual contact, were also included. Cases where 1) the active traveler was lying on the ground in the pre-crash phase, and 2) the VRU was fatally injured, were removed from the data sample. This resulted in 1042 upper extremity injuries sustained by 369 vulnerable road users. Among these cases, 39% required ambulance transport from the crash scene, while an additional 43% sought care at a healthcare facility in connection with the incident. Furthermore, a police report was filed in 34% of the crashes. In addition to the 369 VRUs with an AIS coded injury, 83 VRUs reported to have pain in the upper extremity area. They were, however, not included in the analysis. The ages of the individuals in the dataset were grouped into one of the following age categories: 0-12 years, 13-64 years, 65+ years, or unknown age. The conflict situation was described as either a straight crossing path, where the VRU crossed the path of the vehicle; vehicle turning, where the vehicle was turning either to the left or the right; longitudinal, where the VRU and the vehicle were moving in the same direction prior to the crash; and reversing, where the vehicle was reversing into the VRU and dooring, when the VRU impacted an open door of a stationary vehicle. These situations are further described and illustrated in Table 1. As the main reason for studying upper extremity injuries is that they may lead to long-term consequences, this study included AIS1+ injuries, as a previous study has identified a substantial RPMI for AIS1 injuries of the upper extremity [2]. However, not all upper extremity AIS1 injuries have a substantial RPMI. In the study by Malm et al. [2] external injuries (skin) and thermal injuries were separated from other injuries, showing much lower RPMI for the external/thermal injuries compared to the internal upper extremity injuries of the same severity. Therefore, injuries to the skin were excluded from the analysis performed within this study (AIS codes listed in Table A.1), leaving 347 injuries with a high likelihood of leading to any PMI, sustained by 282 VRUs. In Table 2, an overview of the available dataset is shown. The differences between all VRUs in the database those VRUs sustaining an upper extremity injury were compared to give an understanding in what situations and scenarios upper extremity injuries occur.

The risk, or probability, of sustaining an upper extremity injury, given being exposed to a crash was calculated for different types of VRUs, and for bicyclists and pedestrians for different ages and sexes, crash types and car model years, according to Equation (1):

$$p = \frac{x}{n} \quad (1)$$

where p is the probability of sustaining an upper extremity injury, x is the number of VRUs with upper extremity injury, n is the number of exposed VRUs, meaning they were exposed to a car-to-VRU crash. the 95% confidence intervals were estimated, using binomial regression, according to Equation (2):

$$B(\frac{\alpha}{2}x,(n-x+1)) < p < B(1-\frac{\alpha}{2}x+1,(n-x)) \quad (2)$$

where x is the number of VRUs with upper extremity injury, n is the number of exposed VRUs and B is the pth quantile from a beta distribution and α is the level of significance, in this case, 0.05. For this study, risks were considered to be statistically significantly different if the confidence intervals were not overlapping.

Table 1.
Description of conflict situations.

Conflict situation	Illustration	Description	Conflict situation	Illustration	Description
Straight crossing path		The VRU is crossing the straight path of the car	Turning vehicle		The car is turning right or left and impacts a VRU travelling in any direction
Dooring		The VRU impacts an open door of the car	Longitudinal		The VRU and the car are moving along the same direction
Reversing		A reversing car impacts the VRU that is behind the car			

To analyze how the injuries were distributed over the arm, each upper extremity injury was categorized into one of the following arm regions: shoulder, upper arm, elbow, forearm, wrist, or hand. The shoulder category included injuries to the scapula, the clavicle, the proximal head of the humerus, the associated joints and the surrounding tissues. The upper arm included injuries to the humeral shaft and the surrounding tissues. The elbow included injuries to the distal humerus, the proximal radius, the proximal ulna, the elbow joint and surrounding tissue. The forearm included injuries to the radial and ulnar shafts and the surrounding tissues. The wrist included injuries to the distal radius and ulna, the carpal bones, the associated joints and the surrounding tissues, and the hand included injuries to the metacarpals, the phalanges, the associated joints and the surrounding tissues. An illustration of the injury categorization is shown in Figure 1. The distribution of injuries was considered both for all vulnerable road users as one group and for bicyclists, pedestrians and e-scooter riders separately. To investigate how differences between individuals affected injury location, the distribution of upper extremity injuries over the arm was also analyzed based on sex and age.

To understand more about what causes upper extremity injuries, the reported impact characteristics were analyzed. Due to the retrospective nature of the data collection, detailed coding linking individual impacts to specific injuries was not available for all crashes. Consequently, this study employed an aggregated analytical approach, summarizing the overall impact characteristics for each crash and presenting these in relation to the respective upper extremity regions. The locations of car deformations from VRU impacts were analyzed when information was available (253 car impacts). All analysis were performed using descriptive statistics.

Table 2.
General overview of the dataset.

		VRUs with upper extremity injury [%] N=282	All Exposed VRUs [%] N=1818
VRU	Bicyclist	59	65
	Pedestrian	31	26
	E-scooter rider	9	8
	Other	2	2
Age	Up to 12	4	6
	13-64	70	76
	65 or above	26	17
	Unknown	0	1
Sex	Male	53	52
	Female	46	48
	Unknown	0	0
MAIS	0	0	17
	1	20	45
	2	70	32
	3	9	5
	4	1	0
	5	0	0
Crash type	Car rear – VRU All	5	6
	Car front – VRU side	42	45
	Car front – VRU front or back	13	11
	Car side – VRU front	18	19
	Car side – VRU side or back	7	5
	Other	8	5
	Unknown	6	8
Conflict situation	Straight crossing path	51	52
	Car turning	32	29
	Same direction	5	7
	Reversing	6	6
	Dooring	2	2
	Other	2	2
	Unknown	1	1
Road speed limit	30 km/h	25	24
	40-50 km/h	55	58
	60 km/h or above	11	8
	Unknown	9	10
Car model year	Up to 2009	15	16
	2010-2015	23	21
	2016 or later	60	62
	Unknown	1	1
Light conditions	Darkness/ dusk/dawn	20	22
	Daylight	73	68
	Unknown	7	10
Location	Street	80	81
	Rural road	9	6
	Motorway	0	1
	Other	9	11
	Unknown	2	1

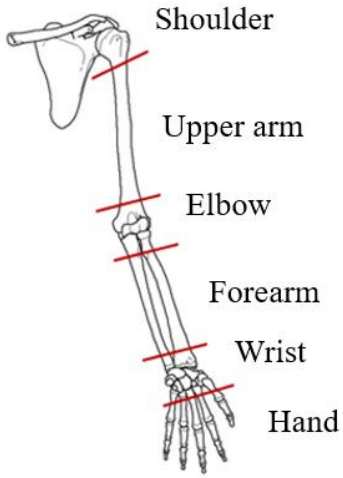

Figure 1. Categorization of the upper extremity injuries into six distinct regions (shoulder, upper arm, elbow, forearm, wrist, and hand) based on injury location.

RESULTS

The data set included 1181 bicyclists, 467 pedestrians, 143 e-scooter riders and 27 other VRUs. In total, 369 VRUs had upper extremity injuries, of which, 216 (59%) were bicyclists, 115 (31%) were pedestrians, 31 (9%) were e-scooter riders and 7 (2%) were other VRUs (Table 2). For all exposed VRUs, the distribution was 65% bicyclists, 26% pedestrians, 8% e-scooter riders and 2% other VRUs. Table 2 highlights that 6% of all exposed VRUs were 12 years or younger, 76% were between 13 and 64 years, and 17% were 65 years old or older. For VRUs sustaining an upper extremity injury, the corresponding distribution was 4%, 70% and 26%, suggesting older individuals more often sustain upper extremity injuries than younger individuals. The gender distribution was 53% males and 47% females when an upper extremity injury was sustained and 51% males and 48% females for all exposures. Straight crossing path was the most common conflict situation, both when an upper extremity injury was sustained (51%) and for all exposures (52%), followed by the car turning situation, 32% when VRU sustained an upper extremity injury compared to 29% for all exposures. Regardless of injury, the most common crash type was *car front - VRU side*, constituting 42% and 45 %, respectively, of cases where upper extremity injuries were sustained and all exposures. *Car side - VRU front* was the second most common crash situation representing 18% and 19% of the cases respectively. Most of the accidents, regardless of injury outcome, occurred in daylight, on city streets with speed limits between 40 and 50 km/h. The actual collision speed was unknown in the majority of cases.

The risk of sustaining an upper extremity injury, likely to lead to any PMI, is shown in Figure 2. The overall upper extremity injury risk was calculated to be 16% (CI: 14%-17%), shown as the risk for all VRUs in the top-left corner of Figure 2. It can be seen that pedestrians are at a slightly higher risk of sustaining an upper extremity injury, having been exposed to a crash, compared to bicyclists and e-scooter riders. However, the difference is not statistically significant as the confidence intervals overlap. Among the bicyclists, females aged 65 or older were at the highest risk of sustaining upper extremity injury (24%, CI: 14%-38%), followed by the males of the same age group (20%, CI: 12%-31%). Also among pedestrians, the older females and males showed the highest risk of upper extremity injury, with 27% (CI: 19%-37%) and 27% (CI: 15%-41%) respectively. Considering crash type, we can see that for bicyclists, impacting the side of the car resulted in slightly higher risks for upper extremity injury compared to impacting the front or the rear of the vehicle. For pedestrians on the other hand, *Car front - VRU front or back* and *Car side - VRU front* resulted in the highest risks. When considering injury risks (Figure 2), no difference could be seen depending on vehicle model year.

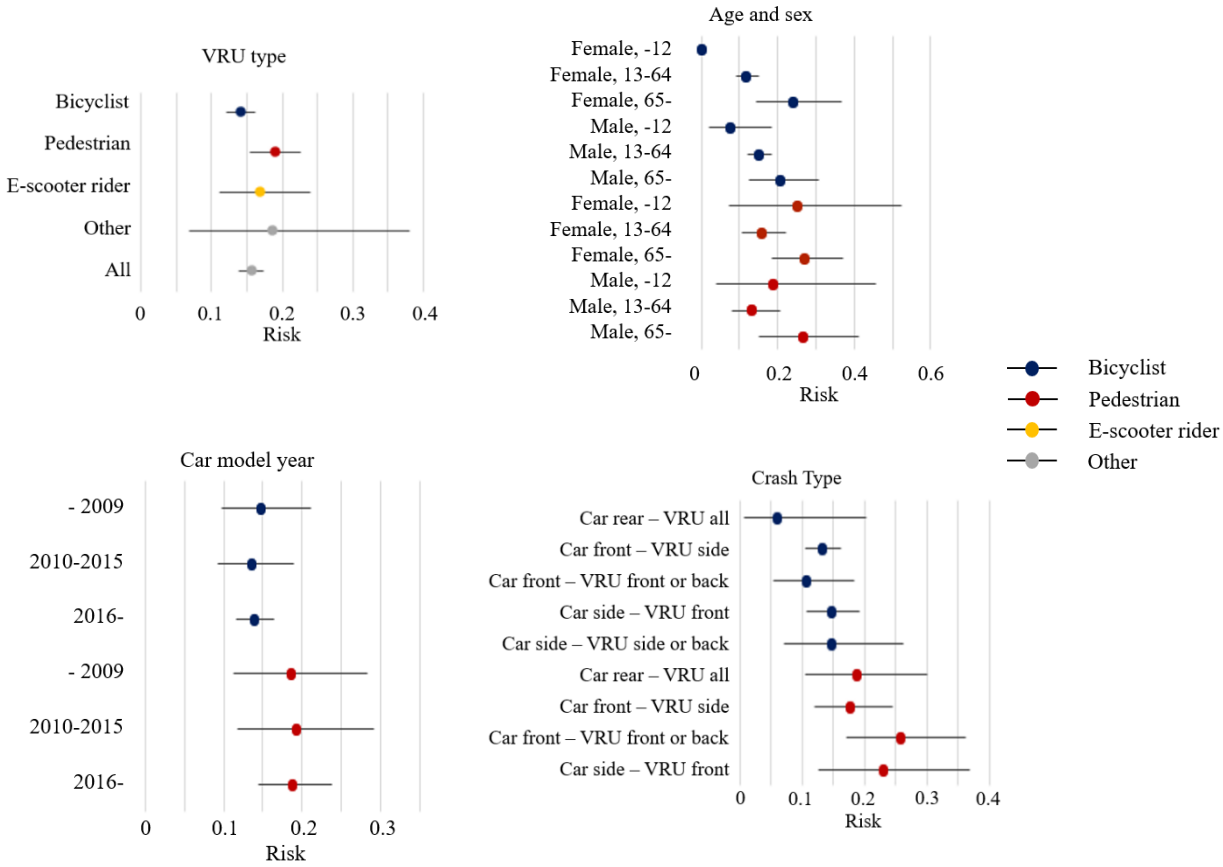

Figure 2. Upper extremity injury risks, calculated per VRU type, Age and Sex, Type of crash and Car model year.

The wrist is the most commonly injured part of the upper extremity among the bicyclists (31%) and for the pedestrians, the shoulder is the most commonly injured region (37%), see Figure 3. Figure 3 also shows the injury severity per upper extremity region and VRU type. In the PAV dataset, most upper extremity injuries are AIS 2 injuries among both the bicyclists and the pedestrians. The number of AIS 3 injuries are low among both pedestrians and bicyclists although the proportion of AIS3 injuries was slightly higher among the pedestrians. Most AIS 1 injuries can be seen to the hand and wrist. Looking further into the data, it was seen that among shoulder injuries, clavicle fractures (proximal third) and fractures to the proximal humerus were the most common, followed by dislocations. Of the upper arm injuries, 10 of the 15 injuries are *Arm fractures, not further specified* and elbow injuries are mainly fractures of the proximal radius or ulna. Of the 29 forearm injuries, 27 were *Forearm fractures, not further specified, including wrist*. Among the wrist injuries, the most common diagnosis was fractures to the distal radius or ulna (which was also the most common injury across all areas of the upper extremity), followed by sprains or dislocations to the carpal joint. Injuries to the hand and fingers were dominated by sprains and dislocations of the phalangeal joints, followed by fractures of the hand, without further specification.

Figure 4 shows how different upper extremity regions are distributed over different sexes and ages. It can be seen that males most often sustained shoulder injuries (28%), while females sustained slightly more wrist injuries (27%), than shoulder injuries (26%). Among the oldest, an overrepresentation of injuries can be seen to the shoulder for both males and females. Among the females, there is also an overrepresentation of wrist injuries within the oldest part of the population. Children aged 12 or younger are few, but in Figure 4 it can be seen that the youngest age group most often sustain injuries to the forearm, whereas shoulder, wrist and hand injuries, that are the most common among the population in general, rarely are sustained by children. In Figure 4, we can also see that multiple upper extremity injuries are common. Among middle-aged VRUs with multiple upper extremity injuries, at least one of the injuries were often seen to the hand, among both males and females. For the oldest age group, sustaining multiple injuries was very common. Out of 71 VRUs aged 65 or older, 15 sustained more than one upper extremity injury, as can be seen from Table 3, and from Figure 4, it can be seen that these are mainly females. The most common injury to sustain together with other injuries among the older females were wrist injury

(9% of all injuries sustained by females), which instead was rare among males of the same age (1% of injuries sustained by males).

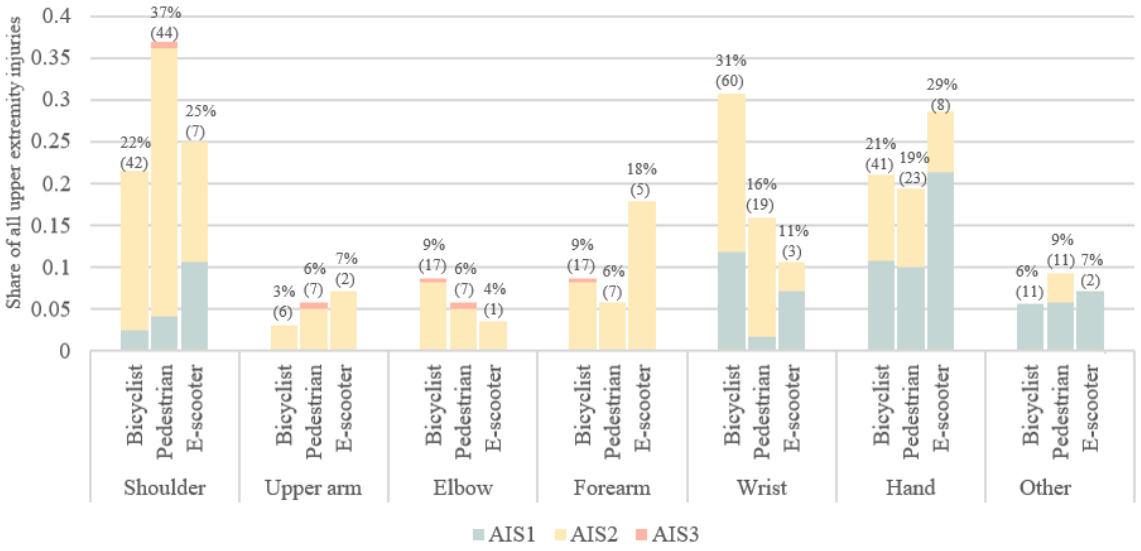

Figure 3. Distribution of upper extremity injuries per body region for each of the VRUs. The AIS level is shown using color coding. Actual number of injuries for each category shown within parentheses.

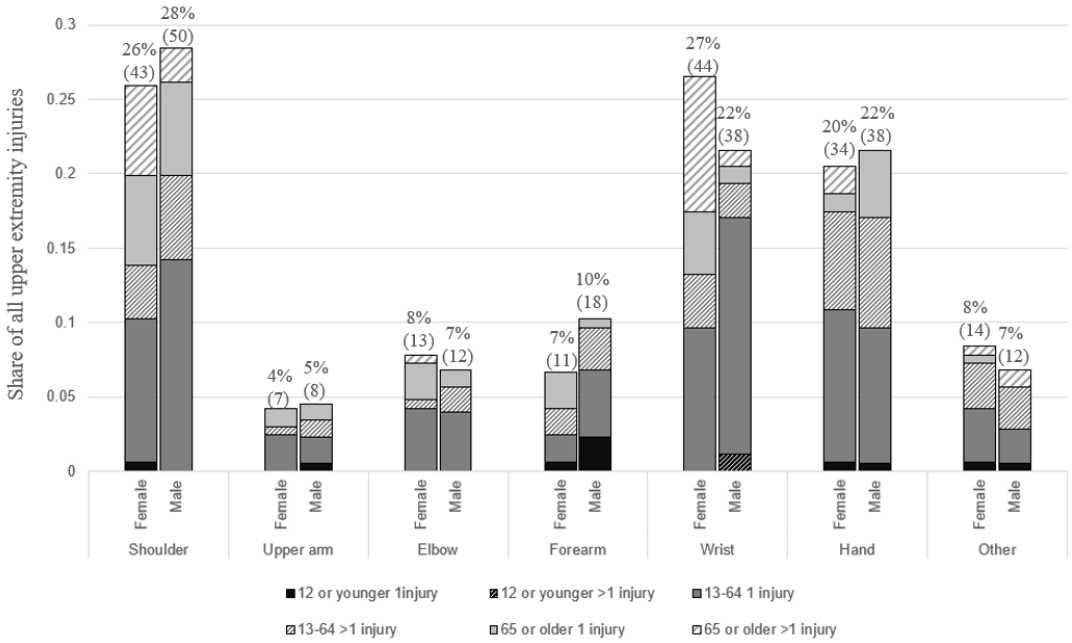

Figure 4. Distribution of upper extremity injuries for the different regions of the arm for males and females. Age and single or multiple injuries are shown using color coding. Actual number of injuries for each category shown within parentheses.

In Table 3, we can also see that most VRUs (230 out of 277) impacted both the vehicle and the ground. In Figure 5, it can also be seen that most injuries, regardless of upper extremity area, occurred when the VRU impacted both the car and the ground (291 out of 342 injuries with recorded impacts). Although injuries from impacting the ground only are few, wrist and forearm injuries account for a majority of these (Figure 5).

Table 3.
Number of VRUs (bicyclists, pedestrians and e-scooter riders) with single and multiple upper extremity injuries.

		Number of VRUs	VRUs with single upper extremity injury	VRUs with multiple upper extremity injuries
Total		277	227	50
Sex	Male	147	124	23
	Female	130	103	27
Age	12 or younger	12	11	1
	13-64	194	160	34
	65 or older	71	56	15
Impacts	Car only	28	23	5
	Ground only	18	15	3
	Car and ground	230	188	42
	No impact	1	0	0

Out of the 727 recorded impacts, 253 impacts caused deformation of the car. Of these, most were seen to the front of the vehicle (41%), 39% of deformations were seen to either of the sides of the car and 20% were seen on the top of the car, illustrated in Figure 6.

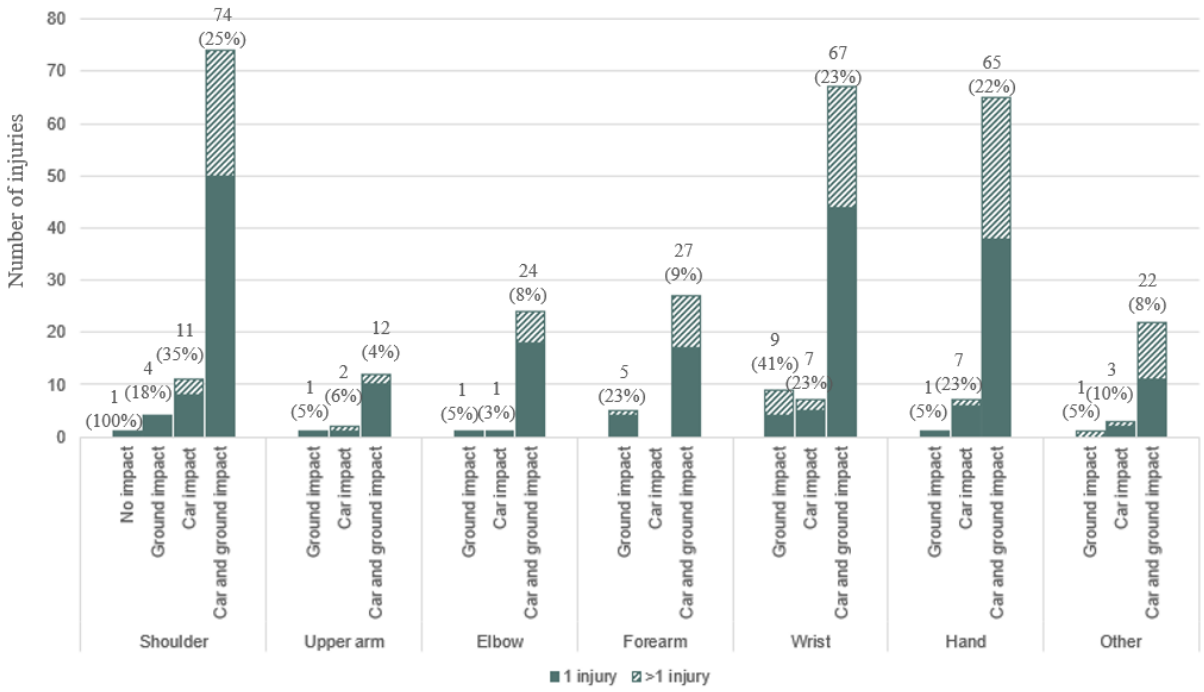

Figure 5. Distribution of upper extremity injuries for the different regions of the arm for different impact combinations. The number of single or multiple injuries are shown using color coding. Percentages are shown within parentheses

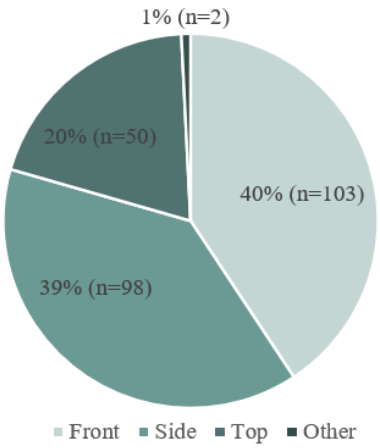

Figure 6. Distribution of car deformation location for the known 253 deformations.

DISCUSSION

This study used insurance data to identify patterns in the occurrence of upper extremity injuries. From Table 2 we could see that the distributions of cases where the VRU sustained an upper extremity injury in general were similar to the cases where no upper extremity injury was sustained. Suggesting that upper extremity injuries follow the general exposures of car to VRU crashes and occur in the same situations as other injuries, which is also supported by previous studies [5], [13]. One exception was age: a higher proportion of the VRUs who sustained upper extremity injuries, compared to all exposed VRUs, were 65 years or older (26% of VRUs compared to 17% of VRUs). This could also be seen when computing the risks for upper extremity injuries for different age- and gender groups. Among pedestrians and bicyclists, males and females above the age of 65 showed the highest risk of upper extremity injury. In general, pedestrians showed a higher risk of upper extremity injury compared to bicyclists and e-scooter riders.

Separating the different VRUs and investigating the injury distribution over the different regions of the upper extremity showed that bicyclists most often sustained injuries to the wrist, while injuries to the shoulders were most common among pedestrians and injuries to the hand were most common among e-scooter riders. However, due to the big differences in the number of VRUs of each kind, the most common injury in general was shoulder injuries, suggesting targeting these injuries for mitigation. However, this study has not investigated if the underlying injury mechanisms were similar between the two different VRU groups. Wrist injuries were the second most common area for upper extremity injury and for no other area we saw as many injuries sustained by a single VRU type. If we also consider that almost all of the sustained forearm injuries were *Forearm fracture, not further specified, including wrist*, and knowing the high share of wrist injuries compared to forearm fractures, we can assume that at least part of the injuries grouped as forearm injuries actually represent injuries to the wrist. If the proportion of wrist injuries within the previously mentioned injury code would be the same as the proportion between the remaining wrist and forearm injuries, 26 injuries would be re-grouped from forearm to wrist and thus, wrist injuries would be the most commonly injured area of the arm. Stigson et al. [14] presented the distribution of upper extremity injuries reported as leading to any PMI. As both studies are based on Swedish insurance data, we can assume that the exposure data should be somewhat similar. Just as in this study, injuries to the shoulder were reported to be common and they were also reported to have a high mean PMI. Stigson et al. [14] also report both high proportions and high mean PMI for fractures to the wrist, which are also commonly seen in this study. Bergsten et al. [15] reported on injuries leading to sick leave among pedestrians and injuries to the shoulder and wrist/hand constituted about 30% of all long-term sick leave reported. Combining the results from this study with previous research highlights the need to focus future predictive and mitigative efforts on the shoulder and wrist area.

This study has identified a difference in injury risk depending on age. From Figure 4 it could be seen that the distribution of upper extremity injuries over the arm also varies depending on age. Particularly, a difference could be seen for older females, sustaining wrist injuries, mainly fractures, to a higher extent than both younger females and males of the same age, this is despite the fact that wrist injuries were mainly sustained by bicyclists, while the older females (over 65 years old) were primarily pedestrians. Younger individuals were instead more likely to

sustain injuries to the hand, mainly sprains and dislocations. It could potentially be explained by the fact that decrease in bone quality, which is most common among females, often progress in the wrist area early [16], potentially resulting in more severe outcomes in older females. Regarding shoulder injuries, older individuals were also overrepresented, but no obvious difference could be seen between males and females, suggesting that bone quality plays a smaller part in shoulder injuries. One reason to why older individuals are more likely to sustain shoulder injuries is a reduced reaction speed and strength, making it more difficult for an older individual to catch themselves [17]. VRUs in the oldest age group were also more likely to sustain multiple injuries, which is also supported by fragility. Particularly wrist injuries were common in combination with other injuries.

In about 50% of all accidents, the initial impact between the car and the VRU was to the front of the vehicle and in 25 % of the cases, the primary contact was to the side of the vehicle (Table 2). The front of the vehicle is where improvements in vehicle design to improve pedestrian safety has been made. Although major changes in ratings and regulations regarding pedestrian safety was made in the early 2000s, incremental improvements are being implemented continuously. This study could, however, not show any difference in upper extremity injury risk depending on car model year. This suggests that the most recent improvements to vehicle design for VRU safety does not affect the risk of upper extremity injury, suggesting other mitigative solutions are needed. This could be due to several different reasons. For example, we have seen that the vehicle fleet has changed over the years, with more new cars being electric and of SUV-models, which has increased the average vehicle weight globally [18]. It is possible that these differences in both vehicle weight and height affects the risk of sustaining upper extremity injuries negatively. Also, when analyzing the impacts, we could see that almost as many of the vehicle deformations were seen to the side of the vehicles (39%), as to the front of the vehicle (40%) despite the difference in initial impact location from Table 2. On the side of the vehicle there are no protective systems for pedestrians, and according to Figure 2, the risk of sustaining upper extremity injuries is slightly higher when impacting the vehicle side compared to impacting the vehicle front, except for a few cases of pedestrians where the vehicle front impacted VRU front or back. This suggests that the existing pedestrian protection have a positive impact on upper extremity injury risk. From Figure 5 it could also be seen that most part of the VRUs experienced both car and ground impacts, as the violence of the crash often makes the VRU fall to the ground eventually. As the data sample used in this study did not link a given impact to a specific injury, it is not possible to say if the upper extremity injury was a result from the impact with the car or the ground. Previous studies have however shown that the force at ground impact, also after vehicle impact, is enough to cause injury [19], [20]. We could therefore hypothesize that many upper extremity injuries are a result of impacting the ground, after the initial impact to the vehicle. In such a case, where the impact causing the injury could be a ground impact, as well as a car impact, it is of high importance to investigate the injury mechanisms on a case-by-case basis to understand what the most appropriate test procedures and countermeasures would be.

LIMITATIONS

This study was only performed on aggregated, retrospective data and no case-by-case studies were performed. This limits the strengths of the conclusion regarding preferred countermeasures as no linking was made between impact location and injury outcome and no attempts on establishing the injury mechanisms was made.

Although this data set could be considered to be representative of the Swedish traffic environment, the results could look different when considering other parts of the world, suggesting that additional studies, covering upper extremity injuries among VRUs in other databases could be needed to confirm the results before generalization.

CONCLUSION

This study highlights the high prevalence of upper extremity injuries among vulnerable road users. The study also shows that upper extremity injuries occur in the same situations as injuries in general. Pedestrians are particularly prone to sustain upper extremity injuries, as is individuals aged 65 or older. Many of the accidents resulted in impacts both to the car and to the ground and many of the high-force impacts occurred to the side of the vehicle. This study also highlighted the need of mitigative systems designed specifically to target upper extremity injuries, as these injuries are both common and a major cause for disability and sick leave. Particularly wrist and shoulder injuries showed high prevalence and due to the high risk of PMI of injuries to these body regions, these should be targeted for future studies. For future development of methods for injury prediction and mitigation it is of high importance to continue and investigate the injury mechanisms

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APPENDIX I

Table A.1

List of AIS codes not considered for upper extremity injuries

AIS codes
710099.1
710202.1
710402.1
710600.1
710602.1
710604.2
710606.3
710800.1
710802.1
710804.2
710806.3