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Understanding Upper Extremity Injuries in Vulnerable Road Users

Field data analysis based on insurance data of car to vulnerable road user collisions

Master's thesis in Biomedical Engineering, MPMED and
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Gelila Abate Mengistu and William Karlander

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GELILA ABATE MENGISTU
WILLIAM KARLANDER

Department of Mechanics and Maritime Sciences
Division of Vehicle safety
Chalmers University of Technology
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GELILA ABATE MENGISTU AND WILLIAM KARLANDER

Supervisor: Amanda Hederskog, Autoliv
Jordanka Kovaceva, Mechanics and Maritime Sciences, Chalmers
Examiner: Johan Iraeus, Mechanics and Maritime Sciences, Chalmers

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Department of Mechanics and Maritime Sciences
Division of Vehicle Safety
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Abstract

Injuries from traffic accidents remain a major threat to quality of life, particularly for vulnerable road users (VRUs) such as pedestrians, cyclists, and scooter riders. While traditional vehicle safety efforts have prioritized preventing fatalities, recent initiatives such as UN's Vision Zero also emphasize reducing non-fatal injuries with long-term consequences. Among these injuries, upper extremity injuries (UEIs) are particularly frequent among VRUs and often lead to long-term impairment. To effectively mitigate these injuries and reduce the risk of loss of quality of life, there is a need for more insight into the UEIs found among VRUs.

This thesis investigates UEIs among VRUs using the People Around the Vehicle crash database (PAV) from If, a Swedish insurance company. PAV focuses on car-to-VRU (car-VRU) collisions, and the sample includes collisions reported between 2020 and 2023, where the VRU sustained at least one UEI. The analysis began with descriptive statistics to characterize the injury patterns and conditions associated with the collisions, followed by chi-squared tests and multiple correspondence analysis to explore potential risk factors. Multinomial logistic regression was then used to assess the effect of these factors on the type and location of UEIs. Lastly, a comparison was conducted between the VRUs to identify any shared vulnerability, potential injury patterns, and risk factors.

The results indicate that there are similarities in injury patterns among the VRUs, with wrist, hand and shoulder injuries being the most commonly injured regions among all the VRUs. The general injury patterns were similar across VRU types, as shoulder and hand injuries were frequent among cyclists, pedestrians and scooter riders, but cyclists experienced a higher frequency of wrist injuries compared to pedestrians and scooter riders. The results indicate that there likely are some differences between the VRUs that needs to be considered when studying different VRUs. Potential risk factors for UEIs was age, as younger VRUs were more likely to sustain forearm injuries. In summary, these findings highlight the need for targeted prevention strategies focusing on the common UEIs to the shoulder, hand and wrist. At the same time there might be a need for different mitigative efforts depending on risk factors such as age. The study provides a foundation for future research aimed at mitigating long-term consequences of VRUs with injuries from car collisions.

Keywords: Vulnerable road users, active travelers, upper extremity injures

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List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AIS	Abbreviated Injury Scale
CDC	Collision Deformation Classification
LTI	Long Term Impairments
MCA	Multiple Correspondence Analysis
NFS	Not Further Specified
PAV	If's People Around the Vehicle Crash Database
QoL	Quality of Life
UE	Upper Extremity
UEF	Upper Extremity Fracture
UEI	Upper Extremity Injury
UN	United Nations
VRU	Vulnerable Road User

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1 Introduction

Ever since automotive vehicles became popular as a means of transportation, injuries and fatalities related to traffic accidents have been a problematic consequence. Each year, between 20 and 50 million people are injured in traffic accidents [1]. These injuries pose serious threats to quality of life (QoL), which further emphasizes the importance of vehicle safety and highlights the need for effective measures to mitigate injuries from traffic accidents.

Road transport is currently the leading cause of accidents, often leading to severe injuries or fatalities [2]. To prevent road accidents and mitigate harm, the Swedish government enacted Vision Zero 1997 [3]. Since then, similar major initiatives have been launched by the European Union [2] and United Nations (UN) [4]. These initiatives state that by 2050 there should be no fatalities in the road transportation system; consequently, most initiatives to mitigate harm in traffic accidents have focused on injuries with a high mortality risk. As a result, fewer resources have been allocated to mitigating non-fatal injuries affecting various road users, such as upper extremity injuries (UEIs). UEIs have lower mortality rate ratios (MRR) compared to other major traumatic injuries such as head injury [5] but often result in long-term impairments (LTI) [6, 7]. Recent developments in road safety policy, including the UN's Vision Zero, now emphasize reducing long-term consequences in addition to fatalities [8]. In line with this shift and the broader goal of improving QoL among road users, greater attention should be directed toward injuries with lasting consequences, such as UEIs.

Some road users have a higher risk for impairments and fatalities than others [9]. These are commonly grouped together under the terms active travelers and VRU. Active travelers refer to an individual traveling by their own physical effort and includes assisted forms of travel, such as e-bikes [10]. VRUs, on the other hand, include road users such as bicyclists, motorcyclists, and pedestrians that are at a higher risk for injuries than car occupants, as they are unprotected [11]. All active travelers are therefore considered as VRUs, but the term VRU encompasses a broader range of road users than just active travelers. Since 2017 there has been an upsurge in the use of e-scooters because the rental scooters provided around many cities [12], making e-scooter users common VRUs. In this thesis, the VRUs traveling by e-scooter will be called scooter riders.

Previous research indicates that VRUs often sustain UEIs, which mostly lead to LTI and impose significant costs on society [7]. There have been some studies on the most common injuries of VRUs, such as pedestrians [13], showing that UEIs are common. There have also been comparisons between pedestrians and bicyclists indicating that UEIs are common among both VRUs, in both collision with cars and single accidents [14, 15].

In addition, there have been attempts to study injury mechanisms for accidents involving pedestrians and bicyclists. By studying the injury mechanism, it is possible to predict potential injuries, but some impact scenarios are very complex, leading to unreliable predictions [16]. UEIs are common consequences of both contact with the ground and wrap projection, which is when a person's body wrap around the vehicle front profile of the bonnet-car [17, 16]. Wrap projection is the most common impact scenario when the VRU is struck by the vehicle front and is also the most complex scenario. These scenarios are only found in vehicle to VRU collision, which means studies on single falls are less comparable to vehicle to VRU collision.

In addition to comparative studies on the injury distribution and injury mechanism, bicyclists have been studied as an independent group. Isaksson-Hellman and Werneke [18] and Lindman et al., [19] indicate that UEIs are the most common type of injuries in any accidents between bicyclists and cars. The claim that UEIs are common among bicyclists has also been supported by Makara et al., [20] and Rizzi et al., [21]. The latter study also investigated hospital admissions and LTI where the authors support previous conclusions that UEIs lead to LTI. Liew et al., [22] and Brenner et al., [23] showed that UEIs are also common among scooter riders. There have also been comparisons between bicyclists and scooter riders on their injury distributions, where the authors found that UEIs are common among both VRUs [24].

The previously mentioned studies report varying frequencies for UEIs, which could be due to different underlying factors such as geographic location, cases included, and sourced data. The possible causes for variations between presented injury distributions are presented in more depth in a later section. However, there seems to be a general lack of comparisons between different VRUs, which hinders effective mitigation efforts. Despite this, existing studies on injury distributions among VRUs consistently show a high prevalence of UEIs, emphasizing the need for targeted countermeasures. To develop these, it is important to compare different VRU groups to identify risk factors and common injury patterns, and to better understand why UEIs are frequent among VRUs.

To add to previous research, this thesis will attempt to guide future initiatives, primarily UEI research at Autoliv, regarding how different VRUs in Sweden incur UEIs. The research will be conducted by investigating the UEIs among VRUs that have been documented in If's People Around the Vehicle crash database (PAV) which is based on insurance claims in Sweden. The database includes collisions between cars and VRUs. In addition to studying the occurrence of UEIs, the study will investigate which factors affect the occurrence of UEIs, the injury severity and lastly examine if there are similarities between different types of VRUs. The upper extremities (UE) are defined through the 2015 abbreviated injury scale (AIS) code and is divided into regions consisting of the shoulder, upper arm, elbow, forearm, wrist, and hand [25]. A different grouping of the arm can be seen in Tan's study where the region of the arm consists of the scapulothoracic,shoulder (including the clavicle, glenohumeral joint, and acromioclavicular joint), arm, forearm (radius, ulna, and elbow joints), wrist, and hand (carpals, metacarpals, phalanges, and interphalangeal joints) [26]. The AIS code is an anatomy-based coding system used to classify and describe injuries [27]. The AIS code describes the injury's location, type and severity. The severity scale ranges from AIS 1 to AIS 6, and AIS 9 when it is not possible to classify according to the AIS scale or information is missing. In

PAV, pain only is also documented, although pain is not classified as injury according to AIS. Each severity level reflect the relative threat to life associated with an injury. The severity scale for UEIs ranges from AIS 1 which is considered a mild injury to AIS 4, which is considered a severe injury [6].

1.1 Overview of the upper extremity

The UE region of a human body consists of shoulder, arm, elbow, forearm, wrist, hand and fingers which work together to achieve everyday life activity. The tissue within the body is classified in accordance to the proximodistal axis and the axis can be the basis for which injury is grouped where. The proximodistal axis describes the orientation from the point closest to the body. For the upper extremities, shoulder would be proximal to the body, and hand distal, as it is the farthest away.

The hand and fingers are commonly grouped together and called hand. The UE consists of structures such as bones, joints, muscles, nerves, connective tissues, and blood vessels. The complex skeletal structure of UE consists of 30 bones, a humerus in the arm, ulna, and radius in the forearm, 8 carpals wrist bones, 5 metacarpals palm bones and 14 phalanges finger bones in the hand [28].

The shoulder, which is the most mobile and complex joint in the body, allows a wide range of movement in daily life for various activities [29]. It is composed of the humerus, scapula and clavicle and has four primary joints named the glenohumeral joint, the acromioclavicular joint, the sternoclavicular joint, and the scapulothoracic articulation. The humerus is the longest bone in the upper arm, which proximally articulates with the scapula at the shoulder and distally with the ulna and radius at the elbow [30]. The other joint in the UE is the elbow which allows flexing and extending of the arms. It primarily moves in two directions including, flexion-extension and pronation-supination. Extension where the arm straightens out away from the body, flexion where the arm bends towards to the body, supination where the palm turns upward and pronation where the palm faces downward [31]. The region between the elbow and wrist is the forearm which consists of two long bones called ulna and radial. Radial is located at the lateral side, and it is responsible for forearm rotation while the ulna is located at the medial side and provides structural support. The wrist and hand of the UE is also a complex anatomical structure consisting of numerous bones and soft tissues. The wrist joint is made from eight carpal bones with the distal radius, the structure within the ulnocarpal space, the metacarpals, and each other [32]. It allows movement such as flexion, extension, radial and ulnar deviation which enables different hand position. The metacarpus or the palm is the intermediate part of the hand consists of the metacarpals bones and the phalanges make the distal region of the hand. Figure 1.1 shows an overview of parts of the UE the study will look into.

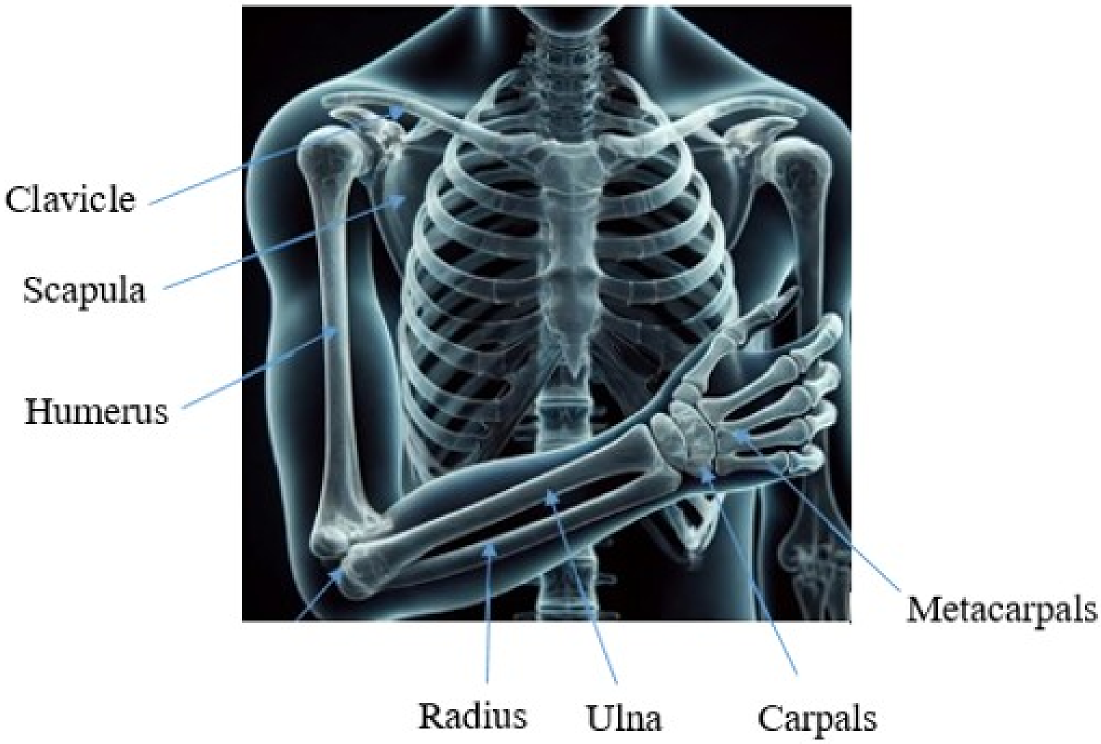


Figure 1.1: Anatomy of Upper Extremity (Image generated by ChatGPT, OpenAI, 2025).

1.2 Overview of VRUs

Bicyclists are the most prone to injuries and are also one of the RUs more prone to suffer UEIs [20]. In addition to being prone to UEIs, bicyclists have become more common during the last two decades [33]. Tan et al., [26] have conducted a study on 177 patients with bicycle related UEIs out of 733 patients treated for bicycle related injuries with both traumatic and other types of injuries. 88 patients sustained bony injuries and 89 patients had isolated soft tissue injuries. 24% of all hospital admitted cyclists suffered some type of UEI. The body regions most frequently affected were shoulders 48%, hand 19% and wrist 19% of the UEI cases. The authors also studied injury mechanisms and found that the most common causes of UEIs were collision with cars 59.8%, falls to the ground accounted for 37.9% and the remaining 2.3% were collisions with stationary structures. Among the injuries to the upper extremities, all areas were mostly isolated injuries with 88% to 94% of the injuries being singular and the only injury in the UE, apart from the scapulothoracic and upper arm where 50% were singular. The latter two regions had few cases which might skew the results [26].

Jancaitis et al., [34] study injuries sustained by competitive bicyclists in the US. They studied the full body and categorized the upper extremities as including clavicle. Out of the 1053 injury reports that were included, the cyclists suffered in total 1808 injuries.

In the 766 reports where sex was was recorded, most of the injured were men (84.8%). The number of body regions injured was a single region injured 33.5% of the cases, two regions 25% of the cases, three regions 29.3% of the cases, and 12% had no confirmed body regions reported. Among the 1808 injuries a total of 841 injuries were found in the UE (46.5%). Each injury report had a mean count of injury of 1.37 injuries. The authors highlight a strong risk factor for sustaining multiple injuries, which was off road cycling such as mountain biking, where the individual had on average twice as many injuries (2.75 injuries per injury report) compared to the competitive road bicyclists in the data set.

Grill et al., [35] compared scooter riders and bicyclists who were admitted to the hospital. Out of the total 400, 360 were bicyclists and 40 were scooter riders. The selection was limited to those who suffered craniofacial injuries and needed some sort of treatment for these injuries. 148 out of 360 bicyclists had some UEI, while 9 out of 40 scooter riders sustained some UEI. UEIs and facial injuries are most common among scooter riders [35]. Scooter riders often rode (52.5%) under the influence of alcohol [35].

Scooter riders have become more prevalent with the use of rented scooters around urban areas [36], which has made this VRU category more interesting to study since they also show tendencies for increased UEI risk. In a study conducted on comparative analysis of accident mechanisms and injury patterns of e-moped, and scooter riders, it was found that UEI were more prevalent among scooter riders with 23.9% sustaining the injury, compared to e-moped riders with 19.4% [23].

UEI including fractures, dislocations and soft tissue damage occur through direct vehicle impact and these injuries make up a significant portion of pedestrian trauma where clavicle fracture, shoulder dislocation, humerus, wrist and forearm fractures being the most common injuries [37]. In a study describing the injury patterns of pedestrians involved in collision with cars, the most frequently injured body regions were the lower extremities (50%), the head/face/neck (38%) and the upper extremities (27%), specifically shoulder or arm (15.57%), elbow or forearm (8.36%) and wrist or hand (3.68%) [38].

1.3 Overview of UEIs among VRUs

Injuries to the UE encompass a variety of conditions involving the bones, muscles, ligaments, tendons, and joints of the arm. These injuries can range from minor abrasions to severe injuries like fractures, dislocation, and even nerve damage resulting from direct impact, fall and collision with vehicles. Due to these injury mechanisms one or multiple parts of the UE can be affected which could lead to long term effects such as chronic pain, functional limitation and reducing QoL. Understanding the UEI for VRUs is essential for developing preventive measures and enhancing safety measures.

One of the most common types of UEIs among VRUs is skeletal injuries, especially fractures, often caused by collisions and direct impacts, in which the severity of injuries includes moderate to severe injuries [39]. The skeletal injury can be classified as fractures, dislocation, and combination of fracture and dislocations [40]. A fracture is a breach in the bone cortex's structural continuity with a degree of injuries to the surrounding soft tissues [41]. There are four types of fracture including a partial, which is an incomplete break across the bone, a complete fracture which is a complete break across the bone, a closed (simple) fracture that does not break through the skin and an open (compound) fracture in which the broken end of the bone protrudes through the skin [28]. A dislocation is a disruption of the normal articulating anatomy of a joint and it can either be a complete disruption of the normal anatomy or a partial dislocation [42].

Building on understanding of skeletal injuries, studies have investigated the prevalence of these injuries among VRUs. In a study where a retrospective review of patients with conventional bicycle-related injuries of the upper extremity was performed, it was found that eighty-eight (49.7%) patients sustained bony injuries including fractures or dislocations, while 89 (50.3%) cases had isolated soft tissue injuries including muscle tears, strains, sprains, and contusions in the upper extremity [26]. In patients who sustained bony injuries, 88.6% had injuries to a single region, while 11.4% had injuries to multiple areas, most commonly to the shoulder and scapulothoracic area (60.0%) and the most common bony injuries were in the shoulder (44.3%), hand (28.4%), and forearm (18.2%) regions. Most of the skeletal injuries were closed injuries with 9% patients sustaining open fracture [26].

In a study on bicyclists interacting with passenger cars, AIS2+ injuries accounted for 15% of all injuries and of all AIS2+ injuries 76% were fractures mainly to the upper extremities (33%), torso (25%) and lower extremities (24%) [19]. Upper extremity fractures associated with road accidents were studied to examine the injury profiles of upper extremity fracture and among the bicycle riders the most common fracture location was the radius (35%), humerus (25%) and ulna (24%). Among the pedestrians the most frequent fractures were humerus (34%), clavicle (32%), and radius (13%)[43]. In similar study on upper extremity fracture (UEF) among hospitalized road traffic accident adults, for the bicycle riders the most frequent fractures were radius (24%), clavicle (21%), and ulna (17%), and in pedestrians the most frequent fractures were humerus (32%), clavicle (17%), and radius (16%) [44]. In a comprehensive study on a review of scooters, UEIs were also prevalent, ranging from 16.7% to 72.5% [45]. These injuries were found primarily in the wrist and forearm, where the most frequent fracture was a fracture to the distal radius and a fracture of the hand involving the rays of the fingers, the fifth metacarpal and the wrist (scaphoid) [46].

Another common type of UEIs among VRUs involve injuries to the soft tissues. Soft tissue injuries involve damage to the connective tissue such as skin, muscles, ligaments tendons, blood vessels and nerves [47]. These injuries to the VRU results from direct impact, fall or collisions with vehicles. Some of the soft injuries on VRU include skin abrasion, skin contusion, skin laceration, ligament injury and some can be combination of soft tissue with skeletal injuries which can lead to more severe complications, e.g., a fracture on the forearm is often accompanied by ligament and muscle damages. The significance of soft tissue injuries to the UE among VRUs have been highlighted in some studies. In a study analyzing injuries among 308 bicyclists, 15% of all injuries were classified as AIS2+ which is moderate to severe injuries while most of it account for fracture but soft tissue injury such as ruptures, and laceration were common in the UE [19]. Tan et al., [26] studied bicycle related injuries in the upper extremities where 50% of the cases were soft tissue injuries including muscle tears, strains, sprains, and contusions and the most common soft tissue injury was shoulder contusion, with soft tissue contusion and sprain to the wrist being the next most common. In a study comparing injury patterns between scooter riders and bicycle riders, it is mentioned that UEFs were more common on both scooter riders (28%) and bicycle riders (47%) and dislocation was observed in 6% of scooters riders and 11% of bicycle riders [24]. To better understand why certain injuries, occur or what aspects decide the severity and other aspect of the injuries, it is possible to study the risk factors. Risk factors are aspects that in some way influence either the severity of an injury, or commonly lead to a different set of injuries. Within this thesis, risk factors denote aspects which are expected to influence the likelihood of a VRU sustaining injuries to a region of the arm, conditioned that they have at least one UEI.

To better understand the UEIs among VRUs and provide information for future studies on possible mitigative efforts, we set the following aims and objectives that need to be reached for this thesis.

1.4 Aim and objectives

The project aims to create an understanding of UEIs among VRUs and provide the information necessary for future decision-making concerning mitigating measures, by identifying what types of UEIs are most prevalent and which VRUs are sustaining them. To fulfil the aim, four objectives are defined:

1. To provide an exploratory data analysis of car-VRU collisions

2. To investigate what upper extremity injuries are the most common among VRUs

3. To determine if there are specific risk factors associated with UEIs for VRUs

4. To investigate if there are similarities in UEI patterns between the different types of VRUs.

1.5 Delimitations

The study is based on data including UEIs among VRUs in all over Sweden. The data covers collisions between cars and VRUs; accidents involving heavy-duty vehicles or collisions between VRUs are excluded. Only data from If's People Around the Vehicle crash database for the years 2020–2023 will be used in the analysis. The database provides AIS codes for the injuries and information regarding both injury and impact. Injury mechanisms for the different accidents will not be studied in depth.

The study focuses on the injuries themselves and not the accident causes, which may exclude some variables from the analysis. The data set should include most common types of VRUs but might also include some specific, rarer, road user cases in the data. The rarer types will likely have too few instances to be included in specific analyses and comparisons, but the study should be able to capture and analyze the more common VRUs. The study does not include motorcyclists or moped drivers or similar powered two-wheelers, which means these will be excluded from the analysis.

1.6 Ethical considerations

All accidents in the crash database used are anonymized and there should therefore be no potential ethical risks with the quantitative data analysis in this project.

Besides potential negative ethical considerations, such as the risk of misinterpreting the data and drawing conclusions that could lead to biased safety measures, the project itself may have positive societal, ethical, and ecological impacts in the future. By conducting studies on the UEIs among VRUs, it may be possible to generate sufficient data as a basis for future mitigating efforts, which in return may lead to higher QoL for VRUs. In addition, the reduced risks for VRUs may lead to cycling (and other sustainable transportation methods) becoming more common. The social responsibility, shared by all stakeholders, is to ensure the goals of Vision Zero can be met. To reach these goals, the stakeholders must collaborate in order to prevent UEIs among VRUs.

2

Background

2.1 Risk factors for UEIs for VRUs

There are different risk factors associated with the UEIs and comprehensive understanding of these risk factors is important to design preventive strategies. Some of the more common injuries sustained by VRUs are injuries to the upper limb. The severity and likelihood of UEIs is highly influenced by demographic characteristics. In a study of bicycle related injuries to the UE, males were found to be the majority (88.1%) of patients compared to female (11.9%) [26]. Dalmases et al., [13] had a classification system for pedestrian injury analysis based on age and gender to account for physiological differences in bone density and fracture and showed that children <12 age boys are at more risk than girls of same age group and elderly females >= 57 and males>= 75 are at higher risk of fracture and severe injuries due to lower bone density.

Alcohol consumption, a behavioral element presented at 2.8% of bicycle related cases [26] is another risk factor for UEIs. Another possible risk factor is not using protective gear such as shoulder pads and wrist guards which have been suggested as a possible mitigative effort against UEIs [26]. The same applies to scooter riders who don't use protective equipment putting them to risk of sustaining UEIs [13].

The type of impacting vehicle highly influences the risk of injuries which can cause more serious trauma and this is due to their mass and velocity of heavy vehicles [26] [13]. Crandall [37] showed that vehicle design like the structure of the bonnet and windshield and also the height affects the nature of pedestrian injuries, for instance raised bonnet can provide more deceleration which can reduce force, but increase risk of injuries to the UE.

Conflict situation has a main role in risk factors associated with UEIs. In a previous study based on If insurance data it was found that 78% of bicycle vehicle collisions occur from the path crossing, while 11% occurred in the same or opposite direction travel in which same or opposite direction travel resulted in more severe injuries [18].

One of the predictors of injury severity is the speed at time of collision. Vehicles with high speed have high energy, which can increase the force of impact and the likelihood of severe trauma increases with higher forces, especially for the upper extremity [37]. Also, Isakson [18] provide arguments that impact speed likely is directly correlated with injury outcome.

2.2 Injury Mechanisms Leading to UEIs

In a previous study different injury mechanism was identified for UEIs among cyclists, including falls from bicycles (37.9%), collisions with cars (33.3%), heavy vehicles (14.1%), other vehicles (12.4%), and stationary objects (2.3%), where fall from bicycle often result in injury to the wrist due to instinctive bracing [26]. Collision with open car doors is also another mechanism which can lead to UEIs and more than 25% of these collisions result in AIS2 to the UE [18].

For pedestrians 71.7% of UEIs is from direct impact with the vehicle especially with the bonnet and windscreen and 31.9% account for secondary impact such as hitting the ground post collision and in some rare cases crushing injuries occurring when limbs are trapped between vehicles and another surface can occur [37].

One of the injury mechanisms in which scooter riders sustain UEIs is through forward fall while trying to brace themselves [48]. 40.7% of crossing path collision involve lateral impacts, either to the right or left. 19.6% were same or opposite direction collisions involving rare impacts, in which the direction influence whether the VRU is thrown forward, sideway, or remain upright, which then affect the body part that is going to be injured and cyclists frequently suffer UEIs due to being flung forward and instinctively extending their arms to break the fall [18].

2.3 Statistical analysis

In this section, the necessary information to conduct the statistical analysis used in this thesis is explained.

2.3.1 Chi-squared test

Qualitative data can be nominal or ordinal, where nominal data is without order and numbers are merely used to identify certain variations and ordinal variables follow a ranked order. When the different categories or descriptions of variable do not have a quantified meaning, it is challenging to find a relationship [49]. A quantified relationship is in many cases ideal, as it gives a direct metric of how useful certain mitigation might be. It is possible to get indications on whether two categorical variables have an interaction or a relationship by using the chi-squared test.

It is common practice within studies in vehicle safety (see e.g. [23, 35, 18]) to test if there is dependence between crash characteristics and injury outcome. Pearson's Chi-squared test is a test intended to investigate potential dependencies between two variables. If there are statistically significant deviations to the chi-squared distribution, it is possible to determine if there is dependence between the variables, if sample data matches a certain distribution or if proportions between groups are different. To use the chi-squared test there are certain assumptions that need to be considered [50]. The observations must be independent of each other; the expected frequency needs to be sufficiently large. The precise number has been determined by Cochran to be 5 but has been questioned and later seen as too restrictive [51]. In many cases the expected frequency can be as low as 0.5 or greater in the smallest cell and still not affect the test to become unreliable [51]. At the same time, it is still ideal to have at least a few expected frequencies of each category within the variables tested, and there are available approaches to mitigate few excepted frequencies.

The chi-squared test is conducted by using the chi-square statistic formula seen in Equation (2.1), where O is the observed counts for all cells in the table, E is the expected value, χ^2 is the cell chi-square value and χ^2_{ij} represents all cells. The expected cell values can be found by Equation (2.2), where M_r is the sum of the row of each cell, M_c is the sum of the column of each cell and n is the total sample size. With the expected values of each cell determined, it is then possible to find the χ^2 for each cell and then summarize all χ^2 and compare to the chi-squared distribution [50]. In R, chi-squared tests can be conducted using the chisq.test() function applied to a contingency table, which directly provides a significance value for the tested contingency table. If the χ^2 is statistically significant for the chosen p-value such as 0.05, the test provides evidence that the groups are independent (statistically significantly different).

$$\sum \chi^2_{ij} = \frac{(O-E)^2}{E} \tag{2.1}$$

$$E = \frac{M_r \times M_c}{n} \tag{2.2}$$

It is common for chi-squared tests to lead to p-values suggesting statistically significant results when the observations are fewer than the required expected values [52]. To overcome this issue, it is possible to approximate p-values through a Monte Carlo algorithm. By adding simulate = TRUE in R the p-values will be approximated based on the descriptions of Hope (1968). The simulated p-value is determined by randomly generating contingency tables with the fixed margins of the original data, based on Hope's approach (see [53]). With sufficient simulations it is therefore possible to conduct chi-squared tests with approximated p-values [54]. With sufficient iterations, Monte Carlo simulated p-values are nearly as efficient as regular chi-squared tests, but if the assumptions are not violated it is better to perform the classic tests [53].

A drawback with chi-squared is that it does not estimate the strength, but instead gives an indication that there are sufficient deviations from a chi-squared distribution, so that there likely is a dependence between the variables. Thus, the chi-squared test requires another method to estimate potential effects of these relationships [55].

2.3.2 Multiple correspondence analysis

Chi-square tests require the researcher to choose which variables to conduct the tests. To avoid bias or potentially missing important variables, it is possible to use multivariate analysis, in which the method highlights potential relationships between variables that may have been overlooked. For qualitative data, multiple correspondence analysis (MCA) is particularly useful to find potential factors that affect type of injury sustained among the VRUs. Similarly to chi-square tests, correspondence analysis is a tool to find a potential association between variables [52]. The idea with correspondence analysis is to describe how different responses from at least two variables are [52].

MCA is an extension of correspondence analysis, when more than two categories are analysed simultaneously. If each individual case has at least one description for each category, it is possible to conduct the MCA. The correspondence analysis utilises single-value decomposition of a matrix from a contingency table, which sets a score on each category, which allows graphical representation of the relationships. As the scoring of the categories can be conducted through many different approaches, it is important to note that this thesis relies on the FactoMineR package [56]. FactoMineR uses the chi-squared distance and principal coordinates scaling derived from singular value decomposition of the centred indicator matrix to score the categories. The scaling could also be based on eigen-decomposition or alternating least-squares algorithms [52]. For more details on multiple correspondence analysis, it is suggested to read the works of le Roux and Rouanet, [57] or [52]. MCA has previously been applied in some studies related to vehicle safety, (see, e.g., [58, 59] for different studies within vehicle safety using MCA).

The table in this thesis used for the MCA is based on the set of VRUs (denoted I) and the categorical descriptions of various aspects of the accident and injuries (denoted Q), then the table is the size I x Q. For different groups of VRUs, the dimension of I will change as the number of VRUs in each group varies, but Q remains constant as the same variables are tested unless there are differences in included variables. From the MCA table there will be two clouds with points, individual and categorical [57]. The individual point cloud is based on the difference within each category. Less common categories move the individual point farther from the centre of the cloud, while categories chosen by the same individuals appear closer. The MCA then identified the eigenvectors that explain the most variance in the table, highlighted with coordinates showing the positions [57].

2.3.3 Regression model

To analyse the effect, or strength of relationship between variables that were identified as potential risk factors, a multinomial logit model was used. Categorized variables such as region of the arm lack order, and then a multinomial logit model is used to find the probability of occurrence for each category. Let $Y \in \{j_1, \ldots, j_p\}$ then J is the number of categories for the dependent variable Y. In the multinomial logit model, one j is chosen as a reference level. Then the model will estimate the log-odds equations for the remaining categories to the reference level. Following the descriptions by Fahrmeir et al., [60] a general multinomial logit model is shown in Equation (2.3). The model finds the logarithmic odds, based on the probability of the response variable Y taking the value j, given the predictors x, divided by the probability of the response variable Y taking the reference category J, given the predictors x. β_{j0} is the intercept term for the category j and $\beta_{j1}, ..., \beta_{jp}$ are the coefficients for each predictor variable $X_1, ..., X_p$ for cateogry j. Thus the model is used to determine the likelihood of an observation belonging to a specific group, based on a reference level in the group, which is predicted using a linear combination of its features.

$$\log\left(\frac{P(Y = j \mid x)}{P(Y = J \mid x)}\right) = \beta_{j0} + \beta_{j1}X_1 + \cdots + \beta_{jp}X_p, \quad \text{for } j = 1, \ldots, J - 1. \tag{2.3}$$

Depending on variables chosen and number of categories, there will be one equation for each J-1 categories, as each equation models the log-odds of a region vs the baseline.

3

Method

3.1 Description of PAV

Data used in the thesis is a dataset from If's People Around the Vehicle crash database (PAV). PAV includes information on motor vehicles to active traveler crashes and motor vehicle to scooter crashes, based on third-party liability claims for all levels of injury, and each case is anonymized. Swedish law requires third party liability insurance [61], and that accidents are reported in accordance with the terms of the insurance. Third-party liability insurance covers both damage to property and personal injuries, providing rich descriptions of various aspects of the accidents. Information in PAV are collected from the insurance information and is representative of Swedish VRU to car crashes as it covers crashes all over Sweden [62].

The information in PAV is collected using insurance claims information, such as descriptions from the driver and active traveler, as well as police report and witness reports and photos of the car if available and hospital records if applicable. PAV includes descriptions of the VRUs impacts when applicable, such as impacts against part of the car, the ground or other items in the surroundings. If there are photos available of the car damage or deformations to the car, the deformations are also coded according to the Society of Automotive Engineers recommended practices , the CDC standard [63].

Injuries sustained by the active traveler are coded according to the AIS 2015 standard [27]. Statements by the active traveler regarding suffering from pain in different body parts are also described in PAV. All injuries were regarded as sustained in car to VRU crashes from impacts to either a detail of the car, to their own means of transportation, i.e., the bicycle or scooter, the ground or the surroundings. Data collection for impacts come in two different methods: The first is impact location data according to the description of the accident sequence from participants and/or witnesses. This captures impacts with and without damage to the car. The second is impact location data collected from inspections of damaged cars. The full information in PAV results in detailed descriptions on accident sequence, accident scene, traffic environment, light and weather conditions, pre-crash conditions for the active traveler and car, crash descriptions, various aspects of the crash for active traveler and car, demographics, injuries and possible impacts.

3.2 Data selection criteria

The data used in the analysis is a sample from PAV for the years 2020 to 2023, filtered to only include active travelers with UEIs. Since PAV is based on active travelers, the VRUs in this study were limited to only include active travelers and scooter riders, thus excluding motorcyclists, mopeds and other motorized VRUs. Given the objectives of the thesis focusing on UEIs, filtering the initial PAV to only include VRUs with UEIs was deemed appropriate, as total exposures was sufficient for contextualizing comparisons. There was a total of 670 VRUs with at least one UEI, compared to 1364 overall VRUs included in PAV for the same time period.

Before conducting the analysis, it is important to thoroughly examine the data set and see that the included cases are relevant for the scope of the thesis [64]. As the goal of the thesis was to provide insight for further in-depth analysis on injuries, causes and mitigative possibilities, it was important that the injuries were possible to be put into context, that it was possible to understand the injury sequence, and that the cases were comparable. In PAV there are 1) cases with individuals lying on the ground pre-crash, 2) cases with near crashes with no contact between VRU and car, and 3) cases where VRUs were overrun. Cases where there is a runover sequence led to difficulties to pinpoint which part of the accident sequence caused which injury, making further conclusions on injury mechanism unreliable. Lying on the ground are also specific cases that are of low interest for the study, as these situations are difficult to mitigate and seem rare. When searching for previous research on kinematics and injury mechanisms there seemed to be no mentioning of studies investigating VRUs lying on the ground pre-crash. Instead focus is more often placed on more common situations see e.g.,[65]. Lastly, the no contact cases were not applicable for the objectives of the study.

By removing the cases which were not useful for the purpose of the study there were 636 VRUs with UEIs remaining. The 636 VRUs suffered 2325 injuries in total and had a total of 2108 impacts. These impacts describe any impacts to the car, the transport mode (for cyclists/scooters) impact to other things such as the ground. A single description of impact may include impacts to the car, cycle, and ground. A single VRU with UEIs can have multiple impacts. As there are many possible impacts, a single impact may include unknowns, but all impacts added together belonging to the case may lead to good descriptions of suffered impacts by the VRU. The injuries among the VRUs included those found in other body regions, which was expected as polytrauma is common among pedestrians and cyclists [66]. Thus, the injuries had to be further filtered and grouped. The filtering process of the data from the initial data set and grouping process is described as a flowchart in Figure 3.1.

The first filtering to the injuries among the sample was to only include the UEIs for the further analysis, which show that there were 947 UEIs among the VRUs in the sample. The UEIs include AIS coded injuries with lower severity and risk of long-term impairment such as skin [21], and injuries with higher severity, with higher risk of long-term impairment, such as fractures. The data also include information if the VRU suffered from pain only, i.e. information without AIS codes since AIS does not include pain. The injuries denoted by pain does not have an AIS code and has to our best knowledge not been studied for long term loss of QoL. There have been studies on long term pain, such as nerve damage [67], but these UEIs denoted by pain does not include detailed information on type of injury or long-term consequences. The injuries in the pain group thus have no determined risk of long-term loss of QoL, skin injuries have a suggested risk of long-term loss of QoL, but which is lower than the risk for other UEIs [21] and the remaining UEIs were thus the grouped injuries with the highest risk of long-term loss of QoL among the UEIs in PAV. The remaining UEIs, such as dislocations, fractures, muscle contusions, and sprains were therefore grouped together and denoted by intricate UEIs. The group of injuries denoted by intricate UEIs consisted mostly of fractures and dislocations. Based on the differences in risk of loss of QoL, the injuries were thus divided into the three groups pain only, skin and intricate UEIs. Since the grouping is based on injuries, there will be individuals that are found in more than one group, due to possible polytrauma. The grouping is not meant to be additive, but instead used to describe the cases which suffered those particular injuries, as such the VRU count does not add up to 636 but is instead higher.

Similarly for the available impacts, these were grouped based on the injury groups. The impact data was divided into groups that match the cases found for the three injury groups. The pain group had 659 impacts for 199 VRUs, skin group 1104 impacts for 330 VRUs and intricate UEIs had 604 impacts among 192 VRUs. Due to the grouping being based on cases with certain injuries, there will also be an overlap between impacts among these groups. Because a single case can involve several different impact types, the grouping is not additive. The impact types are reported descriptively to reflect the presence of each type, not to indicate exclusive or summed categories. The purpose of the grouping was thus to allow meaningful comparisons between interesting aspects of the accidents across injury groups, where it was possible to see if e.g., the distribution of impacts was different for different groups of injuries.

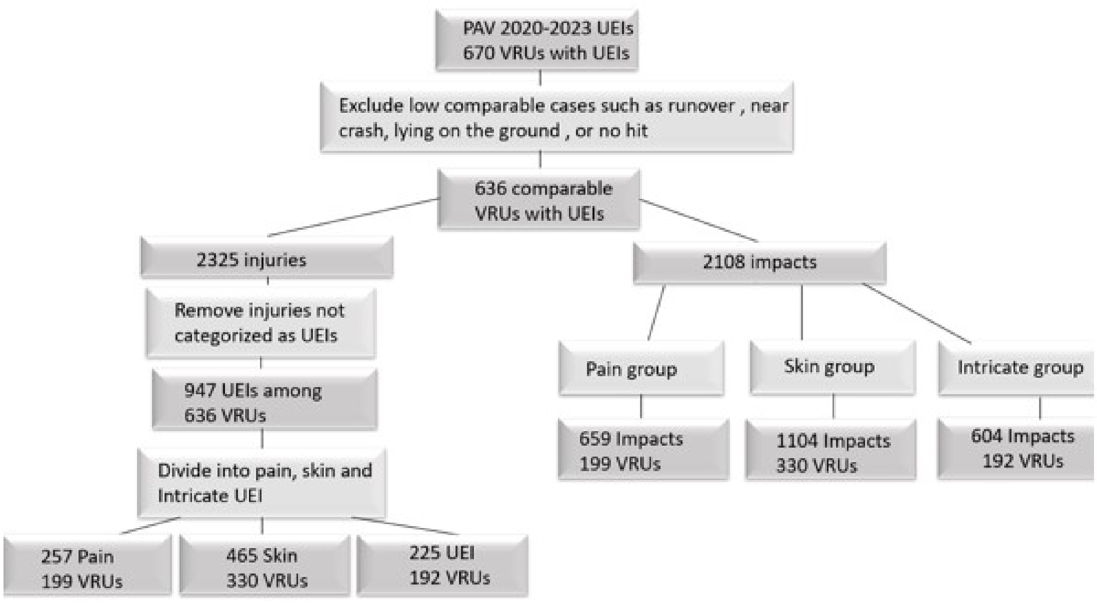


Figure 3.1: Flowchart over filtering and grouping of injuries and available impacts for the sample.

3.2.1 Descriptive statistics

The first objective of this thesis was to provide the descriptions of occurrence necessary for important aspects of the sample. To fulfill the objective, an occurrence table was constructed for the important groups of VRUs within the sample with selected aspects considered relevant for later analysis. The most common VRUs were cyclist (420 cases), pedestrians (160 cases) and scooter (46 cases). The remaining VRUs, four mobility aid devices e.g., electric wheelchairs, three small electric vehicles such as skateboards, two roller skis and one ordinary skateboard were grouped together as other (10 cases). Thus, the table shows four groups.

Before the construction of the table of occurrence for the different VRUs, there were some important decisions to take regarding variable categorization and to some extent variable inclusion. The variables were chosen to be comparable to previous research but also included additional aspects that were considered interesting to investigate. Isaksson-Hellman [62] conducted a similar study on cyclists based on insurance data from If for a different time period and chose to present aspects such as: when during the year, at what times, the traffic environment, light conditions, road states, weather, speed limit, demographics of the VRU and some injury description.

The occurrence table provides similar descriptions to Isaksson-Hellman [62]but only includes variables that were analyzed in later stages as potential risk factors. As risk factors were aspects which were expected to influence the likelihood of a VRU sustaining injuries to a region of the arm, aspects such as light condition, road states and weather were excluded. These variables were excluded, as their influence on arm injuries is not supported by evidence in the literature and was considered outside the scope of this analysis. The variables were only categorized when there were small sample sizes, or when the variables had commonly established relevance such as speed limits. Age can be difficult to categorize as there may not be clear cut-off levels where there is a clear difference between one age and another. The ages were grouped into regions of 0-16, 17-29, 30-44, 45-65 and 65+, covering pediatric, young adults, early middle-aged adults, middle-aged adults and older adults. Particular attention was given to define the boundaries of the youngest and oldest age groups. It was important to define a clear boundary for the transition of the body to adulthood and to account for the increased frequency of higher severity (AIS2+) among pedestrians and cyclists aged 65+ [68] [69]. Lastly, the variable describing traffic environment was not used for subsequent analyses but were useful to contextualize the data.

3.2.2 Conflict situation and Crash Type

The next aspect of the initial data exploration was the conflict situations, which describe the situation before the accident. Conflict situation is already categorized in PAV and includes a wide range of different scenarios. See e.g., Lindman et al., [19] for more examples of conflict situations for accidents identified from insurance data. To better understand how conflict situations were categorized, Table 3.1 presents aggregated categories, a basic example image of an included scenario, and corresponding descriptions. The categories describe the movement of the car and VRU. These situations represent the events leading to the accident and do not always result in the same type of collision and impact (and injuries), as factors like movement and individual reactions may vary. Rather than being used to predict specific injury outcomes, the conflict situation was used to provide contextual information about which types of scenarios were most commonly observed. Not shown in Table 3.1 is the category “unknown situation”, which refers to cases where no information about the conflict scenario was available.

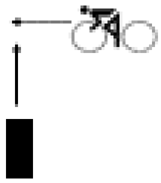
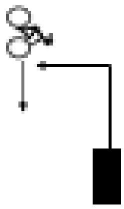
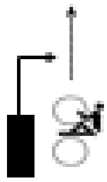
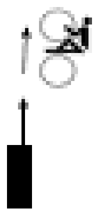
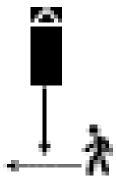
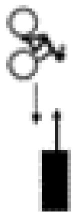
To better capture which conflict situations were common for cyclists, pedestrians and scooter riders with UEIs, a visualized comparison of the distribution of conflict situation per group was conducted. The next step after identifying important conflict situations was to analyze the types of crash between the car and VRU which can be e.g., car front to cyclist side, or car side to cyclist side. It is common practice to use the bounding box method to estimate impact areas of different crash partners [70]. Similarly, the type of crash between the car and the VRUs is described in terms of colliding boxes, to simplify the boundaries of which part was struck in the accident. When seen as a box the VRU or vehicle have a front, back and two sides, allowing for easily interpretable categorizations but reducing reliability and detail. By studying the distribution of type of crash it was possible to see which sorts of collisions were more frequent, which could help to identify if there is any shared vulnerability across the VRUs.

When the frequency distribution of crash type was conducted, it was useful to study the comparison of frequencies of crash type between cyclist, pedestrian and scooter riders to see underlying patterns.

3.2.3 Impacts, deformations and injuries

After the conflict situations had been studied, the next step was to investigate potential impacts and deformations to the car. Injuries can be caused by impacts and thus these are useful to study to find underlying injury patterns. The first investigated impact was if the VRU struck ground. Then the frequency of VRU’s impacts to the car was investigated to see how many impacts to the car the VRUs tended to have in the accidents. As almost all VRUs had details on the impact to the car (except for a few cyclists), it was a variable that was interesting for future analysis. Descriptions of impacts to bicycles and scooters were also available. However, these were not considered in the analysis, as they were often reported as unknown for both cyclists and scooter riders. As the description of impact to the car includes details to what area of the car was struck by the VRU, the impacts were grouped in this thesis into regions of the car. Depending on detail of the car and locality of the car, these were grouped into front, left, right, back or top. After the impacts were examined, damage to the car was another interesting aspect that could cover the accident sequence. There were a minority of cases which included descriptions of damage to the car, as not all impacts by the VRU to the car results in deformations or damage, and thus a simple visualization was conducted to highlight any potential trends regarding accidents. The classification for impact regions and classification for deformations are different, but both can give insight to where the impact and/or damages were located on the car. To investigate impacts and deformations to specific injuries, but also for the analysis on UEIs, the UEIs had to be grouped into regions of the arm, as there were a wide range of UEIs in the sample. The AIS code provides an initial description of the UEI region injured. These categorizations can be sufficient for explorations when studying

Table 3.1: Overview of different conflict situations involving vehicles and VRUs.

Conflict situation	**Visual example**	**Description of the example**	**Aggregated conflict situation**
Straight Crossing Path		Car is moving straight ahead, VRU from the right.	VRU is crossing the straight path of the car
Left Turn		The car is turning left, VRU from opposite direction.	The VRU is traveling in any direction in which the car is turning left
Right Turn		The car is turning right, VRU from the same side.	The VRU is traveling in any direction in which the car is turning right
Same Direction		Car is moving straight ahead, VRU in the same direction in front of the car.	VRU and car are traveling in the same direction
Reversing		Car is reversing, VRU seen to the right.	VRU is traveling in any direction in the way of a reversing car
Dooring		Car occupant on driver side is about to leave the car and VRU is about to crash into the open door.	At least one door is open on either side of the car which is an obstacle for the VRU
Oncoming		Car is moving straight ahead, VRU from the opposite direction.	VRU and car are moving in opposite directions

other body regions, but as the objective was to investigate UEIs to provide material for in-depth studies, there was a need of grouping the injuries differently.

The classification of injuries differs depending on the level of detail required, purpose and data available. Ideally the injury grouping into region of the UEI for this thesis should take into consideration the locality to the arm region, injury mechanism and where long-term consequences are seen for each injury. In most cases, the AIS grouping into region of the UEI is sufficient, but in some cases the long-term consequences of a particular injury does not match the region assigned through the AIS. When an injury did not seem to reflect the long-term consequences, or where a particular injury mechanism is more closely associated to a particular region of the UEI, the grouping of the injury was changed. This was most often when an injury was close to another part of the arm, and where the region of injuries were adjusted when applicable, such as when the location of an injury was close to another part of the arm, and grouping it to the other part of the arm made more sense, in terms of how it is commonly injured and where long-term consequences would be seen.

In this thesis, the upper extremities consist of shoulder, upper arm, elbow, forearm, hand and fingers and is shown in Figure 3.2. Hand and fingers are merged as the region hand. The proximal humerus is included in the shoulder grouping. As shown in Figure 3.2 the division of the upper extremity into these regions are denoted by red lines as boundaries. The lines for division into regions of the arm are approximate and instead relate to the tissue and structure of the parts of the arm, but could indicate where the regions are found.

As these regions consists of several different connected tissues, it is not always clear why an injury is categorized to a specific region. The lack of established, ideal classification allows researchers to group the injuries for their specific purpose. The drawback is that there may be deviations of categorizations between studies making the studies less comparable, but to allow for better transparency and validity, the grouping of arm region is explained with some examples of injuries which could be grouped differently. An example of an injury which could explain the grouping into arm regions conducted in this thesis are injuries to the ulna bone or radius bone found in the forearm. Depending on study, the fracture may be grouped differently. The radius is located in the forearm, connecting proximally to the elbow joint via the humerus and distally to the wrist through the radiocarpal joint. Because of these connections, fractures of the radius can be classified as wrist, forearm, or elbow injuries. An example of an injury that may be classified differently depending on context is the distal radius fracture.

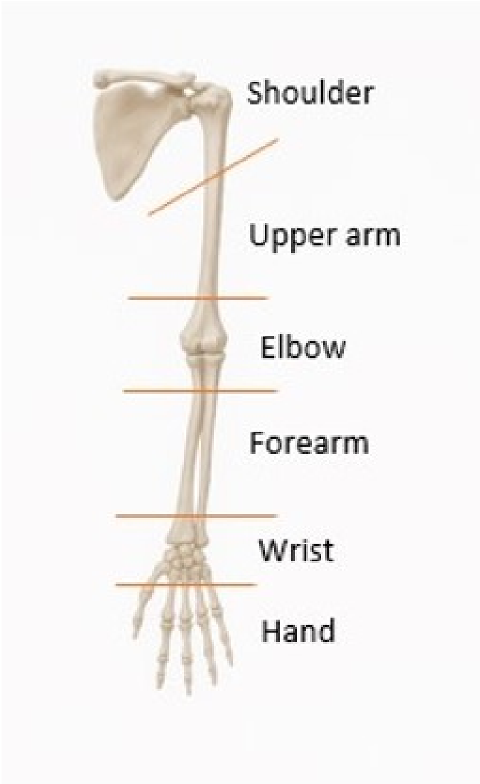


Figure 3.2: An overview of the upper extremities and the divisions into regions.(Image generated by ChatGPT, OpenAI, 2025)

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A distal radius fracture happens close to the wrist and is most often a result of injury mechanisms with low energy, such as falls where the individual tries to mitigate the injury with their extended arms [71]. The distal radius fractures are mostly a result of hyperextensions to the wrist [72]. As such, a distal radius fracture is in this thesis categorized as a wrist injury, since it is locally close to the wrist and the injury mechanism is more closely connected to other injuries found to the wrist. A proximal radius fracture on the other hand is thus grouped as elbow, since the injury is closer to the elbow. The same argument can be applied to injuries to the ulna, where proximal injuries are categorized as elbow, and distal as wrist. By striving to group the injuries to the possibly long-term affected region of the arm, the study could better capture potential risk factors, compared to if injuries were only grouped by where the injured tissue was found, i.e., a fracture to the particular surface of the distal radius or ulna increases the risk of sustaining arthritis, which would then be a long term impairment of the wrist joint. In contrast to the changes in injury grouping for intricate injuries, skin injuries were assumed to have limited, localized long-term consequences. Thus the AIS coded grouping into UE regions should be adequate and skin injuries therefore remained grouped according to the initial AIS based grouping into region of the UE.

An initial exploration was carried out on cases with single, intricate UEIs to assess whether descriptions of vehicle damage occurred frequently enough to support further analysis of the relationship between injured arm regions and vehicle deformations. By specifying the injured arm region in detail, it was possible to examine for each region (e.g., elbow, wrist) whether corresponding deformations were reported in the data, and to identify any potential trends across regions

Overall, deformation data were limited, especially for regions beyond the front of the vehicle. Even for frontal impacts, the number of observations linked to each specific arm region was small, thus leading to exclusion of further analysis of the deformations. It is also important to notice that the investigations in the thesis on single intricate UEIs such as the previously mentioned deformations did not include the upper arm region, as the region was removed from in-depth analysis given its single occurrence among the intricate UEIs.

After the initial injury trends for deformations were observed it was important to see how the injuries were distributed throughout the body. Even though the sample was filtered to only include UEIs, it was shown that there were other body regions that were frequently injured at the same time, which led to further analysis on frequency of polytrauma among the VRUs with UEIs in the sample. Therefore, frequencies of polytrauma for all cases of VRUs with all injuries were conducted, then frequencies of polytrauma for all UEIs was examined and lastly frequencies of polytrauma among only the intricate UEIs were investigated. The idea was that by comparing the polytrauma frequencies, it was possible to see which types of injuries coincide more frequently, and if the method chosen for risk factor investigation was accurate and not misleading. There were more aspects to consider in terms of injury among the VRUs. AIS coded UEIs includes a scale of severity, which could signal what type of injuries are found as well as any potential biases in the sample. Based on the severity distribution, there could be a tendency for overrepresentation of injuries of a certain severity. UEIs generally have lower injury severity, and therefore both the maximum AIS (MAIS) and other associated injuries are likely to be less severe. To explore this, the distribution of severity among all AIS-coded UEIs was first examined. This was then compared across cyclists, pedestrians, and scooter riders with respect to their distribution of MAIS. Their respective distribution of MAIS was examined to see if the trends of severity differed between the VRUs.

3.2.4 Examining common UEIs among VRUs

After the initial exploration of the accident descriptions, analysis of impacts and general injury patterns were conducted, it was now possible to examine injuries on a deeper level. Starting with a visualization of the twelve most common injuries among all VRUs, it was possible to see which injuries were common among the VRUs. It was at this stage that skin injuries were excluded, and the focus turned to the intricate UEIs. By excluding skin injuries, it allowed analysis of injuries which are more clinically significant and relevant for LTI outcomes. Therefore, only the twelve most common intricate UEIs were analyzed among the VRUs. The injuries were translated from their AIS code to the injury name in accordance with the AIS code book. As there were some more injuries shown among only the intricate UEIs, a more general visualization for all the UEIs among all VRUs was conducted. The generalized visualization was conducted for cyclists, pedestrians and scooter riders as well, to see if there were any noteworthy differences among the UEIs found among the different VRUs. Then a comparison of tissue injured among all VRUs with intricate UEIs was conducted, as potential cues for injury patterns based on tissue potentially could be seen. The tissues in this sample were skeletal, joints, nerves and soft tissue.

3.3 Analyzing risk factors

With some cues for potential injury patterns and aspects that may influence the outcome of injuries to a specific arm region, it was now possible to try investigating potential risk factors. As risk factors were aspects of a VRU which potentially change the outcome of an injury, there were many potential risk factors to test. The chosen variables were connected to either demographic such as gender and age, the crash severity through estimated speed, speed limit and kinematic of the VRU, the position of the VRU and impacts through service weight of the car, or the direction of which the VRU was hit by the car. In tables and figures using the direction of which the VRU was hit the variable is denoted Hit VRU. The variables were also connected to impacts such as crash type, if the VRU struck the ground, the number of impacts to car, number of impacts to the ground or other objects, as well as count of available deformations. Lastly, aspects relating to the accident such as conflict situation or if there was a crossing of some sort were considered. These variables were tested for dependence using chi-squared tests. By testing dependence between the chosen variable and arm region for all VRUs, the test could show if the categories are statistically significantly different i.e., if there is a dependence between the tested variables category levels. Similar tests for dependence were then conducted for the variables and arm regions, but only for the cyclists. Then the same chi-squared tests were used on the arm region injured and pedestrian, before dependence was analyzed for the variables and tissue injured among all the VRUs. The risk factor tests required independence of the cases analyzed. Therefore, the intricate UEIs had to be either weighted, or multiple cases excluded. By excluding the polytrauma cases, the samples could be considered independent, at the cost of fewer samples. The cases can be seen as independent, as the accidents likely affected different VRUs. By only using the cases with single intricate UEIs, the injuries are also independent, as they are caused by accidents which are independent. It is not possible to confirm that the cases are truly independent, but should have a sufficient degree of independence for the methods to not violate any assumptions.

In addition to independence, for the methods to work as intended, outliers or very small samples may be better to exclude and thus the single nerve injury and the single case of upper arm injury were excluded as these would make the tests unreliable. From 225 intricate UEIs, 162 were used for risk factor analysis.

The variables used for risk factor analysis were also mostly already categorized. In addition, whenever grouping of the variables improved the observation count without breaking any logical reasonings, or when there were many categorical levels within a single variable, an attempt to group them was conducted. Crash type had many variations of cases and had to be grouped to conduct tests. The variable was grouped in two different ways, one based on the description of the car, the other based mainly on the description of the VRU. As they were seen as boxes, the variable was thus grouped based on the box of the car or VRU. In the end, it was seen as better to use a grouping of the car for the basis of the group, as the car is a larger object, thus the potential limitations with seeing the car as a box were less restricting than for the VRU.

The crash type was grouped into back, front or side. The direction of which the VRU was hit by the car based on the clock was also divided into front, right, back or left, as shown in Figure 3.3.

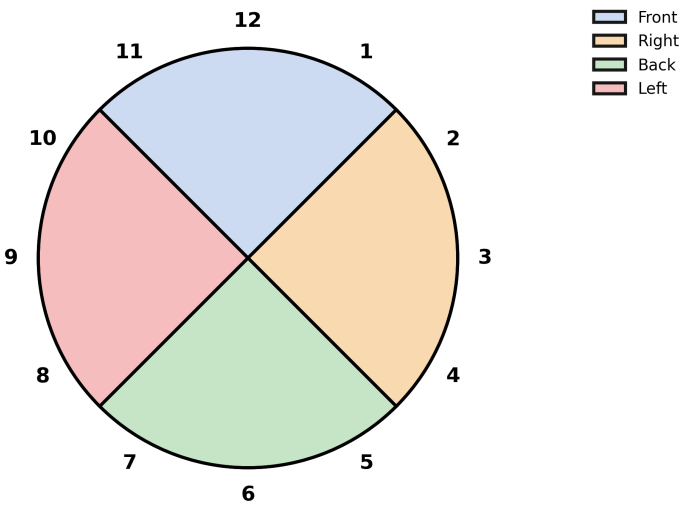


Figure 3.3: From which direction the VRU was struck by the car, seen as a clock. The numbers are grouped into the regions front, right, back, left.

The numbers eleven, twelve and one were grouped as being struck to the front, two, three and four was grouped as right and so forth. The grouping of speed limit remained from before, with speed limits over 80 grouped together as 80+. There were few observations for 70, which could have led to the grouping being 70+, but was not incorporated into the final grouping. Number of impacts to the car were the sum of impacts to the car for each VRU, transformed in terms of 0, 1, 2, or 3+ impacts. As all the VRUs suffering from intricate UEIs had at least 1 impact to the car, the 0 is not visible in any regression models or similar. A similar categorization of number of times the ground or other objects was struck was used to see if there were any patterns between more impacts to the ground. Deformations were also grouped in terms of number of deformations, as there was an idea that more damages to the car in an accident could be an approximation for more severe accident sequence.

The chi-squared tests were conducted using the chisq.test() command in R on contingency tables of the variable and the region of the arm, or tissue. The sample had 162 intricate UEIs. When there were fewer observations than two in a cell, p-values were simulated to provide higher reliability to the tests. When simulating, it is appropriate to use a seed for replication and in this thesis the seed was set with seed(123) to 123 in R.

To contextualize potential injury trends, statistically significant variables from the chi-squared test were presented at this stage. In addition to the statistically significant variables, age was included as it has been shown to influence severity of injuries sustained [69][68]. As the chi-squared tests did not yield much guidance regarding potential risk factors, MCA was used to see if an algorithm could give cues on potential relationships. MCA was conducted for the same intricate UEIs as the previous tests for independence, then for the intricate UEIs filtered to only include cyclists, and lastly intricate UEIs but filtered only for pedestrians. The MCA can be based on all variables in the data set, but to make interpretations easier, variables that were not potential risk factors such as weather (which is assumed to minimally affect the injury sustained from a particular collision) were removed. The final list of variables used for the MCAs were mostly connected to demographics, injury nature or impacts and is shown in Appendix A.1.

The resulting tests gave some indications on potential variables of interest. The variables for the regression were chosen based on the chi-squared tests and if previous research gave indications that these aspects were potential risk factors. All the variables with significance in the chi-square tests were tested. Initially the variables were tested together, and then for a range of combinations. Among all the VRUs with intricate UEIs, age, conflict situation, from which direction the VRU was hit by the car and number of impacts to the car were used to test the potential effect of these variables on arm region. As the regression included four categorical variables, each required a reference level. The reference levels were: 30–44 years for age, same direction for conflict situation, front for the direction from which the VRU was struck, and one for number of impacts.

Then multiple multinomial regressions with various variable combinations were conducted to see if the individual variables had any significance on the dependent variable. Arm regions for all the VRUs were tested with age, then with conflict situation, after that with the direction, from which the VRU was hit by the car and lastly number of impacts to the car to see if there were any changes in effect and significance. The regression with these variables is described in Equation 3.1

$$\log\left(\frac{P(\text{Arm region} = j)}{P(\text{Arm region} = \text{Hand})}\right) = \beta_{0j} + \beta_{1j}\text{Age} + \beta_{2j}\text{Conflict} + \beta_{3j}\text{HitVRU} + \beta_{4j}\text{ImpactCar} \quad (3.1)$$

The regressions estimations are based on reference levels for the dependent variable and independent variable. Equation 3.1 was initially conducted with reference level hand for arm region, 30-44 for age, turning left for conflict and impact to car as 1. Then the resulting regression model had some cells with 0 p-value, which then led to the same model being re-conducted with a different reference level for age, 45-65. The regressions conducted seemed unreliable with poor level of explanaton of the variables. Thus only one regression equation is included, and the regression model with the two different reference levels for age, based on that equation is shown in the result.

3.4 Injury patterns among the VRUs

The idea was to conduct risk factors before comparing the VRUs, as it could provide useful information regarding injury patterns among the VRUs. Unfortunately, the risk factors were not possible to compare. To see any patterns among the VRUs, more comparisons over injury aspects were conducted, focusing on those that were best explaining the intricate UEIs. The first comparison was using the twelve most common injuries found among cyclists and comparing the proportion of those injuries among pedestrians and scooter riders. To highlight the proportion of these injuries out of the total injuries suffered, a grouping called other was implemented for the remaining injuries which would otherwise be hidden. The group other consists of all the other AIS coded injuries, which were cut off from the twelve most common ones, and consisted of fewer cases. Then the frequency of severity was compared between the VRUs to see if the severity was similar among the three VRU types. Lastly there were direct comparisons between injuries found to each arm region. As there were three tested VRUs, there were two visualizations required. The initial two visualizations compare the injury frequency of all AIS coded UEIs for each arm region among cyclists and pedestrians. Then the injury frequency of all AIS coded UEIs for each arm region was compared between scooter and pedestrians. Then the injury patterns for which arm regions the intricate UEIs were common to was examined, first between cyclist and pedestrian, then again scooter compared to pedestrians.

4

Results

This chapter presents the results of the study. It starts with an initial exploration of the dataset and then a description of the accident situation, first described by accident situation and crash type. This is followed by an overview of the impacts to ground and car, as well as deformations seen on the cars. The section then explores common UEIs among VRUs, the associated risk factors and finally compares injury patterns across different types of VRUs.

4.1 Data summary

The most frequently occurring VRUs in the PAV sample were cyclists, pedestrians and scooter riders, as seen in Table 4.1. The category other included mobility aid devices, electric skateboards and roller skis.

Table 4.1 shows how the most common age group was 45-65 with 33.33% in the UEI sample. Most VRUs were male 54.09%. The most common conflict situation was straight crossing path (SCP) with 50.3% of the cases. The service weight of the cars were most often between 1500 and 1999 kgs 43.71% of the accidents. The accident situations most often occurred in intersections, 51.57% of the time.The speed limit was most commonly 40 km/h (33.96%). The crash type meant VRUs most often were struck to the side, 54.25% of the time. The direction, from which the VRU was hit by the car (HIT VRU) was most often unknown. The VRUs most often struck the ground, 73.11% of the time and they mainly struck another object once (91.98%). They tended to strike the car once 67.45% of the time, and most of the cases had no available information on damage to the car (deformations). The same information but only including intricate UEIs can be found in A.2

Table 4.1: Distribution of age, sex, speed limit, vehicle weight, time of day, traffic environment, crossing and season.

	Cyclist (n=420)		Pedestrian (n=160)		Scooter (n=46)		Other (n=10)		Total (n=636)	
Variable	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Age										
0–16	35	8.33	14	8.75	15	32.61	0	0.00	64	10.06
17–29	66	15.71	28	17.50	16	34.78	0	0.00	110	17.30
30–44	103	24.52	28	17.50	8	17.39	2	20.00	141	22.17
45–65	160	38.10	39	24.38	7	15.22	6	60.00	212	33.33
65+	54	12.86	51	31.88	0	0.00	2	20.00	107	16.82
Unknown	2	0.48	0	0.00	0	0.00	0	0.00	2	0.31
Sex										
Male	245	58.33	63	39.38	29	63.04	7	70.00	344	54.09
Female	175	41.67	97	60.63	17	36.96	3	30.00	292	45.91
Conflict situation										
Reversing	6	1.42	28	15.56	2	4.17	0	0.00	36	5.45
Straight Crossing Path	220	52.13	82	45.56	26	54.17	4	40.00	332	50.30
Dooring	14	3.32	1	0.56	0	0.00	0	0.00	15	2.27
Opposite Direction	5	1.18	4	2.22	0	0.00	0	0.00	9	1.36
Same Direction	28	6.64	12	6.67	0	0.00	0	0.00	40	6.06
Turning left	66	15.64	12	6.67	7	14.58	4	40.00	89	13.48
Turning right	77	18.25	13	7.22	11	22.92	2	20.00	103	15.61
Unknown	4	1.00	8	5.00	0	0.00	0	0.00	0	0.00
Service weight of car in kg										
<1199	30	7.14	12	7.50	2	4.35	1	10.00	45	7.08
1200–1499	122	29.05	31	19.38	14	30.43	2	20.00	169	26.57
1500–1999	182	43.33	78	48.75	14	30.43	4	40.00	278	43.71
>2000	42	10.00	20	12.50	8	17.39	2	20.00	72	11.32
Unknown	44	10.48	19	11.88	8	17.39	1	10.00	72	11.32
Traffic environment										
Urban	361	85.95	107	66.88	44	95.65	10	100.00	522	82.08
Rural	35	8.33	11	6.88	0	0.00	0	0.00	46	7.23
Unknown	24	5.71	42	26.25	2	4.35	0	0.00	68	10.69
Crossing										
Roundabout	50	11.90	11	6.88	8	17.39	1	10.00	70	11.01
Intersection	248	59.05	49	30.63	24	52.17	7	70.00	328	51.57
No	115	27.38	92	57.50	13	28.26	2	20.00	222	34.91
Unknown	7	1.67	8	5.00	1	2.17	0	0.00	16	2.52
Speed limit										
30 km/h	99	23.57	37	23.13	10	21.74	3	30.00	149	23.43
40 km/h	150	35.71	41	25.63	23	50.00	2	20.00	216	33.96
50 km/h	107	25.48	44	27.50	7	15.22	4	40.00	162	25.47
60 km/h	10	2.38	5	3.13	0	0.00	1	10.00	16	2.52
70 km/h	16	3.81	2	1.25	1	2.17	0	0.00	19	2.99
80+ km/h	9	2.14	3	1.88	0	0.00	0	0.00	12	1.89
Unknown	29	6.90	28	17.50	5	10.87	0	0.00	62	9.75
Crash type										
Back	20	4.76	7	4.38	0	0.00	0	0.00	27	4.25
Front	130	30.95	14	8.75	17	36.96	1	10.00	162	25.47
Side	228	54.29	86	53.75	24	52.17	7	70.00	345	54.25
Unknown	42	10.00	53	33.13	5	10.87	2	20.00	102	16.04
Hit VRU										
Back	12	2.86	6	3.75	1	2.17	0	0.00	19	2.99
Frontal	117	27.86	9	5.63	17	36.96	1	10.00	144	22.64
Left	105	25.00	27	16.88	2	4.35	3	30.00	137	21.54
Right	97	23.10	27	16.88	18	39.13	5	50.00	147	23.11
Unknown	89	21.19	91	56.88	8	17.39	1	10.00	189	29.72
Ground										
No	99	23.57	65	40.63	6	13.04	1	10.00	171	26.89
Yes	321	76.43	95	59.38	40	86.96	9	90.00	465	73.11
N other										
1	383	91.19	150	93.75	43	93.48	9	90	585	91.98
2+	37	8.8	10	6.25	3	6.52	1	10	51	8.01
N Car										
1	271	64.52	128	80	25	54.34	5	50	429	67.45
2	85	20.24	25	15.625	11	23.91	4	40	125	19.65
3+	64	15.24	7	4.38	10	21.74	1	10	82	12.89
Number of deformations										
0	282	67.14	130	81.25	23	50	6	60	441	69.34
1	51	12.14	17	10.62	7	15.21	1	10	76	11.95
2	41	9.76	10	6.25	8	17.39	3	30	62	9.74
3+	46	10.95	3	1.87	8	17.39	0	0	57	8.96

4.1.1 Accident descriptions

The most common conflict situation was when the car was going straight forward, and the VRU was crossing the street in front of the car 52.2%, while the second most frequent accident situation was when the car is turning either left or right 30.2%. Figure 4.1 shows the frequency of each accident situation.

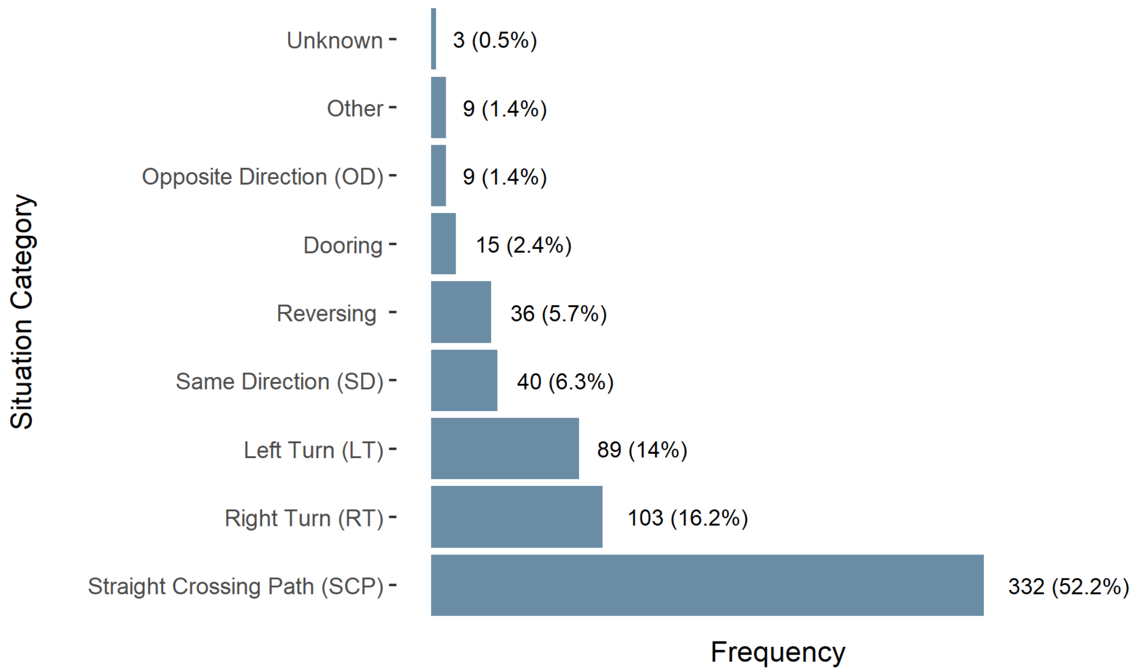


Figure 4.1: Frequencies of each accident situation for all VRUs with UEI.

The three different VRUs were mostly involved to the same frequency in the same type of accident situations. Figure 4.2 shows how cyclists, pedestrians and scooter riders were most often struck in the Straight Crossing Path (SCP) situation, with 52.9%, 53.9% and 56.5% respectively. When the car is turning in either direction was more common among cyclists and scooter riders, 34.4% and 39.1% respectively, compared to pedestrians 16.5%. Pedestrians on the other hand were more frequently involved in reversing situations with 18.4% of their cases being a result of reversing situations.

The actual crash types between car and VRU are shown in Figure 4.3. The most frequent case, which was 49.8% of all cases, was when the front of the car struck the side of the VRU. The second most common one was when the front of the VRU struck the side of the car with 19.9% of all crashes.

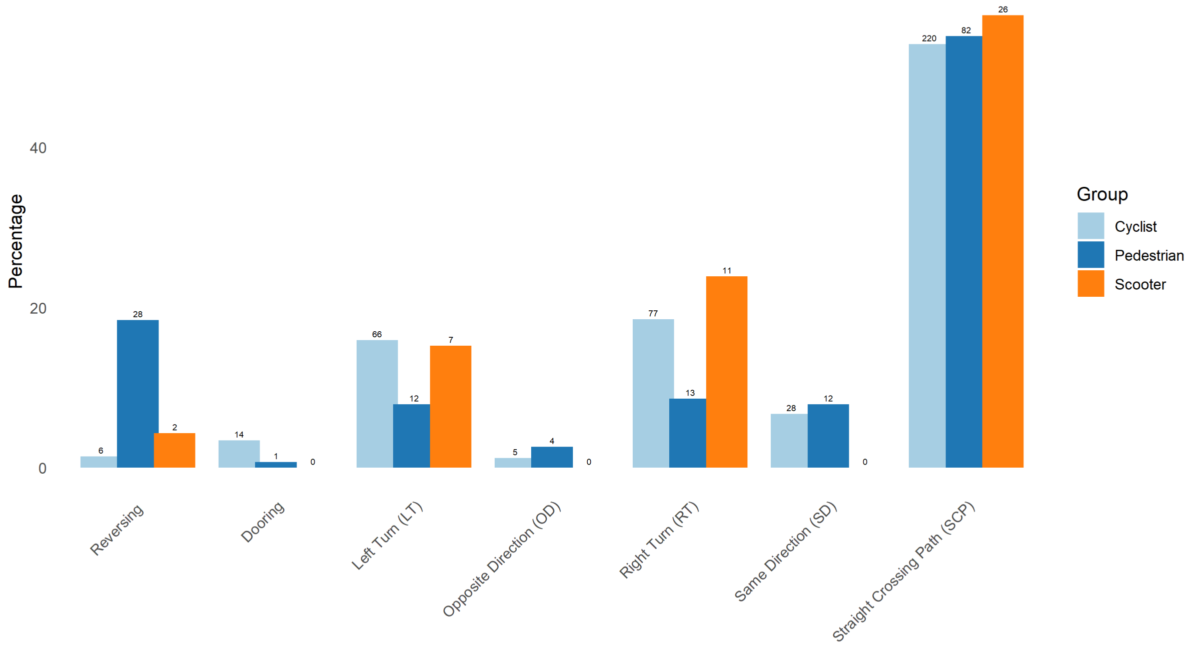


Figure 4.2: Comparison of frequencies of accident situations between cyclist, pedestrian and scooter riders in percentage and the numbers on top of the bars show the number of cases for each bar.

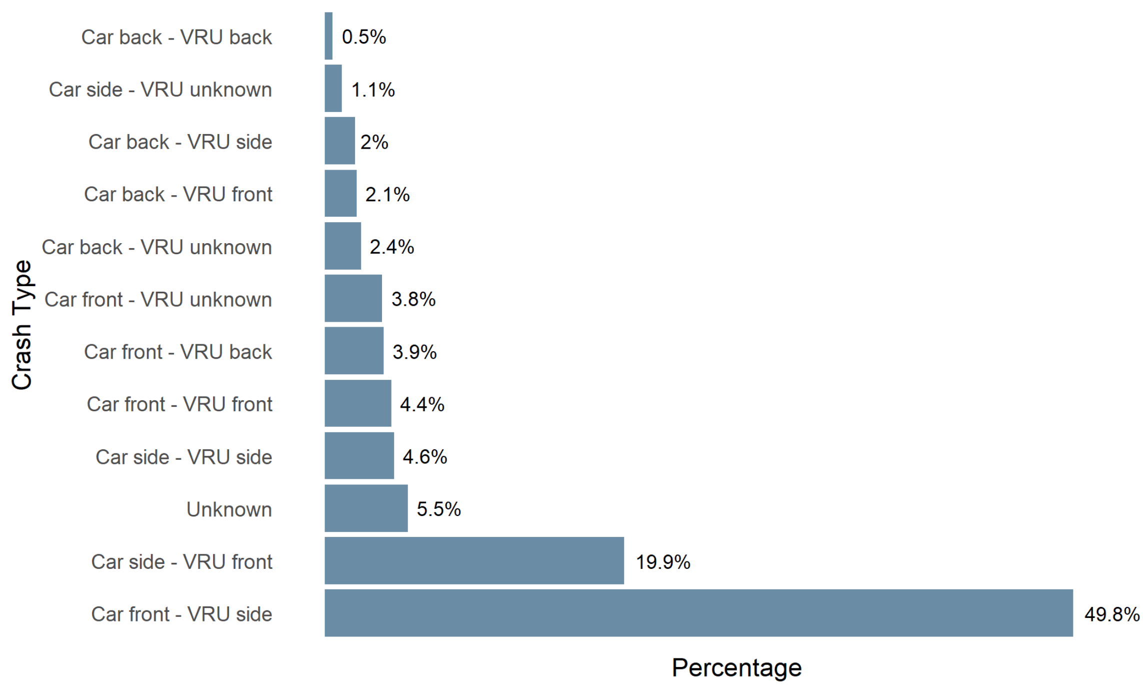


Figure 4.3: Frequencies of crash type found among all VRUs with UEIs.

The comparison of frequency for crash type between VRUs is presented in Figure 4.4 and show that the three types of VRUs were subject to front of car to side of VRU in similar frequencies. Cyclists 50.2%, pedestrians 46.4% and scooter riders 53.3% indicate that on a per group level VRUs were still mostly struck by a car front to the side. Cyclists and scooter riders were also frequently involved in crashes with the front of the VRU struck the side of the car, 25.6% and 31.1% respectively, while pedestrians only were found in that type of crash 2.0% of the time.

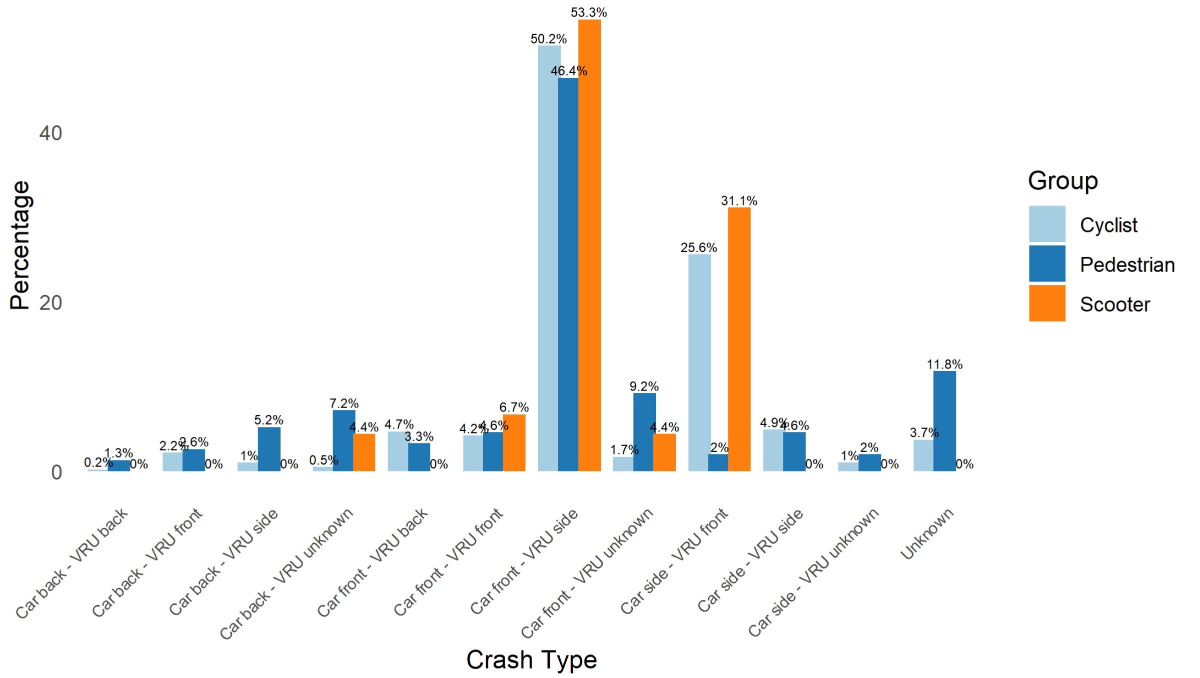


Figure 4.4: Comparison of the ratio of occurrence of each crash type for cyclist, pedestrian and scooter riders.

4.1.1.1 Impacts

Among the 636 cases where the VRU sustained an UEI, there was a total of 2108 impacts reported: with 943 to the car, 522 to the ground and 11 to other items in the traffic environment.

The VRUs frequently struck the ground after being hit by the car. A comparison of how frequently different VRUs struck the ground at least once is shown in 4.5. Pedestrians were the group with lowest amount of VRUs striking the ground at least once.

The VRUs frequency in impacts to the car show that individuals most frequently had one impact to the car. Figure 4.6 shows a comparison of impacts to the car among the VRUs with UEIs.

Assessing the available impacts to the car for the intricate UEIs, 192 cases, Figure 4.7 showed that most impacts, 235, were to the front. There were few impacts to the right, left and back with 24, 14 and 17 respectively.

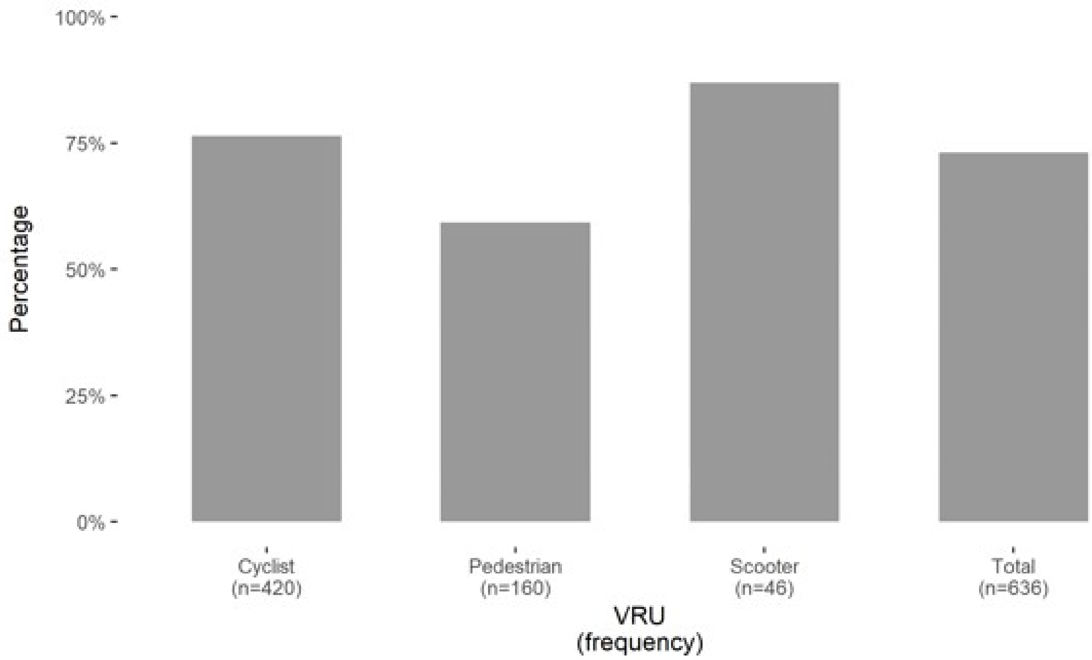


Figure 4.5: Comparing the distribution of how many VRUs in each group struck the ground at least once.

Figure 4.6: Comparison over frequency of impacts to the car among the VRUs with UEIs where 1 is a single impact to the car, 2 is two impacts to parts of the car, and 3+ is three or more impacts to various parts of the car.

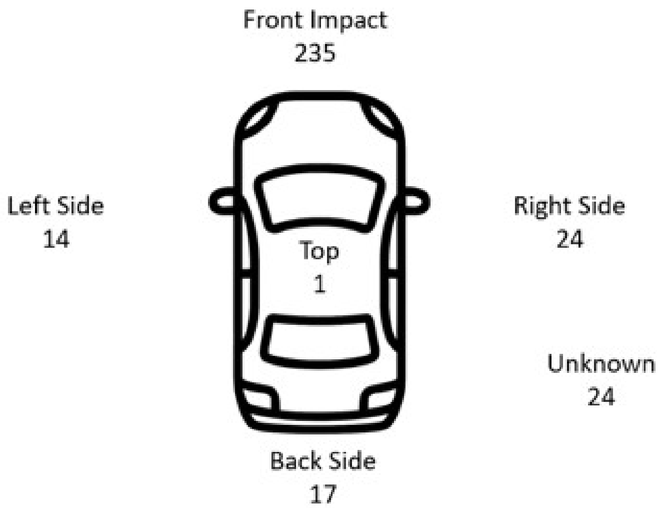


Figure 4.7: Overview of impacts to the car among the VRUs with intricate UEIs.

All impacts described by the people involved in a crash do not necessarily lead to car damage. Specific analyses were conducted for the intricate group with car damage or deformations. When filtered for single intricate, there were 43 unique cases with deformations, where car damage was coded according to the CDC standard.

The deformations to the cars are shown in Figure 4.8. Deformations were mostly seen to the lower parts of the car to the side and front, denoted with a red line. The red arrows instead show that the hood and front part of the roof were locations where deformations were also seen. The deformations to hood and front were frequently seen in all three regions of the deformation zones to the car.

When studying the cases with deformations on an injury level, Figure 4.9 highlight how there were few single intricate injuries with associated deformation codes to their cases. These samples were so small that further analysis based on deformations were mostly excluded.

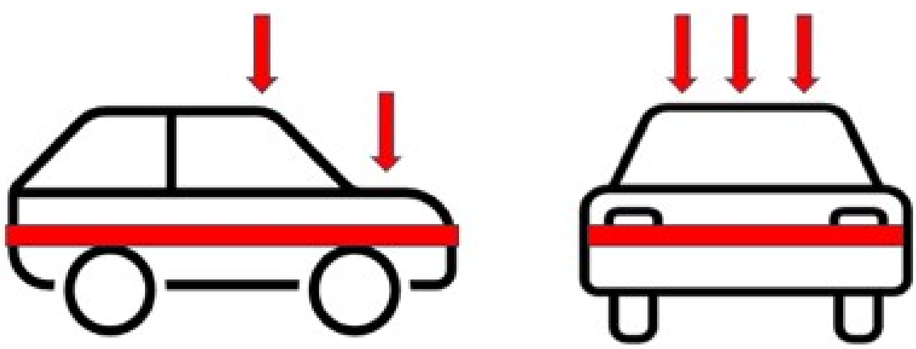


Figure 4.8: Deformations found to the car.

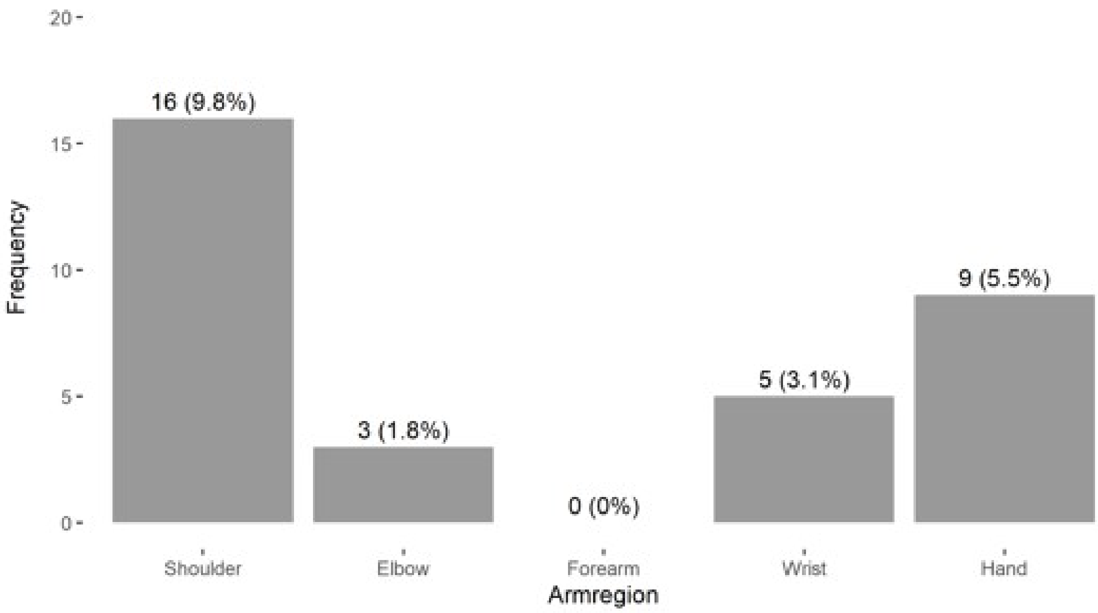


Figure 4.9: Frequency of injuries found to the arm regions with confirmed deformation to the front of the car.

4.1.2 Initial context on injuries

Even though the sample is filtered for UEIs among the VRUs, there were many other injuries sustained by the VRUs in the sample. Table 4.2 present the body regions where injuries were found, the number of injuries, as well as the percentage out of the total injury count. Injuries to the upper and lower extremities were the most common.

Table 4.2: Description over all injuries found among the VRUs.

Body region	**Number**	**Percent (%)**
Head	146	6.3
Face	191	8.2
Neck	5	0.2
Thorax	75	3.2
Abdomen	13	0.6
Spine	175	7.5
Upper extremity	953	41.0
Lower extremity	729	31.4
External	38	1.6
Total	**2325**	**100**

Among the sample of VRUs with UEIs, when considering all injuries, 88.5% of the VRUs sustained polytrauma, as shown in Figure 4.10. When only UEIs were considered, the frequency of polytrauma is 36.6%. In the focus group of the study, the intricate UEIs, polytrauma accounts for 14.6% of the cases.

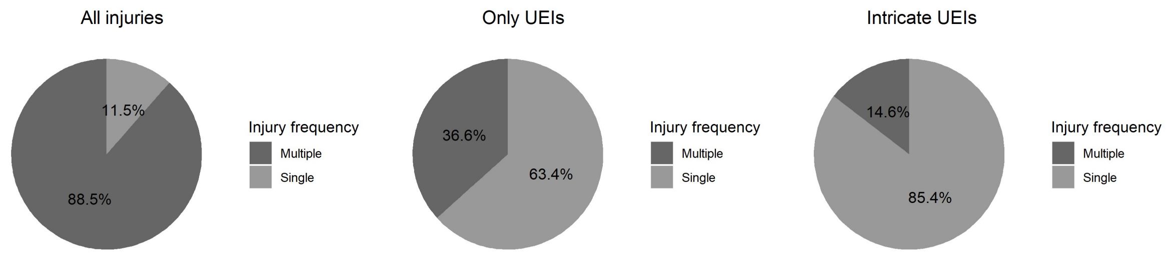


Figure 4.10: Frequency of isolated injuries compared to polytrauma for the different injury categorizations.

The severity among all the AIS coded UEIs are presented in Figure 4.11. The UEIs in the sample were mostly AIS 1 76.2%. Note that there was a single AIS 3+ injury found among a pedestrian which is not shown in this Figure.

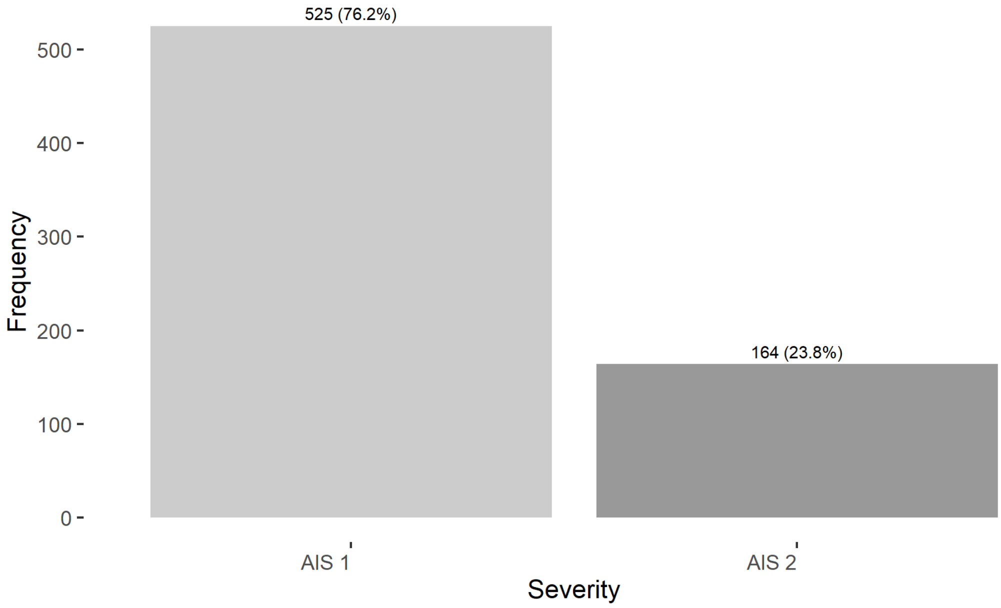


Figure 4.11: Visualization of severity among the AIS coded UEIs for all VRUs. The single case of injury with AIS 3 severity found among pedestrians is excluded in this image.

Figure 4.12 shows the MAIS severity of all sustained injuries between the VRUs with UEIs. The pedestrians have higher MAIS on average where 40.6% sustained at least one moderate injury (MAIS 2), compared to 30.7% for cyclists and 30.4% for scooter riders.

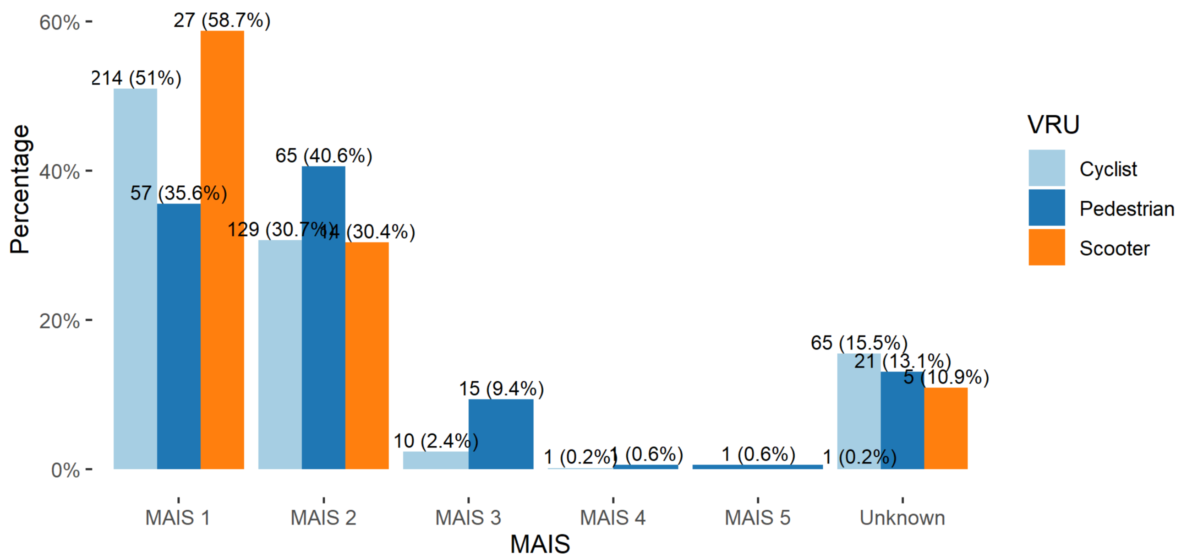


Figure 4.12: Comparison of MAIS between the VRUs with UEIs.

4.2 Common UEIs among VRUs

The VRUs suffered many different UEIs. In total there were 70 different types of AIS coded UEIs found in the sample. The twelve most common UEIs are presented in Figure 4.13. The figure show that most of the UEIs were skin related injuries, such as skin abrasion, skin contusion and minor skin laceration. The most common UEI not related to skin was forearm fracture (including wrist NFS).

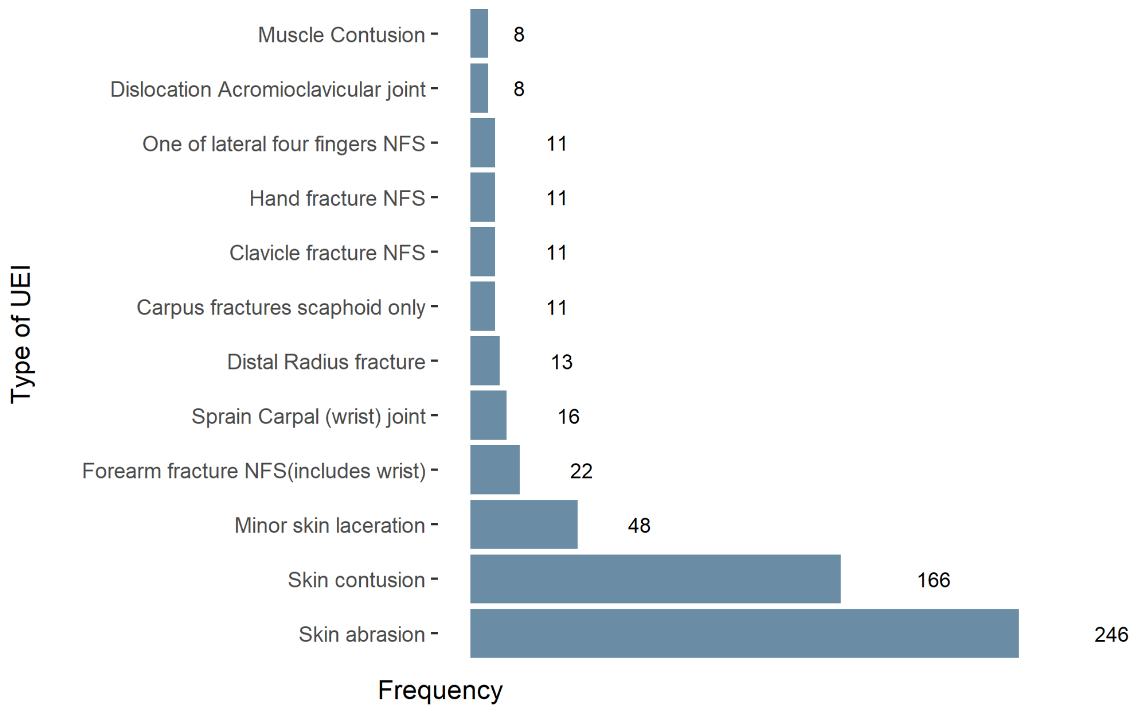


Figure 4.13: Frequency distribution over the twelve most common AIS coded UEIs among all VRUs.

Figure 4.14 shows the frequency distribution when excluding skin. Arm fracture NFS (includes elbow), rotator cuff injury and sprain of metacarpophalangeal or interphalangeal joints, all with seven cases respectively are now included. The twelve most common UEIs were thus seven different fractures, three various sprains, muscle contusion and dislocation of the acromioclavicular joint.

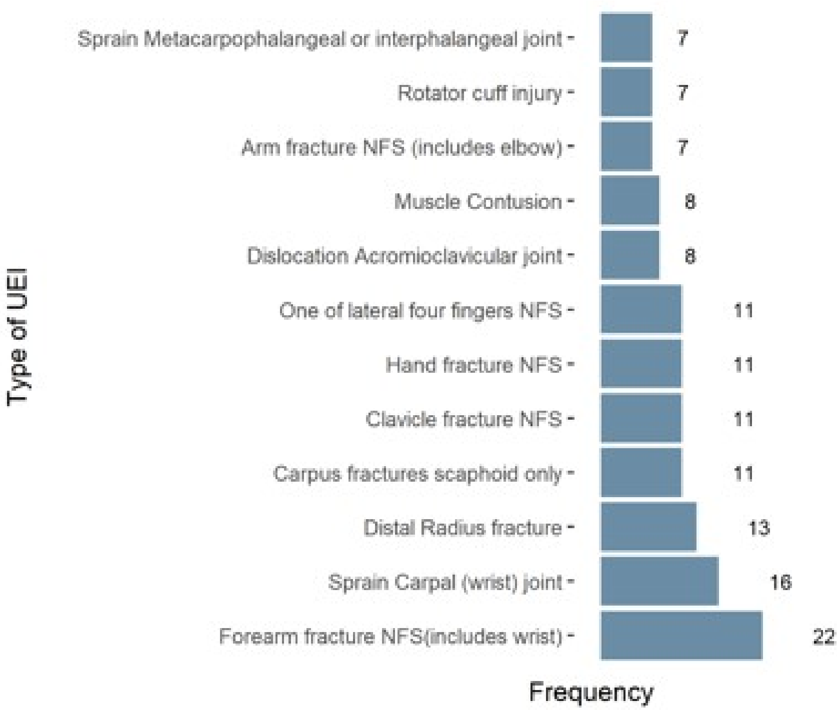


Figure 4.14: Frequency distribution over the twelve most common AIS coded UEIs among all VRUs when excluding skin.

The frequency of UEIs found in the UEI sample, when categorized are shown in Figure 4.2. The most injured part of the arm among all VRUs were shoulder (258 injuries), hand (215), and elbow (200). The most frequent injuries categorized as pain were to the shoulder (109), upper arm (39) and hand (36). Skin injuries were mostly found to the elbow (139), hand (130) and upper arm (80). The intricate UEIs were found most frequently in the shoulder (77), the hand (49) or wrist (49). The frequency of intricate UEIs to overall injuries were highest in the wrist with 48.5% of wrist injuries being categorized as intricate, followed by forearm with 43.4% of UEIs being intricate, shoulder with 29.8% of UEIs being intricate, hand with 22.7% of UEIs and elbow with 13% of UEIs being intricate.

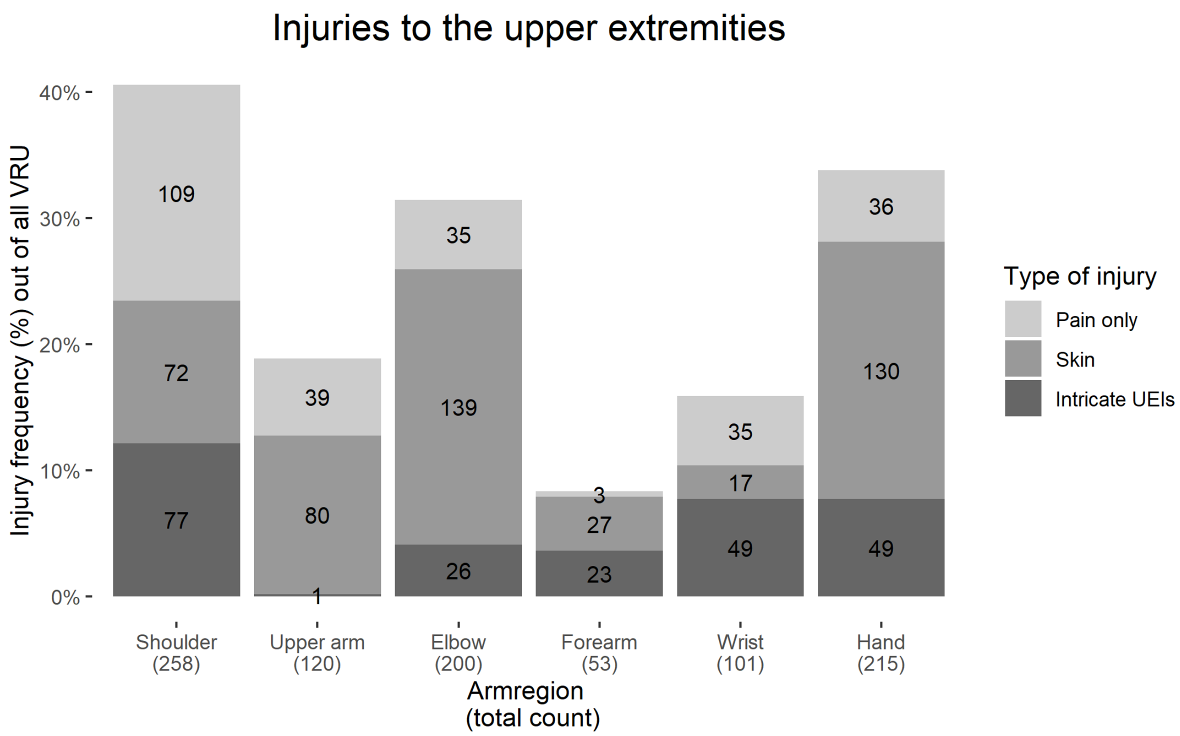


Figure 4.15: F
requency of each injury type found in the arm region among all VRUs for all UEIs.

Figure 4.16 highlights the type of tissue injured for each arm region when studying the intricate UEIs. Note that due to the categorization of injuries in this thesis, the upper arm and forearm could not have any injured joints, as they would be categorized to neighbouring regions of the arm. Elbow and forearm only had injuries affecting mostly skeletal tissue among the intricate UEIs. Hand and shoulder had injuries which affected mostly either skeletal, joint or soft tissue. Intricate wrist injuries mostly affected skeletal and joints, but there were single injuries affecting mostly nerve or soft tissue. Upper arm had a single intricate injury which mainly affected soft tissue.

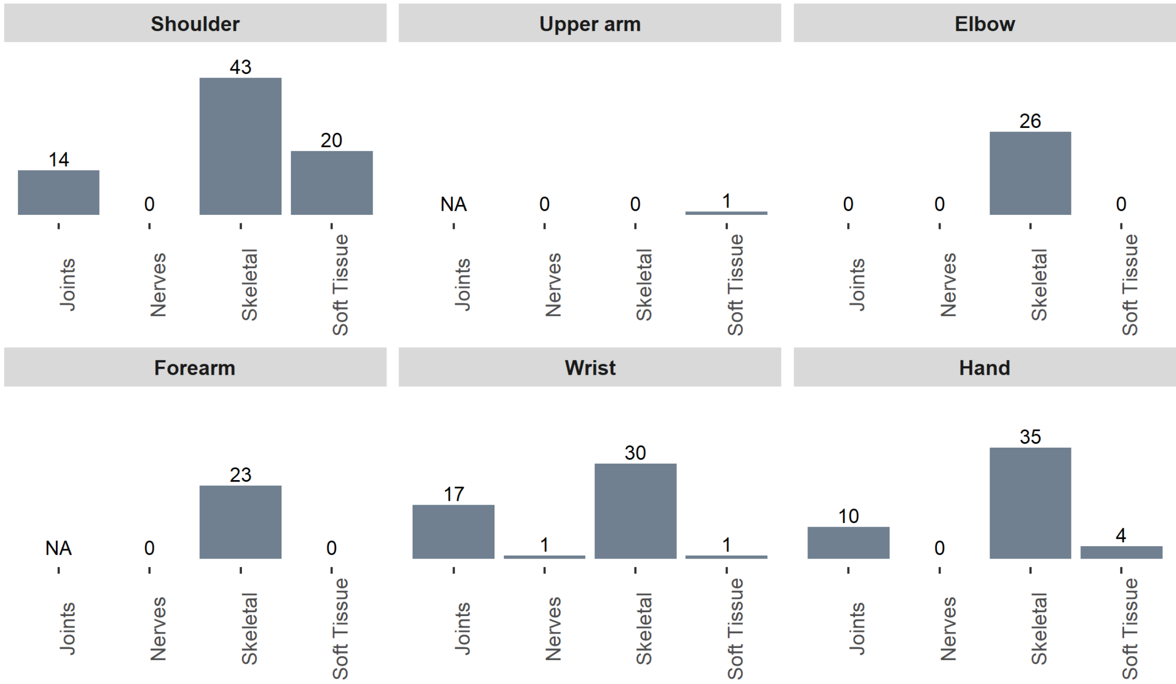


Figure 4.16: Comparison over tissue injured between the regions of the arm.

The distribution and frequencies of each injury types for cyclists, pedestrians and scooter riders UEIs were captured by Figure 4.17. For the cyclist, the arm region with most injuries found in the sample were shoulder (170), elbow (133) and hand (131). Skin injuries were most commonly found to the elbow (94), hand (79) and upper arm (57). The intricate injuries were most common in the wrist (40), shoulder (33) and hand (26). The region of the arm for cyclists with the highest frequency of intricate injuries compared to UEIs found were the wrist (50%). Then the forearm (38.7%), hand (19.8%), shoulder (19,4%) and elbow (11.3%). Upper arm had no intricate UEIs.

For the pedestrian the most frequently injured arm region was shoulder (66) or hand (66). Skin injuries were mostly found to the hand (40), elbow (33) or upper arm (17). Intricate injuries were most common in the shoulder (36), hand (16) or elbow (9). The region of the arm with the highest frequency of intricate injuries out of UEIs were the shoulder (54.4%), wrist (50%), forearm (41.2%), hand (24.2%) and elbow (19.1%) in order.

Among scooter riders the shoulder (18), elbow (15) and hand (14) were the most frequent injured arm regions among scooters. Skin injuries were most often found to the elbow (9), hand (8), shoulder (6) or upper arm (6). The intricate injuries were most common in the shoulder (7), hand (6) or forearm (4). The frequency of intricate injuries out of all UEIs were highest in forearm (100%), hand (42.9%),and shoulder (38.9%).

The distribution of injuries among the VRUs, in addition to the total exposure in PAV, are presented in Table 4.3. Cyclists with intricate UEIs of age 45-65 were the most

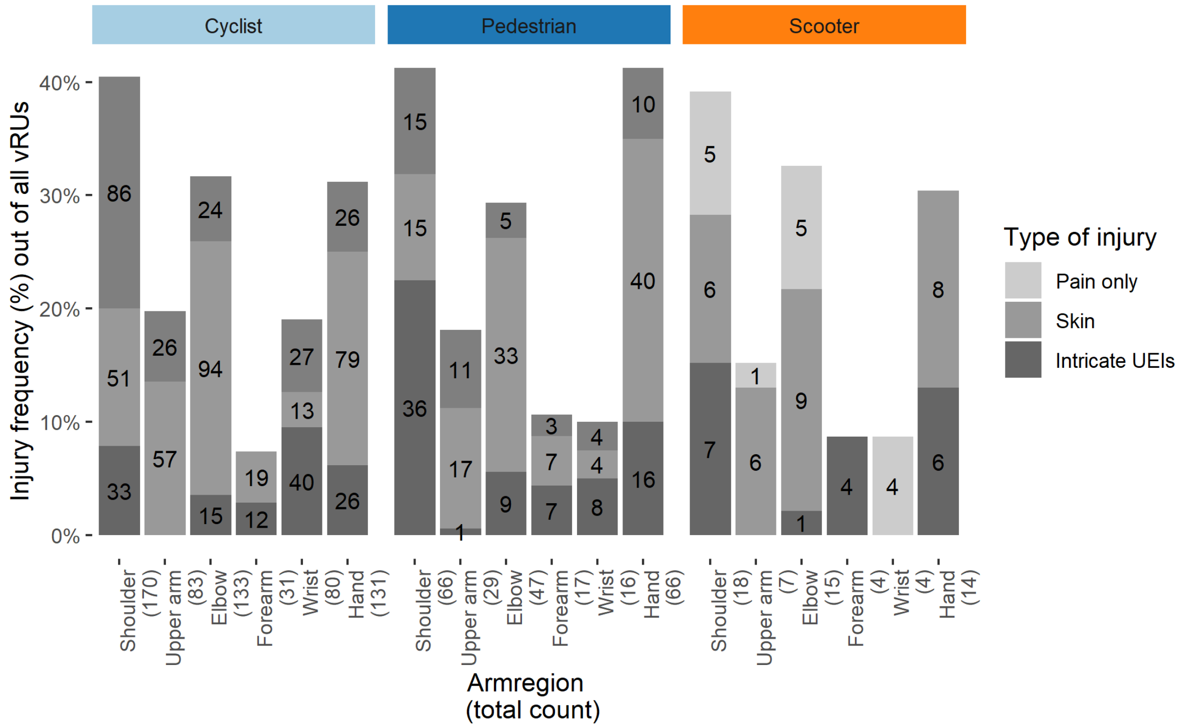


Figure 4.17: Frequency of each injury type found in the arm among cyclists, Pedestrians and scooter riders for all UEIs.

common age group among cyclists, with 39 cases. For same age group the total exposure in PAV is 321, making it the most common age group among cyclist. Their injuries were mostly to the shoulder (12) and wrist (13). The age group 65+ was the most common for pedestrian with intricate UEIs, 21 which is similar with total exposure 110 making it the common age group. Their injuries were most common to the shoulders (10), forearm (4) and elbow (3) or hand (3). The age groups with highest frequency among scooter riders with intricate UEIs were 0-16 and 17-29.

Table 4.3: Injury frequency found to each arm region by age category.

VRU type	Age	Elbow	Forearm	Hand	Shoulder	Wrist	Total in single intricate UEIs sample	Total exposures
Cyclist	0–16	3	3	1	1	4	12	97
	17–29	3	3	1	4	3	14	158
	30–44	3	0	6	4	7	20	211
	45–65	5	1	8	12	13	39	321
	65+	2	1	3	6	3	15	100
Scooter	0–16	0	3	1	0	0	4	23
	17–29	0	0	2	3	0	5	34
	30–44	1	1	0	0	0	2	22
	45–65	0	0	0	2	0	2	11
	65+	0	0	0	0	0	0	0
Pedestrian	0–16	1	2	1	0	0	4	36
	17–29	2	0	2	1	2	7	60
	30–44	0	0	3	3	0	6	58
	45–65	3	1	1	3	2	10	94
	65+	3	4	3	10	1	21	110

The frequency of injuries to the arm regions depending on sex is presented in Table 4.4. Cyclists with intricate UEIs were predominantly male, while pedestrians with intricate UEIs were mostly female for both the samples with UE and total exposure.

Table 4.4: Frequency of injuries to the arm regions depending on sex.

Injury Region	**Cyclist**		**Pedestrian**		**Scooter**	
	Male	Female	Male	Female	Male	Female
Elbow	7	7	5	4	1	0
Forearm	7	1	2	5	0	2
Hand	10	9	4	6	2	1
Shoulder	17	10	4	13	5	1
Wrist	18	12	2	3	0	0
Total in signle intricate UEIs sample	59	39	17	31	8	4
Total exposures	477	414	141	215	57	37

4.3 Common risk factors

The potential risk factors are shown in Tables 4.5–4.8 for different samples of intricate UEIs for arm region. The four tables of tests for independence for various samples and either arm region or tissue, indicate that it is difficult to establish any relationships between the potential risk factors and region of arm injured using statistical tests, with only few variables being statistically significant.

Table 4.5 suggest that age, conflict situation, the direction from which the VRUs were hit by the car (Hit VRU), and possibly number of impacts to car may be influencing the arm region injured for all VRUs are statistically significant. Table 4.6 indicate that the speed of the cyclist, conflict situation, number of impacts to the car and possibly where the cyclist struck the car were risk factors for certain injuries to the arm among cyclists. Table 4.7 shows that for intricate UEIs among pedestrians, speed limit on the road where the VRU was struck was the only variable that seemed to influence which arm region sustained. Table 4.8 instead shows the intricate UEIs potential risk factors for type of tissue affected. Only number of deformations appeared to influence the type of tissue injured.

The MCAs to find more potential interesting variables for the regression models are shown in Appendix A.1. The MCA shows the point cloud for injuries to the arm region for the VRUs suffering intricate UEIs. The closeness of the confidence intervals, as well as the low variance explanation of the dimensions indicate high similarity among the different regions of injuries.

Table 4.5: Distribution of intricate UEIs across potential risk factors among all VRUs. Values are shown as frequency (percentage). *Unknown in conflict situation was excluded from the analysis due to small sample size.

	Arm region						
Category	Elbow	Forearm	Hand	Shoulder	Wrist	Significance (p-value)	Simulated
Age							
0–16	1 (5,9)	8 (47,1)	3 (17,6)	1 (5,9)	4 (23,5)		
17–29	5 (19,2)	3 (11,5)	5 (19,2)	8 (30,8)	5 (19,2)	0.0011	Yes
30–44	4 (13,8)	0 (0,0)	9 (31,0)	8 (27,6)	8 (27,6)		
45–65	8 (15,1)	2 (3,8)	10 (18,9)	18 (34,0)	15 (28,3)		
65+	6 (16,2)	5 (13,5)	6 (16,2)	16 (43,2)	4 (10,8)		
Sex							
Female	11 (14,9)	8 (10,8)	16 (21,6)	24 (32,4)	15 (20,3)	0.9834	No
Male	13 (14,8)	10 (11,4)	17 (19,3)	27 (30,7)	21 (23,9)		
Conflict situation							
Reversing	1 (9,1)	2 (18,2)	1 (9,1)	5 (45,5)	2 (18,2)		
Straight crossing path	13 (15,7)	12 (14,5)	14 (16,9)	26 (31,3)	18 (21,7)		
Dooring	0 (0,0)	0 (0,0)	1 (33,3)	1 (33,3)	1 (33,3)	0.0191	Yes
Same direction	6 (66,7)	0 (0,0)	0 (0,0)	2 (22,2)	1 (11,1)		
Left Turn	2 (8,7)	4 (17,4)	6 (26,1)	6 (26,1)	5 (21,7)		
Right Turn	2 (6,9)	0 (0,0)	11 (37,9)	8 (27,6)	8 (27,6)		
Unknown*	0 (0,00)	0 (0,0)	0 (0,0)	3 (75,0)	1 (25,0)		
Crossing							
No	8 (14,3)	9 (16,1)	7 (12,5)	20 (35,7)	12 (21,4)	0.2847	No
Yes	16 (15,1)	9 (8,5)	26 (24,5)	31 (29,2)	24 (22,6)		
Crash type							
Back	2 (40,0)	0 (0,0)	1 (20,0)	2 (40,0)	0 (0,0)		
Front	3 (7,9)	2 (5,3)	9 (23,7)	11 (28,9)	13 (34,2)	0.08439	Yes
Side	15 (17,6)	8 (9,4)	19 (22,4)	24 (28,2)	19 (22,4)		
Unknown	4 (11,8)	8 (23,5)	4 (11,8)	14 (41,2)	4 (11,8)		
Hit VRU							
Back	2 (50,0)	0 (0,0)	1 (25,0)	1 (25,0)	0 (0,0)		
Frontal	2 (6,5)	1 (3,2)	8 (25,8)	8 (25,8)	12 (38,7)	0.0317	Yes
Left	9 (29,0)	3 (9,7)	9 (29,0)	5 (16,1)	5 (16,1)		
Right	4 (9,8)	4 (9,8)	6 (14,6)	18 (43,9)	9 (22,0)		
Unknown	7 (12,7)	10 (18,2)	9 (16,4)	19 (34,5)	10 (18,2)		
Speed limit							
30	7 (20,6)	5 (14,7)	5 (14,7)	12 (35,3)	5 (14,7)		
40	7 (12,3)	5 (8,8)	11 (19,3)	22 (38,6)	12 (21,1)		
50	3 (7,7)	4 (10,3)	9 (23,1)	12 (30,8)	11 (28,2)	0.8081	Yes
60	1 (14,3)	1 (14,3)	3 (42,9)	1 (14,3)	1 (14,3)		
70+	2 (28,6)	0 (0,0)	1 (14,3)	2 (28,6)	2 (28,6)		
Unknown	4 (22,2)	3 (16,7)	4 (22,2)	2 (11,1)	5 (27,8)		
Ground							
No	6 (15,8)	4 (10,5)	8 (21,1)	14 (36,8)	6 (15,8)	0.8379	No
Yes	18 (14,5)	14 (11,3)	25 (20,2)	37 (29,8)	30 (24,2)		
N impact car							
1	17 (15,9)	12 (11,2)	19 (17,8)	29 (27,1)	30 (28,0)	0.0521	No
2	5 (20,0)	5 (20,0)	6 (24,0)	7 (28,0)	2 (8,0)		
3+	2 (6,7)	1 (3,3)	8 (26,7)	15 (50,0)	4 (13,3)		
N impact other							
1	22 (14,6)	16 (10,6)	30 (19,9)	50 (33,1)	33 (21,9)	0.5838	Yes
2+	2 (18,2)	2 (18,2)	3 (27,3)	1 (9,1)	3 (27,3)		
Service weight of car							
<1199	1 (9,1)	1 (9,1)	2 (18,2)	6 (54,5)	1 (9,1)		
1200–1499	3 (7,9)	2 (5,3)	3 (7,9)	17 (44,7)	13 (34,2)	0.1322	Yes
1500–1999	13 (20,0)	8 (12,3)	12 (18,5)	17 (26,2)	15 (23,1)		
2000<	4 (16,7)	3 (12,5)	8 (33,3)	5 (20,8)	4 (16,7)		
Unknown	3 (12,5)	4 (16,7)	8 (33,3)	6 (25,0)	3 (12,5)		
N deformations							
0	18 (16,4)	17 (15,5)	18 (16,4)	31 (28,2)	26 (23,6)		
1	1 (6,7)	1 (6,7)	4 (26,7)	4 (26,7)	5 (33,3)	0.1906	Yes
2	3 (21,4)	0 (0,0)	3 (21,4)	6 (42,9)	2 (14,3)		
3+	2 (8,7)	0 (0,0)	8 (34,8)	10 (43,5)	3 (13,0)		

Table 4.6: Distribution of arm injuries across potential risk factors among cyclists. Values are shown as frequency (percentage). *Unknown in conflict situation was excluded due to small sample size.

	Arm region						
Category	Elbow	Forearm	Hand	Shoulder	Wrist	Significance (p-value)	Simulated
Age							
0–16	0 (0,0)	3 (33,3)	1 (11,1)	1 (11,1)	4 (44,4)		
17–29	3 (21,4)	3 (21,4)	1 (7,1)	4 (28,6)	3 (21,4)	0.161	Yes
30–44	3 (15,0)	0 (0,0)	6 (30,0)	4 (20,0)	7 (35,0)		
45–65	5 (12,8)	1 (2,6)	8 (20,5)	12 (30,8)	13 (33,3)		
65+	2 (13,3)	1 (6,7)	3 (20,0)	6 (40,0)	3 (20,0)		
Sex							
Female	6 (15,8)	1 (2,6)	9 (23,7)	10 (26,3)	12 (31,6)	0.5168	No
Male	7 (11,9)	7 (11,9)	10 (16,9)	17 (28,8)	18 (30,5)		
Conflict situation							
Straight crossing path	6 (11,5)	6 (11,5)	8 (15,4)	15 (28,8)	17 (32,7)		
Dooring	0 (0,0)	0 (0,0)	1 (33,3)	1 (33,3)	1 (33,3)	0.0488	Yes
Same direction	4 (80,0)	0 (0,0)	0 (0,0)	1 (20,0)	0 (0,0)		
Left Turn	2 (12,5)	2 (12,5)	4 (25,0)	4 (25,0)	4 (25,0)		
Right Turn	1 (5,3)	0 (0,0)	6 (31,6)	5 (26,3)	7 (36,8)		Unknown*
0 (0,00)	0 (0,0)	0 (0,0)	1 (50,0)	1 (50,0)			
Crossing							
No	3 (14,3)	3 (14,3)	2 (9,5)	5 (23,8)	8 (38,1)	0.5269	No
Yes	10 (13,2)	5 (6,6)	17 (22,4)	22 (28,9)	22 (28,9)		
Crash type							
Back	1 (50,0)	0 (0,0)	0 (0,0)	1 (50,0)	0 (0,0)		
Front	1 (3,3)	2 (6,7)	8 (26,7)	9 (30,0)	10 (33,3)	0.7404	Yes
Side	10 (18,5)	5 (9,3)	9 (16,7)	13 (24,1)	17 (31,5)		
Unknown	1 (9,1)	1 (9,1)	2 (18,2)	4 (36,4)	3 (27,3)		
Hit VRU							
Back	1 (100,0)	0 (0,0)	0 (0,0)	0 (0,0)	0 (0,0)		
Frontal	1 (4,0)	1 (4,0)	7 (28,0)	7 (28,0)	9 (36,0)	0.06479	Yes
Left	8 (32,0)	2 (8,0)	6 (24,0)	4 (16,0)	5 (20,0)		
Right	2 (8,3)	3 (12,5)	1 (4,2)	9 (37,5)	9 (37,5)		
Unknown	1 (4,5)	2 (9,1)	5 (22,7)	7 (31,8)	7 (31,8)		
Speed limit							
30	5 (27,8)	2 (11,1)	2 (11,1)	4 (22,2)	5 (27,8)		
40	6 (14,6)	3 (7,3)	7 (17,1)	13 (31,7)	12 (29,3)	0.8945	Yes
50	1 (4,8)	2 (9,5)	4 (19,0)	5 (23,8)	9 (42,9)		
60	0 (0,0)	0 (0,0)	2 (50,0)	1 (25,0)	1 (25,0)		
70+	1 (20,0)	0 (0,0)	1 (20,0)	2 (40,0)	1 (20,0)		
Unknown	0 (0,0)	1 (12,5)	3 (37,5)	2 (25,0)	2 (25,0)		
Ground							
No	1 (5,3)	1 (5,3)	6 (31,6)	7 (36,8)	4 (21,1)	0.3253	Yes
Yes	12 (15,4)	7 (9,0)	13 (16,7)	20 (25,6)	26 (33,3)		
N impact car							
1	9 (15,5)	3 (5,2)	7 (12,1)	15 (25,9)	24 (41,4)	0.03502	No
2	2 (11,8)	4 (23,5)	5 (29,4)	4 (23,5)	2 (11,8)		
3+	2 (9,1)	1 (4,5)	7 (31,8)	8 (36,4)	4 (18,2)		
N impact other							
1	11 (12,5)	7 (8,0)	17 (19,3)	26 (29,5)	27 (30,7)	0.7862	No
2+	2 (22,2)	1 (11,1)	2 (22,2)	1 (11,1)	3 (33,3)		
Service weight of car							
<1199	1 (14,3)	0 (0,0)	1 (14,3)	4 (57,1)	1 (14,3)		
1200–1499	3 (11,5)	1 (3,8)	2 (7,7)	9 (34,6)	11 (42,3)	0.1693	Yes
1500–1999	5 (13,2)	5 (13,2)	6 (15,8)	10 (26,3)	12 (31,6)		
2000<	4 (28,6)	1 (7,1)	4 (28,6)	2 (14,3)	3 (21,4)		
Unknown	0 (0,0)	1 (8,3)	6 (50,0)	2 (16,7)	3 (25,0)		
N deformations							
0	10 (16,9)	7 (11,9)	7 (11,9)	15 (25,4)	20 (33,9)		
1	0 (0,0)	1 (10,0)	2 (20,0)	2 (20,0)	5 (50,0)	0.2461	Yes
2	1 (11,1)	0 (0,0)	3 (33,3)	3 (33,3)	2 (22,2)		
3+	2 (10,5)	0 (0,0)	7 (36,8)	7 (36,8)	3 (15,8)		
Movement							
Slow cycling	0 (0,0)	0 (0,0)	2 (33,3)	1 (16,7)	3 (50,0)	0.0402	Yes
Fast cycling	0 (0,0)	2 (11,1)	4 (22,2)	11 (61,1)	1 (5,6)		
Unspecified	13 (17,8)	6 (8,2)	13 (17,8)	15 (20,5)	26 (35,6)		

Table 4.7: Distribution of arm injuries across potential risk factors among pedestrians. Values are shown as frequency (percentage). *Unknown in conflict situation was excluded due to small sample size.

	Arm region						
Category	Elbow	Forearm	Hand	Shoulder	Wrist	Significance (p-value)	Simulated
Age							
0–16	1 (25,0)	2 (50,0)	1 (25,0)	0 (0,0)	0 (0,0)		
17–29	2 (28,6)	0 (0,0)	2 (28,6)	1 (14,3)	2 (28,6)	0.2045	No
30–44	0 (0,0)	0 (0,0)	3 (50,0)	3 (50,0)	0 (0,0)		
45–65	3 (30,0)	1 (10,0)	1 (10,0)	3 (30,0)	2 (20,0)		
65+	3 (14,3)	4 (19,0)	3 (14,3)	10 (47,6)	1 (4,8)		
Sex							
Female	4 (12,9)	5 (16,1)	6 (19,4)	13 (41,9)	3 (9,7)	0.5701	No
Male	5 (29,4)	2 (11,8)	4 (23,5)	4 (23,5)	2 (11,8)		
Conflict situation							
Reversing	1 (9,1)	2 (18,2)	1 (9,1)	5 (45,5)	2 (18,2)		
Straight crossing path	5 (25,0)	5 (25,0)	3 (15,0)	6 (30,0)	1 (5,0)	0.2693	Yes
Same direction	2 (50,0)	0 (0,0)	0 (0,0)	1 (25,0)	1 (25,0)		
Left Turn	0 (0,0)	0 (0,0)	2 (50,0)	2 (50,0)	0 (0,0)		
Right Turn	1 (14,3)	0 (0,0)	4 (57,1)	1 (14,3)	1 (14,3)		
Unknown*	0 (0,0)	0 (0,0)	0 (0,0)	2 (100,0)	0 (0,0)		
Crossing							
No	4 (13,3)	5 (16,7)	4 (13,3)	13 (43,3)	4 (13,3)	0.2211	No
Yes	5 (27,8)	2 (11,1)	6 (33,3)	4 (22,2)	1 (5,6)		
Crash type							
Back	1 (33,3)	0 (0,0)	1 (33,3)	1 (33,3)	0 (0,0)		
Front	2 (40,0)	0 (0,0)	0 (0,0)	1 (20,0)	2 (40,0)	0.1459	Yes
Side	4 (20,0)	2 (10,0)	7 (35,0)	5 (25,0)	2 (10,0)		
Unknown	2 (10,0)	5 (25,0)	2 (10,0)	10 (50,0)	1 (5,0)		
Hit VRU							
Back	1 (33,3)	0 (0,0)	1 (33,3)	1 (33,3)	0 (0,0)		
Frontal	1 (33,3)	0 (0,0)	0 (0,0)	0 (0,0)	2 (66,7)		
Left	1 (20,0)	1 (20,0)	2 (40,0)	1 (20,0)	0 (0,0)	0.1291	Yes
Right	1 (11,1)	0 (0,0)	4 (44,4)	4 (44,4)	0 (0,0)		
Unknown	5 (17,9)	6 (21,4)	3 (10,7)	11 (39,3)	3 (10,7)		
Speed limit							
30	1 (8,3)	3 (25,0)	1 (8,3)	7 (58,3)	0 (0,0)		
40	1 (11,1)	1 (11,1)	4 (44,4)	3 (33,3)	0 (0,0)	0.0447	Yes
50	2 (13,3)	2 (13,3)	3 (20,0)	7 (46,7)	1 (6,7)		
60	1 (33,3)	1 (33,3)	1 (33,3)	0 (0,0)	0 (0,0)		
70+	1 (50,0)	0 (0,0)	0 (0,0)	0 (0,0)	1 (50,0)		
Unknown	3 (42,9)	0 (0,0)	1 (14,3)	0 (0,0)	3 (42,9)		
Ground							
No	5 (31,3)	1 (6,3)	1 (6,3)	7 (43,8)	2 (12,5)	0.1873	No
Yes	4 (12,5)	6 (18,8)	9 (28,1)	10 (31,3)	3 (9,4)		
N impact car							
1	6 (15,4)	7 (17,9)	9 (23,1)	12 (30,8)	5 (12,8)	0.1606	Yes
2	3 (60,0)	0 (0,0)	0 (0,0)	2 (40,0)	0 (0,0)		
3+	0 (0,0)	0 (0,0)	1 (25,0)	3 (75,0)	0 (0,0)		
N impact other							
1	9 (19,6)	6 (13,0)	9 (19,6)	17 (37,0)	5 (10,9)	0.4012	Yes
2+	0 (0,0)	1 (50,0)	1 (50,0)	0 (0,0)	0 (0,0)		
Service weight of car							
<1199	0 (0,0)	1 (25,0)	1 (25,0)	2 (50,0)	0 (0,0)		
1200–1499	0 (0,0)	0 (0,0)	0 (0,0)	5 (71,4)	2 (28,6)	0.14	Yes
1500–1999	7 (30,4)	3 (13,0)	6 (26,1)	5 (21,7)	2 (8,7)		
2000<	0 (0,0)	2 (28,6)	3 (42,9)	1 (14,3)	1 (14,3)		
Unknown	2 (28,6)	1 (14,3)	0 (0,0)	4 (57,1)	0 (0,0)		
N deformations							
0	6 (14,6)	7 (17,1)	9 (22,0)	14 (34,1)	5 (12,2)		
1	1 (50,0)	0 (0,0)	0 (0,0)	1 (50,0)	0 (0,0)	0.6972	Yes
2	2 (66,7)	0 (0,0)	0 (0,0)	1 (33,3)	0 (0,0)		
3+	0 (0,0)	0 (0,0)	1 (50,0)	1 (50,0)	0 (0,0)		
Movement							
Walking	6 (20,7)	5 (17,2)	7 (24,1)	8 (27,6)	3 (10,3)		
Jogging	1 (20,0)	1 (20,0)	2 (40,0)	1 (20,0)	0 (0,0)	0.8041	Yes
Standing	1 (20,0)	0 (0,0)	0 (0,0)	3 (60,0)	1 (20,0)		
Unknown	1 (14,3)	1 (14,3)	1 (14,3)	4 (57,1)	0 (0,0)		
Other	0 (0,0)	0 (0,0)	0 (0,0)	1 (50,0)	1 (50,0)		

Table 4.8: Distribution of injury tissue types across potential risk factors among all VRUs. Values are shown as frequency (percentage). Unknown in conflict situation was excluded due to small sample size

	Tissue				
Category	**Joints**	**Soft tissue**	**Skeletal**	**Significance (p-value)**	**Simulated**
Age					
0–16	2 (11,8)	2 (11,8)	13 (76,5)		
17–29	4 (15,4)	4 (15,4)	18 (69,2)	0.5636	No
30–44	8 (27,6)	3 (10,3)	18 (62,1)		
45–65	9 (17,0)	2 (3,8)	42 (79,2)		
65+	6 (16,2)	2 (5,4)	29 (78,4)		
Sex					
Female	11 (14,9)	7 (9,5)	56 (75,7)	0.6065	Yes
Male	18 (20,5)	6 (6,8)	64 (72,7)		
Conflict situation					
Reversing	0 (0,0)	0 (0,0)	11 (100,0)		
Straight crossing path	16 (19,3)	8 (9,6)	59 (71,1)		
Dooring	0 (0,0)	1 (33,3)	2 (66,7)	0.1672	Yes
Same direction	1 (11,1)	0 (0,0)	8 (88,9)		
Left Turn	4 (17,4)	0 (0,0)	19 (82,6)		
Right Turn	8 (27,6)	4 (13,8)	17 (58,6)		
Unknown*	0 (0,00)	0 (0,00)	4 (100)		
Crossing					
No	6 (10,7)	4 (7,1)	46 (82,1)	0.1916	No
Yes	23 (21,7)	9 (8,5)	74 (69,8)		
Crash type					
Back	1 (20,0)	0 (0,0)	4 (80,0)		
Front	8 (21,1)	2 (5,3)	28 (73,7)	0.9525	Yes
Side	15 (17,6)	7 (8,2)	63 (74,1)		
Unknown	5 (14,7)	4 (11,8)	25 (73,5)		
Hit VRU					
Back	0 (0,0)	0 (0,0)	4 (100,0)		
Frontal	6 (19,4)	2 (6,5)	23 (74,2)	0.8783	Yes
Left	7 (22,6)	1 (3,2)	23 (74,2)		
Right	7 (17,1)	5 (12,2)	29 (70,7)		
Unknown	9 (16,4)	5 (9,1)	41 (74,5)		
Speed limit					
30	3 (8,8)	2 (5,9)	29 (85,3)		
40	18 (31,6)	5 (8,8)	34 (59,6)		
50	5 (12,8)	2 (5,1)	32 (82,1)	0.1678	Yes
60	1 (14,3)	1 (14,3)	5 (71,4)		
70+	1 (14,3)	1 (14,3)	5 (71,4)		
Unknown	1 (5,6)	2 (11,1)	15 (83,3)		
Ground					
No	8 (21,1)	2 (5,3)	28 (73,7)	0.735	Yes
Yes	21 (16,9)	11 (8,9)	92 (74,2)		
N impact car					
1	18 (16,8)	7 (6,5)	82 (76,6)	0.041	No
2	2 (8,0)	1 (4,0)	22 (88,0)		
3+	9 (30,0)	5 (16,7)	16 (53,3)		
N impact other					
1	28 (18,5)	13 (8,6)	110 (72,8)	0.5838	Yes
2+	1 (9,1)	0 (0,0)	10 (90,9)		
Service weight of car					
<1199	1 (9,1)	3 (27,3)	7 (63,6)		
1200–1499	8 (21,1)	5 (13,2)	25 (65,8)	0.2098	Yes
1500–1999	10 (15,4)	3 (4,6)	52 (80,0)		
2000<	4 (16,7)	1 (4,2)	19 (79,2)		
Unknown	6 (25,0)	1 (4,2)	17 (70,8)		
N deformations					
0	20 (18,2)	7 (6,4)	83 (75,5)		
1	1 (6,7)	1 (6,7)	13 (86,7)	0.0289	Yes
2	1 (7,1)	0 (0,0)	13 (92,9)		
3+	7 (30,4)	5 (21,7)	11 (47,8)		

The conducted regressions for the statistically significant variables for each sample showed few significant estimations of effect to injuries found within each arm region for the chosen statistically significant variables. The regressions were thus mostly insignificant and could not explain the effect of a chosen variable to which arm region was injured.

One of the conducted regressions are shown in Table A.3. Table 4.9 shows estimated ratios from Table A.3. The table shows the region of the arm, the independent variable, the estimated effect (transformed through exponential), the standard error if applicable, z-value, as well as p-value. Table 4.9 shows how the estimation of forearm for the reference age (30-44), 0-16 and 17-29 among all VRUs have a very low p-value, which would suggest the results to be statistically significant, but they are likely not. The regression models cannot estimate cell observatons of 0. When examining the same regression with another reference level, seen in Table 4.10, the estimations for age get different p-values. Then it is suggested that forearm injuries are less frequent for VRUs between the ages of 45-65 and more frequent for VRUs aged 0-16, which both had p-values under the chosen significance level of 0.05. Note that the other estimations in Table 4.9 and Table 4.10 remain unchanged, so did the model evaluation metrics such as AIC, BIC and McFadden's pseudo R2. Thus, it was shown that the reference level is important for the multinomial logistic regression, but that it does not affect the total model, just the independent variable tested.

Table 4.9: Some estimated ratios from the regression shown in B.1 based on equation (3.1) with age reference 30-44.

Arm region	Variable	Estimate	SE	Z-value	P-value
Forearm	(Intercept)	-25.407	1.367	-18.585	0.000
Forearm	Age 0–16	25.576	0.830	30.816	0.000
Forearm	Age 17–29	23.430	0.938	24.977	0.000
Wrist	ImpactCar 2	-1.965	0.953	-2.060	0.039
Wrist	ImpactCar 3+	-1.363	0.741	-1.840	0.066

Table 4.10: Some estimated ratios from the regression shown in B.2 based on equation (3.1) with age reference 45-65.

Arm region	Variable	Estimate	SE	Z-value	P-value
Forearm	(Intercept)	-3.007	1.702	-1.767	0.077
Forearm	Age 0–16	3.175	1.332	2.383	0.017
Forearm	Age 17–29	1.029	1.315	0.782	0.434
Wrist	ImpactCar 2	-1.965	0.953	-2.060	0.039
Wrist	ImpactCar 3+	-1.363	0.741	-1.840	0.066

4.4 Comparison of UEIs among VRUs

Investigating the injuries found among the VRUs show that the injuries found among them differ. Figure 4.18 shows that there are many different injuries sustained by the different VRUs. Cyclists have 34.1% of their injuries not visible with name, pedestrians 59.7% and scooter riders 50% when studying the cyclists twelve most common injuries.

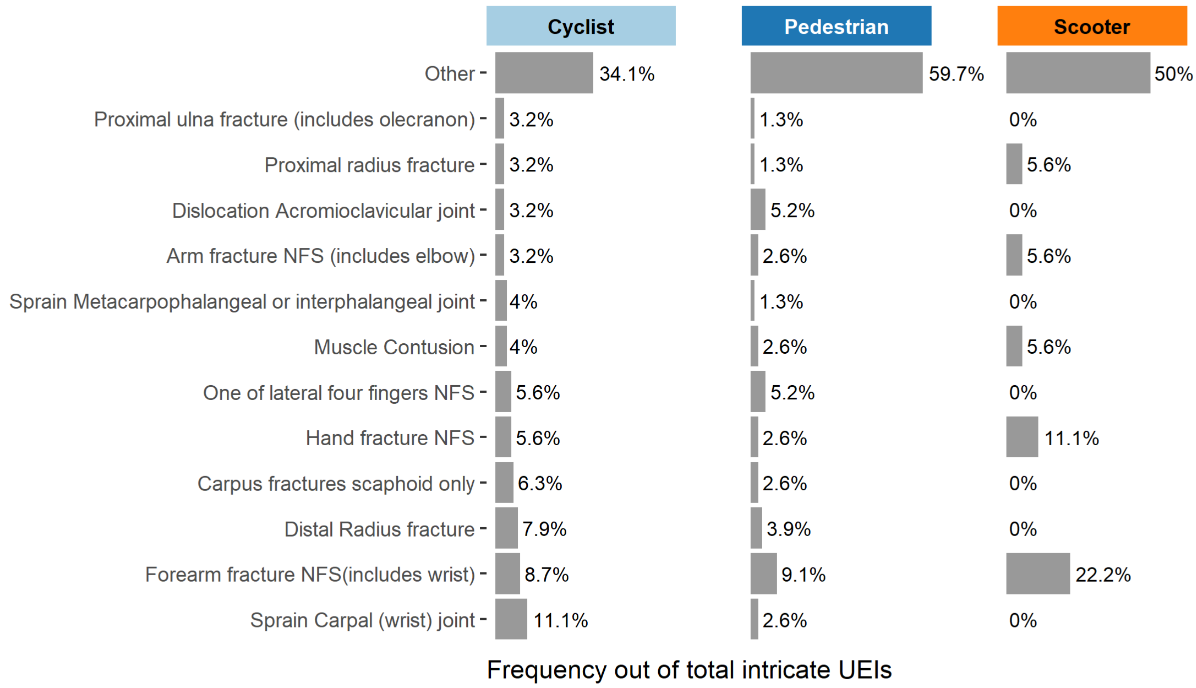


Figure 4.18: Comparison between cyclists, pedestrian and scooter riders of common injuries found among cyclists.

Figure 4.19 shows the frequencies of severity of the injuries found among the different VRUs. Among the intricate UEIs, cyclists had 70.6% of the injuries being moderate (AIS 2), pedestrians 80.3% and scooter riders had 61.1% of the intricate UEIs categorized as moderate.

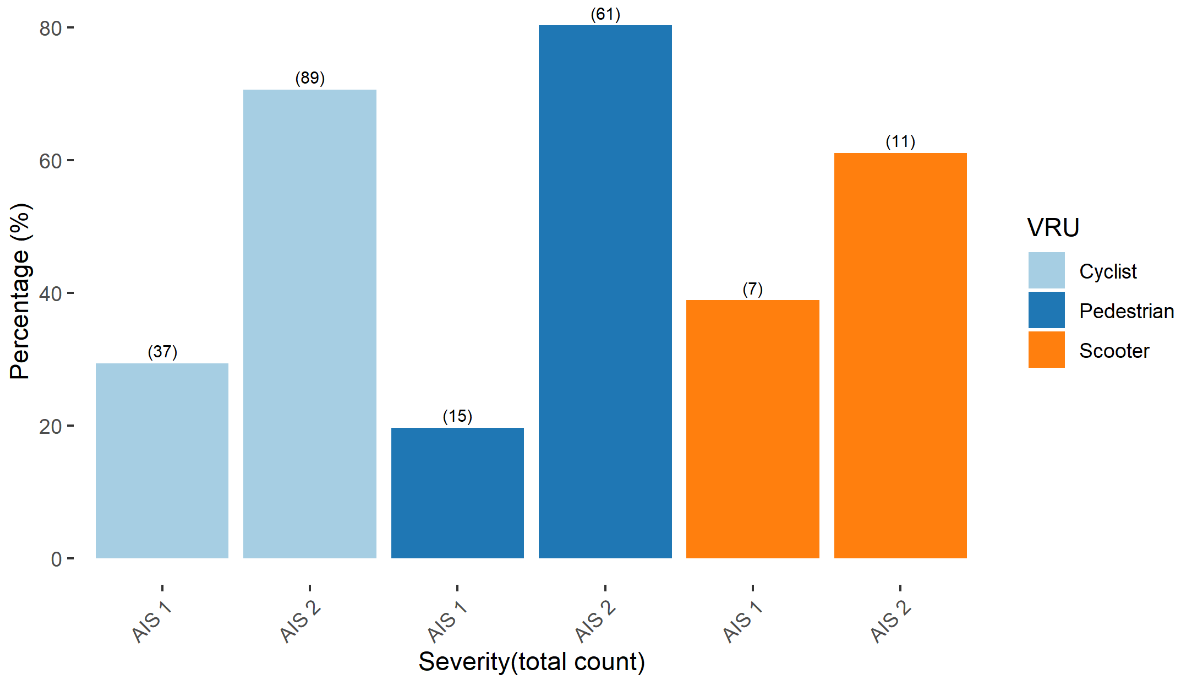
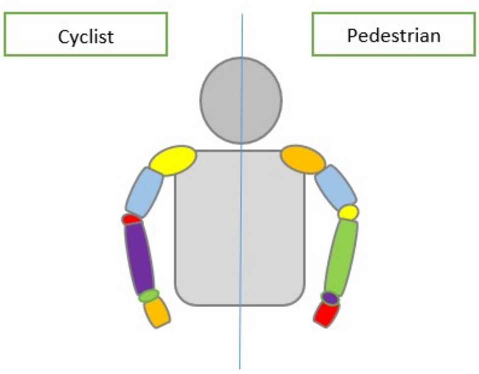


Figure 4.19: Comparative plot over severity between the three most common groups of VRUs with intricate injuries.

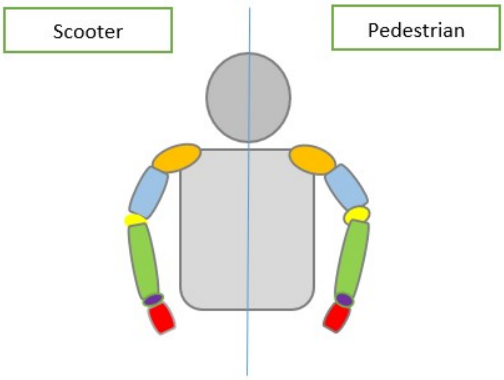
Figure 4.20 shows a comparison of injury distribution for all UEIs based on arm region categorization between cyclist and pedestrian. The most common injuries in order among cyclists were to the elbow, hand and shoulder, while pedestrians had hand, shoulder and elbow respectively.



		Cyclist	Pedestrian
	Most common UEIs	Elbow (24.8%)	Hand (29%)
	Very common UEIs	Hand (23.9%)	Shoulder (26.4%)
	Fairly common UEIs	Shoulder (19.1%)	Elbow (21.8%)
	Common UEIs	Upper arm (13%)	Upper arm (9.3%)
	Less common UEIs	Wrist (12.1%)	Forearm (7.3%)
	Least common UEIs	Forearm (7.1%)	Wrist (6.2%)

Figure 4.20: Comparisons in frequency of injuries to the arm region between cyclist and pedestrian for all AIS coded UEIs.

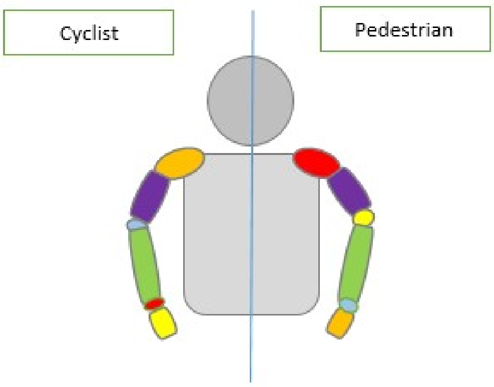
Figure 4.21 shows a similar comparison of frequency of injuries to the arm region, but between scooter riders and pedestrian. Scooters most commonly suffered UEIs to the hand, shoulder and elbow.



		Scooter	Pedestrian
	Most common UEIs	Hand (29.8%)	Hand (29%)
	Very common UEIs	Shoulder (27.7%)	Shoulder (26.4%)
	Fairly common UEIs	Elbow (21.3%)	Elbow (21.8%)
	Common UEIs	Upper arm (12.8%)	Upper arm (9.3%)
	Less common UEIs	Forearm (8.5%)	Forearm (7.3%)
	Least common UEIs	Wrist (0.0%)	Wrist (6.2%)

Figure 4.21: Comparisons in frequency of injuries to the arm region between scooter riders and pedestrian for all AIS coded injuries.

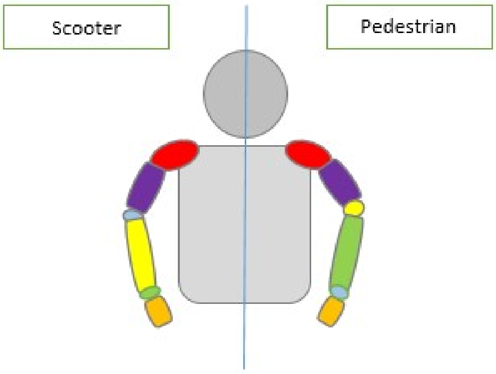
Figure 4.22 Shows the comparison of intricate UEIs grouped by arm region among cyclists and pedestrians. Now injuries to the wrist, shoulder and hand were most common among cyclists. Pedestrians most frequently suffered injuries to the shoulder, hand and elbow.



		Cyclist	Pedestrian
	Most common UEIs	Wrist (31.7%)	Shoulder (46.8%)
	Frequently common UEIs	Shoulder (26.2%)	Hand (20.8%)
	common UEIs	Hand (20.6%)	Elbow (11.7%)
	Less common UEIs	Elbow (11.9%)	Wrist (10.4%)
	Rarely common UEIs	Forearm (9.5%)	Forearm (9.1%)
	Least common UEIs	Upper arm (0.0%)	Upper arm (1.3%)

Figure 4.22: Comparisons in frequency of injuries to the arm region between cyclist and pedestrian for intricate UEIs.

Figure 4.23 Shows the comparison between frequencies of intricate UEIs to the arm region between scooter riders and pedestrians. Scooter most frequently suffered injuries to the shoulder, hand and forearm.

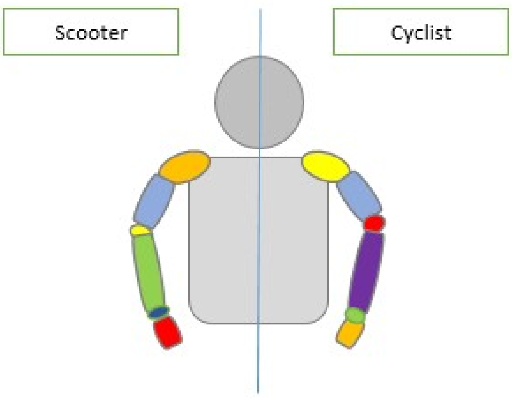


		Scooter	Pedestrian
	Most common UEIs	Shoulder (38.9%)	Shoulder (46.8%)
	Frequently common UEIs	Hand (33.3%)	Hand (20.8%)
	common UEIs	Forearm (22.2%)	Elbow (11.7%)
	Less common UEIs	Elbow (5.6%)	Wrist (10.4%)
	Rarely common UEIs	Wrist (0.0%)	Forearm (9.1%)
	Least common UEIs	Upper arm (0.0%)	Upper arm (1.3%)

Figure 4.23: Comparisons in frequency of injuries to the arm region between scooter riders and pedestrian for intricate UEIs.

Considering Figure 4.22 and Figure 4.23 the injury patterns between scooter riders and pedestrians seem similar, while cyclists tend to suffer injuries to different arm regions.

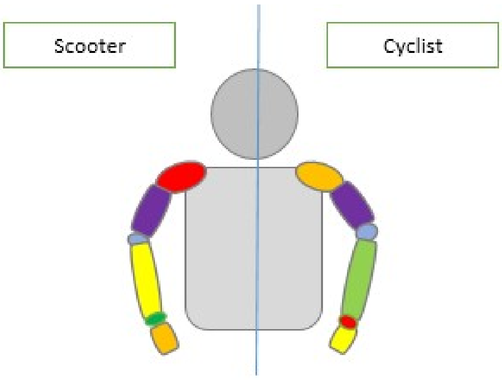
Figure 4.24 shows a comparison of injury distribution for all UEIs based on arm region categorization between scooter riders and cyclist. The most common injuries in order among scooter riders were to the hand, shoulder and elbow, while cyclist had elbow, hand and shoulder respectively.



		Scooter	Cyclist
	Most common UEIs	Hand (29.8%)	Elbow (24.8%)
	Frequently common UEIs	Shoulder (27.7%)	Hand (23.9%)
	common UEIs	Elbow (21.3%)	Shoulder (19.1%)
	Less common UEIs	Upper arm (12.8%)	Upper arm (13%)
	Rarely common UEIs	Forearm (8.5%)	Wrist (12.1%)
	Least common UEIs	Wrist (0.0%)	Forearm (7.1%)

Figure 4.24: Comparisons in frequency of injuries to the arm region between scooter rider and cyclist for all AIS coded UEIs.

Figure 4.25 Shows the comparison of intricate UEIs grouped by arm region among scooter riders and cyclist. Injuries to the shoulder, hand and forearm were most common among scooter riders. Cyclist most frequently suffered injuries to the wrist, shoulder and hand.



		Scooter	Cyclist
	Most common UEIs	Shoulder (38.9%)	Wrist (31.7%)
	Frequently common UEIs	Hand (33.3%)	Shoulder (26.2%)
	common UEIs	Forearm (22.2%)	Hand (20.6%)
	Less common UEIs	Elbow (5.6%)	Elbow (11.9%)
	Rarely common UEIs	Wrist (0.0%)	Forearm (9.5%)
	Least common UEIs	Upper arm (0.0%)	Upper arm (0.0%)

Figure 4.25: Comparisons in frequency of injuries to the arm region between scooter rider and cyclist for intricate UEIs.

5

Discussion

In this thesis, data for car-VRU accidents in which the VRU sustained UEIs were investigated. Aspects such as accident descriptions, impacts, common injuries, injury patterns and risk factors were examined to determine important aspects to consider when studying car-VRU accidents in a more detailed manner for potential mitigative efforts. The methods of the project mapped out the most common UEIs among VRUs and patterns between different types of VRUs. The chi-squared tests showed that age, conflict situation, the direction from which the VRU were hit by the car and number of impacts to the car sustained likely influences which arm region is injured. The regression modelling indicated that it is difficult to determine risk factors and that type 1 errors might be common [50].

5.1 Exploring car-VRU crashes and injuries

The first objective of the study was to provide an initial data set exploration of car-VRU crashes with UEIs and associated injuries. The exploration showed that PAV was a valuable source of information for analyzing accidents, impact and injuries involving VRUs. The exploration reinforced the idea that insurance data provides rich descriptions on car-VRU crashes, as indicated by previous studies on cyclists based on insurance data [18][19]. The initial descriptions of aspects related to the car-VRU crashes, highlight the age distribution of the VRUs with UEIs. Cyclists with UEIs were most frequently aged 45-64, while pedestrians with UEIs tended to be 65+ and a majority of scooter riders with UEIs were below 30 years old, compared to the total which were 27.4%. The proportion of males was higher among cyclists (58.3%) and scooter riders (63.0%) compared to the total sample (54.1%). In contrast, the majority of pedestrians were female (60.0%), highlighting a distributional difference in sex across the groups. Pedestrians are much more likely to be involved in conflict situations where the car is reversing, and they had higher levels of unknowns in traffic environment, speed limit, and crash type, which could impact risk factor analysis, as the methods might not be able to explain potential patterns.

The initial exploration highlighted how the most common conflict situation pre–crash is Straight Crossing Path (SCP) and car turning. Figure 4.2 further illustrates that across all VRUs groups, straight crossing path was the most common accident situation, with similar frequency patterns across VRUs. This aligns with previous research that there is high risk of sustaining UEIs in this type of accident situation for VRUs [16, 13].

It was previously shown for cyclists that SCP and turning was common conflict situations [19]. In contrast to [19], cases where the car is not moving in the accidents were less common, where cyclists with UEIs were involved in dooring situations 3.4% of the time in this data set, compared to 10% of the time in their study ([19]) on car-cyclist crashes.

The VRUs were mostly struck by the front of the car to the sides, with most cyclists, pedestrians and scooter riders being involved in those crash type scenarios. Cyclists were commonly subject to accidents involving the front of the cyclist and the side of the car, which has been shown previously [19]. Scooter riders were also often involved in those crash types. Notably, the data used in this thesis includes information on impacts and damage to the car, which were explored to explain injury distribution and patterns. Most of the VRUs struck the ground. Cyclists commonly strike the ground [15, 14, 21, 11], pedestrians commonly strike the ground in car-VRU crashes [17, 65, 15], scooter riders as well [46, 48]. The sample of VRUs with intricate UEIs had mostly similar frequencies of striking the ground, but pedestrians had a slightly higher frequency, while scooter riders had a somewhat lower frequency of striking the ground. The frequency of impacts to the car suggests similar trends among the VRUs, with a single impact to the car being most common, but with the caveat that cyclists and scooter riders more frequently suffer two or more impacts to the car, while pedestrians mostly only struck the car once. When examining the injury regions and number of deformations, it was clear that there were limited available deformations in the data set, thus making further studies on the connection between injuries and deformations with more available data interesting to determine if there are any connections. Out of the 160 VRUs with a single intricate UEI, there were 235 impacts found to the front. About one third of those had descriptions of damage to the car. Among those which had descriptions of damage to the front of the car, only 33 injuries were possible to connect to deformations to the front, i.e., too few observations to conduct in depth comparisons.

The initial context on injuries showed that polytrauma is common among the VRUs with UEIs, but that polytrauma is more common with different regions, as opposed to multiple injuries within the UEIs when studying this sample. The UEIs were mostly of lower severity compared to other injuries to the body, which was expected as UEIs categorized as AIS 3 or higher are rare to the UEIs, as highlighted by the study conducted by Malm et al., [6]. Similarly, the VRUs rarely MAIS 3+, with pedestrians sustaining an injury categorized as AIS 3+ in 9.4% of the cases, cyclists 2.4% and scooter riders 0%, indicating that the injuries sustained in the accidents filtered to include UEIs tend to be less severe.

5.2 Common UEIs among VRUs

The second objective of this thesis was to address the question of what upper extremity injuries are the most common among VRUs. Studying the sampled group of VRUs with UEIs in detail showed that skin abrasion, skin contusion and minor skin laceration were most common among the VRUs with UEIs. When excluding skin injuries, the most frequent injuries were fractures, sprains, dislocations and muscle contusions. The injuries were often not further specified, which could be problematic when investigating for a specific case of injury.

As it is the injured person that chooses what medical records they are willing to share, the quality of details may differ on a case-by-case basis. Previous studies on insurance data also highlight how details on the injuries from medical records often is collected through consent of the VRU in insurance data [68, 19, 62, 18]. Additionally, the use of AIS means injuries may be grouped together under broader injury codes which are NFS. Certain injuries, such as forearm fracture NFS (includes wrist) may influence the outcome of frequencies for each arm region. In the grouping of the arm used in this thesis, forearm and wrist are different regions, and certain AIS codes may affect the injury grouping to a different region, compared to the preferred grouping if more details were available. Thus, leading to injuries such as forearm fracture NFS (includes wrist) being potentially differently grouped than ideal in this thesis, leading to inflating forearm counts with reduced wrist counts. A drawback with the grouping of injuries is e.g, that some of the injuries, such as forearm fracture NFS (includes wrist) may better reflect wrist injuries but is currently grouped as forearm. As such it is useful to be aware of the limitations of utilizing AIS codes, and that grouping of the injuries into other regions than the AIS based ones may be necessary.

The AIS codes and their grouping enhance comparability across injuries and data sets but may reduce the details needed for deeper injury analysis. The deeper injury analysis investigates the full body of material for each crash in medical records and accompanying documents. As such the results from our common injuries found among the VRUs with UEIs have less granular detail. To provide a good basis for future research, it is important to utilize the categorization of injuries into region of the arm for future mitigative efforts.

The figures analyzing the three types of injuries among all VRUs and then per VRU type gave an overview of the frequency distribution of injuries among the regions of the arm, as well as a relative frequency of how common each group of injuries (pain, skin and intricate) were compared to the overall number of injuries sustained in that arm region. From 4.2 it was shown that out of the injuries found to the wrist and forearm, they were often intricate, stressing the need to consider that certain regions tend to consist of more complex injuries, which would make them more important in terms of QoL loss. Shoulder, hand and elbow injuries were most common in the sample, but some of the injuries, such as skin injuries found to these regions may potentially lead to less long-term consequences, stressing the idea that the injured arm regions may have different importance depending on purpose. The intricate injuries had higher severity and thus might more frequently lead to LTI [6], which signals higher importance for mitigative efforts.

From 4.16 the tissue injured was shown, and it was evident that the intricate UEIs in the sample most often were affecting skeletal tissue, but in more complex regions of the arm with higher mobility demands such as shoulder, wrist and hand, soft tissue and joints were affected as well. According to Zeelenberg et al., VRUs suffering skeletal injuries often had higher levels of impairment [7], which could indicate that regions with high frequency of injuries to skeletal tissue might be more important to mitigate. There could be possible under representation of soft tissue injuries as they do not show on x-rays. In this thesis the injury frequencies reported were not modified in any way, but it is important to keep in mind that soft tissue injuries could be under reported.

From Tables 4.3 and 4.4 which compared injury data of the sample with single intricate

UEIs and the total exposed injuries including other part of the body; a consistent pattern has been seen within this sample. It was found that males shows higher exposure to both UEIs and to other parts of the body as opposed to females across all types of VRUs. The age group 45–65 shows the highest number of UEIs among cyclists in both the single intricate UEIs sample and total exposure, for scooters it was the 17-29 age group that had most common injuries in both samples while for pedestrian it was age group 65 and older. These trends suggest that younger age groups are more exposed depending on the mode of transport they use. The findings in this thesis on risk factors shows that age related safety interventions might be needed which can reduce injury rates among VRUs.

Lastly, the frequency distribution of injuries among the regions of the arm for each type of VRU with UEIs highlights some trends between the VRUs in terms of frequency for arm region injured. The most frequently injured region among cyclists, pedestrians and scooter riders were the shoulder for all groups. Pedestrians also suffered hand injuries as frequently as shoulder injuries. The forearm was less commonly injured among cyclists, while both pedestrians and scooter riders had lower counts of injuries to forearm and wrists. For intricate UEIs, wrist was most frequently an intricate injury among cyclists, while the shoulder had most cases of intricate injuries for both pedestrians and scooter riders. The distribution of injuries indicate a potential need for protective efforts towards shoulders for all VRUs and also wrist injuries for cyclists. The figures also showed that the injuries between scooter riders and cyclists are different, even when pre-crash descriptions were mostly similar between the two types of VRUs. This could be due to e.g., their differences in body position, speed limits, potential helmet usage or many other risk factors. The thesis does not answer why there potentially is a difference in injury patterns between the two types of VRUs, but identify indications that there are differences.

5.3 Risk factors

While most studies ([46, 24, 48, 11]) examine risk factors in terms of injury occurrence or injury severity, this study focused on identifying factors associated with injury location within the UE among VRUs who sustained UEIs. The chi-squared tests gave indications on four aspects being statistically significant different on a category level for arm region injured among all VRUs. Age, conflict situation, the direction from which the VRU are hit by the car and number of impacts to car had statistically significant test results with the chosen significance level of 0.05. The chi-squared tests for tissue only suggested number of impacts to car as statistically significantly different between category levels. The chi-squared tests for cyclists indicated conflict situation, number of impacts to car and movement of the cyclists as potential risk factors for injury location of the arm. For pedestrians speed limit was the only statistically significant variable.

The MCA for arm region, among all VRUs with single intricate UEIs did not provide any new suggestions on potential risk factors compared to previous studies. Neither did the MCA for arm region for cyclists and pedestrians respectively. MCA has been used to some success in previous studies on vehicle safety ([58, 59]) and should in theory be useful when determining risk factors. However, the results from the MCAs in this thesis suggests that the variables tested in the MCA for the cases of injuries in the data set are similar, regardless of injury sustained, as no clear deviations were shown in the MCA. This could possibly indicate a random effect to what injuries are sustained in car-VRU collisions.

The regression models had some issues with predicting the true effect of certain categorical levels, as any cells with observations of 0 among the tested variables lead to the estimated probability being 0, and the respective coefficients diverge to infinity. Whenever a cell in a given category had no observations, the regression models could not find the likelihood. Being aged 0-16 increases the likelihood of sustaining forearm injuries, and two impacts to car reduce the likeliness of sustaining wrist injuries. Apart from those category levels, the regression model in appendix A.3 only yielded estimations with p-values which were above the chosen significance level, or p-values estimated as 0, but with no true effect and instead showing significance due to no observations in the chosen category level. The results suggest that determining risk factors for sustaining injuries to a specific arm region is complex and might not be possible with the chosen methods. The methods provide some cues, but do not provide statistically significant results.

The regression models were better when at least one observation was seen in each cell, leading to the conclusion that ensuring the tested sample includes at least one observation on each category level is key to avoiding predictability issues within the regression models which this thesis ran into. It is possible to mitigate this issue by grouping the category levels further, but they need to be logical. In some situations, it does not make sense to group the category levels, and in this study, it was not possible to avoid the issue with further grouping. The same issue was apparent for regressions on tissue prediction for all VRUs with intricate UEIs, arm region prediction among cyclists with intricate UEIs and pedestrians with intricate UEIs. Models predicting risk factors for scooter riders were not attempted due to the too small sample after the filtering for intricate UEIs. With a larger sample of intricate UEIs, the methods might be more appropriate and thus with a longer time period for the sample of VRUs with UEIs, it might be possible to better determine potential risk factors.

Although previous research has identified several common risk factors for VRUs, these might not be accurate for the type of analysis conducted in this study. Janikian [46] highlight common risk factors among scooter riders such as sex, age, lack of helmet usage, alcohol and drug consumption, speed, rider distractions, traffic environment and crash locations. These aspects were all deemed to be influencing the injury rate and severity among scooter riders. In contrast, our analysis yielded only age, conflict situation, and the direction from which the VRU were hit to be potential relevant risk factors for injury location of the UE among the VRUs with UEIs. This suggests that predicting specific injury locations within the UE may be more complex and less influenced by the factors typically associated with injury risk or severity. One possible explanation is that injury location may not strongly correlate with severity, and that the data set with VRUs suffering UEIs, limits variability. To our knowledge, no existing studies have examined risk factors specifically in relation to anatomical injury location within the UE, highlighting a potential gap in the literature and an opportunity for further research.

5.4 Comparison of UEIs among VRUs

This section explores how UEIs among VRUs differ across VRU type, to understand whether injury patterns vary by VRU type and potential factors that may influence these potential differences. The comparison of UEIs among the different types of VRUs suggests that the injuries sustained by the various VRUs are somewhat similar. Despite a wide range of 70 UEIs being included in the sample, many UEIs were less common with single or few cases observed. As shown in figure 4.18 the twelve most frequent UEIs among the cyclists captured 66% of all the injury frequencies, while the remaining 34% UEIs were grouped together as other. A comparison of these twelve injuries across VRUs showed that pedestrians sustained all twelve UEIs which cyclists did, suggesting considerable overlap. However, scooter riders showed greater variation, where several of the common UEIs among cyclists had no observations. Some injuries were prevalent among all three types of VRUs such as forearm fracture NFS (includes wrist). In contrast, sprains to the wrist were mostly found among cyclists, less so among pedestrians and not at all among scooter riders. Injuries grouped as "other" made up nearly 60% of pedestrian UEIs and 50% of scooter rider UEIs, suggesting injury variation between the different types of VRUs. The twelve most common UEIs among the pedestrians and scooter riders are shown in Appendix A.2 and A.3 respectively.

In terms of injury severity, all VRU groups showed a similar distribution, with most intricate UEIs rated as AIS 2. Pedestrians had the highest proportion of AIS 2 injuries, followed by cyclists and scooter riders. Prior studies offer limited insight into UEI frequency by arm region across VRU types. Tan et al. [26] found that cyclists most often suffered injuries to the shoulder, hand, wrist, forearm, and upper arm. Martin et al., [38] reported that pedestrians primarily sustained shoulder or upper arm injuries, followed by elbow/forearm and then wrist/hand. For scooter riders, Stormann et al. [73] identified fractures to the grouped forearm/wrist/hand as most frequent, followed by shoulder and elbow. De Putter et al., [74] reported that among hospitalized UEI patients, 62% had fractures and 38% had soft tissue injuries, consistent with the predominance of fractures in intricate UEIs shown in Figure 4.16.

Comparing injuries by arm region, cyclists most often sustained injuries to the elbow, hand, and shoulder when all AIS-coded injuries were included. Pedestrians more commonly had hand, shoulder, and elbow injuries, while scooter riders sustained mostly hand, shoulder, and elbow injuries as well. When focusing only on intricate UEIs, injury patterns shifted. Cyclists most often sustained wrist, shoulder, and hand injuries. Pedestrians most often sustained shoulder, hand, and elbow injuries. Scooter riders sustained mostly shoulder, hand, and forearm injuries. Interestingly, scooter riders' injury distribution more closely resembled that of pedestrians than cyclists, despite sharing more similar crash characteristics with cyclists. These findings may reflect differences in body positioning during a crash. Scooter riders, like pedestrians, stand upright, which may influence falls, as well as how forces are distributed upon impact. These results align with findings from Han et al., [65], which emphasize the role of body positioning and kinematics in determining injury patterns among VRUs. From 4.4 it is shown that there is a high proportion of female pedestrians with shoulder injuries. The risk factor analysis did not find that sex is statistically significant to the outcome of injuries among pedestrians, and such the thesis cannot explain this apparent trend. Pedestrians were also on average older, and shoulder injuries were most common among the age group 65+ 4.3. This could suggest that the combination of older age and being female could be a risk factor for sustaining shoulder injuries, but these combinations of variables were not explored. As the risk factor did not provide results for each VRU type, due to scooter riders beeing too few, these were not available as comparisons. Thus it was not possible for us to determine why there are potential differences within UEI sustained by the different types of VRUs, instead only signaling that there may be a noticeable difference between the types of VRUs.

5.5 Future work

In future studies of UEIs sustained in car-VRU crashes based on insurance data, there could be more emphasize on the impacts to car, with modern cars more likely to include crash recorders. The crash recorders could provide video over the whole accident sequence, rather than relying on deformations and witness information. This study tried to establish whether there were any trends or connections between impact regions of the car and UEIs sustained by the VRUs, but did not provide any reliable results. There is also seemingly a lack of studies incorporating the impacts and connecting injuries to impacts on certain regions of the car, as injuries can arise in many different phases of the crash sequence. Insurance data is in particular useful for this purpose, but in this study, we were somewhat hindered by the sample, in which the focus on intricate UEIs led to less available cases to compare the various regions of impacts and available deformations. Any of the tests for risk factors would not have sufficient samples for reliable and accurate results and thus were omitted. The lack of deformations in the sample may be due to the low crash severity, and for future research on the connection between deformation and UEIs, a sample of higher severity crashes might be more suitable.

There seems to be a lack of comparative efforts for these three types of VRUs, where we believe there needs to be more studies conducted on different geographical areas to see any potential biases in the samples. Conducting research across different regions can help account for location-specific factors (e.g., traffic culture, infrastructure, or enforcement) and thereby reduce the risk of bias introduced by studying only one setting. For future studies on common UEIs among VRUs it would also be interesting to see if there are any differences between samples, such as between two time periods, or between different data sets, to highlight if there are differences over time and regions respectively, on UEIs sustained by VRUs. The results from this thesis provide some insight into UEIs suffered by VRUs based on Swedish insurance data. It could be used to represent UEIs suffered by VRUs in Sweden and regions with similar traffic characteristics. Comparison of UEIs suffered by VRUs in car-VRU accidents in Sweden to other regions might be less reliable as traffic characteristics may be different between regions.

The risk factor analysis in this thesis did not lead to reliable identification of risk factors for injury location within the UE. Future research could test combinations or interactions of typically assumed risk factors, use other methods, such as more robust regression modeling, or other novel methods to investigate risk factors. Previous studies on cyclists within specific crash conditions have been conducted previously, such as [75], and similar studies on the three types of VRUs could give better insight into specific crash conditions.

The findings in this thesis highlight some important aspects for future research. Studies based on more detailed injury classification, different data sets, and connecting the injuries to biomechanics are needed to better understand the mechanisms behind UEIs among VRUs. These efforts are vital to develop targeted injury mitigation strategies, refining vehicle safety standards and improving the safety of VRUs.

6

Conclusion

In summary this thesis shows through the initial exploration of car to vulnerable road users (VRUs) collisions that upper extremity injuries (UEIs) were commonly found among cyclists, pedestrians and scooters. The UEI sample covers mostly accidents in urban areas. The most common UEIs found among VRUs differ depending on type of VRU. For the total group of VRUs, intricate UEIs were mostly found to the shoulder, hand and wrist. Cyclists mostly suffered from intricate UEIs to the wrist, shoulder and hand. Pedestrians mostly suffered from intricate UEIs to shoulder, hand and elbow, while scooter riders mainly suffered intricate UEIs to the shoulder, hand and forearm. The categorization of UEIs to regions of the UE is important and affects the result of the study, as forearm fracture (includes wrist) NFS could be classed as wrist injuries and then the scooter riders would suffer wrist injuries instead of forearm injuries. There were indications that few impacts to the car could lead to higher frequencies of wrist injuries, but this could be connected to cyclists generally suffering wrist injuries, rather than due to the car hitting the bicycle. The patterns among the VRUs indicate that cyclists and scooters tend to have similar underlying accident statistics, but the injuries found to the arm region differs. Scooters instead are most alike pedestrians in their injury frequencies to the arm region, suggesting that body position of the VRU is more important than other aspects such as speed or movement on the road for VRUs. The risk factor analysis did yield evidence for age influencing the injury outcome to the upper extremity, but the chosen method had troubles determining the strength of effect of various aspects affecting the VRU. This difficulty could indicate a random effect of what injury is sustained to the upper extremity as a VRU in a car-VRU collision.

Bibliography

[1] A. A. Mohammed, K. Ambak, A. M. Mosa, and D. Syamsunur, "A Review of the Traffic Accidents and Related Practices Worldwide," *The Open Transportation Journal*, vol. 13, no. 1, pp. 65–83, Jun. 2019. [Online]. Available: https://opentransportationjournal.com/VOLUME/13/PAGE/65/

[2] "EU Road Safety: Towards "Vision Zero" - European Commission." [Online]. Available: https://cinea.ec.europa.eu/publications/digital-publications/eu-road-safety-towards-vision-zero_en

[3] "Nollvisionen - Transportstyrelsen." [Online]. Available: https://www.transportstyrelsen.se/sv/om-oss/statistik-och-analys/statistik-inom-vagtrafik/olycksstatistik/statistik-over-vagtrafikolyckor/nollvisionen/

[4] United Nations, "Road Safety Strategy: A Partnership for Safer Journeys," https://www.un.org/sites/un2.un.org/files/2020/09/road_safety_strategy_booklet.pdf, 2020, accessed: 2025-06-11.

[5] S. H. S. Hoseinian, M. H. Ebrahimzadeh, M. T. Peivandi, F. Bagheri, J. Hasani, S. Golshan, and A. Birjandinejad, "Injury patterns among motorcyclist trauma patients: A cross sectional study on 4200 patients," *Archives of Bone and Joint Surgery*, vol. 7, no. 4, p. 367 – 372, 2019, cited by: 18. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85077073877&partnerID=40&md5=5f0df8e12517e14fe0827ce249d9ff4c

[6] S. Malm, M. Krafft, A. Kullgren, A. Ydenius, and C. Tingvall, "Risk of permanent medical impairment (RPMI) in road traffic accidents," *Annals of Advances in Automotive Medicine. Association for the Advancement of Automotive Medicine. Annual Scientific Conference*, vol. 52, pp. 93–100, Oct. 2008.

[7] M. L. Zeelenberg, D. Den Hartog, S. Halvachizadeh, H.-C. Pape, M. H. Verhofstad, and E. M. Van Lieshout, "The impact of upper-extremity injuries on polytrauma patients at a level 1 trauma center," *Journal of Shoulder and Elbow Surgery*, vol. 31, no. 5, pp. 914–922, May 2022. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S1058274621007540

[8] M. Khayesi, "Vision Zero in the United Nations," in *The Vision Zero Handbook*. Springer, Cham, 2022, pp. 1–10. [Online]. Available: https:

//link.springer.com/rwe/10.1007/978-3-030-23176-7_23-1

[9] P. Olszewski, P. Szagała, D. Rabczenko, and A. Zielińska, "Investigating safety of vulnerable road users in selected EU countries," *Journal of Safety Research*, vol. 68, pp. 49–57, Feb. 2019. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0022437518304171

[10] S. Cook, L. Stevenson, R. Aldred, M. Kendall, and T. Cohen, "More than walking and cycling: What is 'active travel'?" *Transport Policy*, vol. 126, pp. 151–161, Sep. 2022. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0967070X22002025

[11] G. Yannis, D. Nikolaou, A. Laiou, Y. A. Stürmer, I. Buttler, and D. Jankowska-Karpa, "Vulnerable road users: Cross-cultural perspectives on performance and attitudes," *IATSS Research*, vol. 44, no. 3, pp. 220–229, Oct. 2020. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0386111220300716

[12] E. Howe, "Global Scootersharing Market Report 2018," Motoservices, Tech. Rep., 2018, accessed: 2025-06-18. [Online]. Available: https://www.m-way.ch/media/microsites/global_scootersharing_market_report_2018.pdf

[13] C. Arregui-Dalmases, F. J. Lopez-Valdes, and M. Segui-Gomez, "Pedestrian injuries in eight European countries: An analysis of hospital discharge data," *Accident Analysis & Prevention*, vol. 42, no. 4, pp. 1164–1171, Jul. 2010. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0001457510000084

[14] J. C. Stutts and W. W. Hunter, "Motor vehicle and roadway factors in pedestrian and bicyclist injuries: an examination based on emergency department data," *Accident Analysis & Prevention*, vol. 31, no. 5, pp. 505–514, Sep. 1999. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S000145759900007X

[15] Directorate-General for Mobility and Transport (European Commission) , N. Bos, L. T. Aarts, R. Welsh, P. Thomas, J. J. F. Commandeur, M. Lerner, S. Niesen, and R. J. Davidse, *Study on serious road traffic injuries in the EU*. Publications Office of the European Union, 2016. [Online]. Available: https://data.europa.eu/doi/10.2832/29647

[16] C. Simms and D. Wood, Eds., *Pedestrian and Cyclist Impact: A Biomechanical Perspective*, ser. Solid Mechanics and Its Applications. Dordrecht: Springer Netherlands, 2009, no. 166.

[17] K. Mizuno, M. Horiki, Y. Zhao, A. Yoshida, A. Wakabayashi, T. Hosokawa, Y. Tanaka, and N. Hosokawa, "Analysis of fall kinematics and injury risks in ground impact in car-pedestrian collisions using impulse," *Accident Analysis & Prevention*, vol. 176, p. 106793, Oct. 2022. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0001457522002287

[18] I. Isaksson-Hellman and J. Werneke, "Detailed description of bicycle and

passenger car collisions based on insurance claims," *Safety Science*, vol. 92, pp. 330–337, Feb. 2017. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S092575351600045X

[19] M. Lindman, S. Jonsson, L. Jakobsson, T. Karlsson, D. Gustafson, and A. Fredriksson, "Cyclists Interacting with Passenger Cars; A Study of Real World Crashes," in *Proceedings of the 2015 IRCOBI Conference on the Biomechanics of Impact*, ser. IRCOBI Conference Proceedings. Lyon, France: International Research Council on Biomechanics of Injury (IRCOBI), 2015, pp. 1–12, iRC-15-10. [Online]. Available: https://www.ircobi.org/wordpress/downloads/irc15/pdf_files/10.pdf

[20] J. Makara, S. Shen, A. Nwosu, W. Arnold, G. Smith, and M. Zhu, "A cross-sectional study of characteristics of bicyclist upper and lower extremity injuries in bicycle-vehicle crashes in Ohio, United States, 2013–2017," *BMC Public Health*, vol. 21, no. 1, p. 428, Dec. 2021. [Online]. Available: https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-021-10452-1

[21] M. Rizzi, H. Stigson, and M. Krafft, "Cyclist Injuries Leading to Permanent Medical Impairment in Sweden and the Effect of Bicycle Helmets," in *Proceedings of the 2013 IRCOBI Conference on the Biomechanics of Impact*. Dublin, Ireland: International Research Council on the Biomechanics of Injury (IRCOBI), 2013, pp. IRC–13–46, paper IRC-13-46. [Online]. Available: https://www.ircobi.org/wordpress/downloads/irc13/pdf_files/46.pdf

[22] Y. Liew, C. Wee, and J. Pek, "New peril on our roads: a retrospective study of electric scooter-related injuries," *Singapore Medical Journal*, vol. 61, no. 2, pp. 92–95, Feb. 2020. [Online]. Available: http://www.smj.org.sg/article/new-peril-our-roads-retrospective-study-electric-scooter-related-injuries

[23] A. Brenner, D. Niry, I. Blum, G. Shendler, A. Rabinowich, D. Stav, Y. Ran, A. Weiss-Meilik, and O. J. Ungar, "Comparative analysis of accident mechanisms and injury patterns of e-moped and e-scooter operators," *The American Journal of Emergency Medicine*, vol. 92, pp. 32–36, Jun. 2025. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0735675725001536

[24] Şimşek and T. Demircan, "Retrospective Study to Compare Injury Patterns and Associations in 170 Patients Following Electric Scooter and Bicycle Accidents in Turkey," *Medical Science Monitor*, vol. 31, Jan. 2025. [Online]. Available: https://www.medscimonit.com/abstract/index/idArt/947155

[25] "Abbreviated Injury Scale," May 2025, page Version ID: 1291942780. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Abbreviated_Injury_Scale&oldid=1291942780

[26] J.-H. Tan, C. C. Hong, L. Peter, P. Daniels, D. Murphy, and W. S. Kuan, "Bicycle-Related Injuries of the Upper Extremity," *The Archives of Bone and Joint Surgery*, no. Online First, Nov. 2022. [Online]. Available: https://doi.org/10.22038/abjs.2022.58487.2892

[27] Association for the Advancement of Automotive Medicine, *Abbreviated Injury Scale: 2015 Revision*, 6th ed. Chicago, IL: Association for the Advancement of Automotive Medicine, 2018.

[28] G. J. Tortora and B. H. Derrickson, *Principles of anatomy and physiology.* Nashville, TN: John Wiley & Sons, Feb. 2014.

[29] H. Veeger and F. Van Der Helm, “Shoulder function: The perfect compromise between mobility and stability,” *Journal of Biomechanics*, vol. 40, no. 10, pp. 2119–2129, Jan. 2007. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0021929006003812

[30] E. Mostafa, O. Imonugo, and M. A. Varacallo, “Anatomy, Shoulder and Upper Limb, Humerus,” in *StatPearls.* Treasure Island (FL): StatPearls Publishing, 2025. [Online]. Available: http://www.ncbi.nlm.nih.gov/books/NBK534821/

[31] N. R. Marshall, M. R. Randell, and A. J. Nicholls, “Elbow anatomy, biomechanics and clinical examination,” *Surgery (Oxford)*, vol. 43, no. 2, pp. 85–90, Feb. 2025. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0263931924002278

[32] M. N. Bajuri and M. R. Abdul Kadir, “The Wrist Joint,” in *Computational Biomechanics of the Wrist Joint.* Berlin, Heidelberg: Springer Berlin Heidelberg, 2013, pp. 1–12. [Online]. Available: https://link.springer.com/10.1007/978-3-642-31906-8_1

[33] R. Lloyd, A. Tucker, P. Archbold, and N. Eames, “The changing face of serious bicycle injuries from a UK Regional Trauma Centre,” *Journal of Science and Cycling*, vol. 6, no. 3, Jan. 2018. [Online]. Available: https://www.jsc-journal.com/index.php/JSC/article/view/358

[34] G. Jancaitis, A. R. Snyder Valier, and C. Bay, “A descriptive and comparative analysis of injuries reported in USA cycling-sanctioned competitive road cycling events,” *Injury Epidemiology*, vol. 9, no. 1, p. 22, Jul. 2022. [Online]. Available: https://injepijournal.biomedcentral.com/articles/10.1186/s40621-022-00385-8

[35] F. D. Grill, C. Roth, M. Zyskowski, A. Fichter, M. Kollmuss, H. Stimmer, H. Deppe, K.-D. Wolff, and M. Nieberler, “E-scooter-related craniomaxillofacial injuries compared with bicycle-related injuries – A retrospective study,” *Journal of Cranio-Maxillo-Facial Surgery*, vol. 50, no. 9, pp. 738–744, September 2022, epub 2022 Jun 23. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/35965223

[36] T. Campisi, A. Nikitas, M. A. Al-Rashid, A. Nikiforiadis, G. Tesoriere, and S. Basbas, “The Rise of E-scooters in Palermo: A SWOT Analysis and Travel Time Study,” in *Computational Science and Its Applications – ICCSA 2022 Workshops*, O. Gervasi, B. Murgante, S. Misra, A. M. A. C. Rocha, and C. Garau, Eds. Cham: Springer International Publishing, 2022, vol. 13380, pp. 469–483. [Online]. Available: https://link.springer.com/10.1007/978-3-031-10542-5_32

[37] J. R. Crandall, K. S. Bhalla, and N. J. Madeley, “Designing road vehicles for pedestrian protection,” *BMJ*, vol. 324, pp. 1145–1148, 2002.

[38] J.-L. Martin, A. Lardy, and B. Laumon, “Pedestrian Injury Patterns According to Car and Casualty Characteristics in France,” *Annals of Advances in Automotive Medicine*, vol. 55, pp. 137–146, 2011.

[39] M. E. Kelley, J. W. Talton, A. O. Usoro, A. A. Weaver, E. R. Barnard, and A. N. Miller, “Upper Extremity Injury Patterns in Side-Impact Crashes,” in *Proceedings of the IRCOBI Conference*, 2017, pp. 104–112.

[40] F. X. McGuigan, “Skeletal Trauma,” in *Essentials of Orthopedic Surgery*, S. W. Wiesel and J. N. Delahay, Eds. New York, NY: Springer New York, 2011, pp. 35–73. [Online]. Available: http://link.springer.com/10.1007/978-1-4419-1389-0_2

[41] J. R. Sheen, A. Mabrouk, and V. V. Garla, “Fracture Healing Overview,” in *StatPearls*. Treasure Island (FL): StatPearls Publishing, 2025. [Online]. Available: http://www.ncbi.nlm.nih.gov/books/NBK551678/

[42] J. N. Delahay and S. T. Sauer, “Skeletal Trauma,” in *Essentials of Orthopedic Surgery*, S. W. Wiesel and J. N. Delahay, Eds. New York, NY: Springer New York, 2007, pp. 40–83. [Online]. Available: http://link.springer.com/10.1007/978-0-387-38328-6_2

[43] G. Rubin, K. Peleg, A. Givon, and N. Rozen, “Upper extremity fractures among hospitalized pediatric road traffic accident victims,” *The American Journal of Emergency Medicine*, vol. 33, no. 5, pp. 667–670, May 2015. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0735675715000790

[44] G. Nimrod, Rubin, K. Peleg, A. Givon, and Rozen, “Upper extremity fractures among hospitalized road traffic accident adults,” *The American Journal of Emergency Medicine*, vol. 33, no. 2, pp. 250–253, Feb. 2015. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0735675714008833

[45] A. B. Brownson, P. V. Fagan, S. Dickson, and I. D. Civil, “Electric scooter injuries at Auckland City Hospital,” *The New Zealand Medical Journal*, vol. 132, no. 1505, pp. 62–72, Nov 2019. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/31697664/

[46] G. S. Janikian, J. K. Caird, B. Hagel, and G. Reay, “A scoping review of E-scooter safety: Delightful urban slalom or injury epidemic?” *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 101, pp. 33–58, Feb. 2024. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S1369847823002802

[47] E. D. Athanaselis, T. Mylonas, E. Konstantinou, M. Hantes, T. Karachalios, and S. Varitimidis, “The long-term functional outcome of the mangled upper extremity intricate management. A single center experience,” *Journal of Hand and Microsurgery*, vol. 17, no. 1, p. 100167, Jan. 2025. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0974322724005295

[48] A. Spota, S. Granieri, L. Ferrario, B. Zamburlini, S. Frassini, E. Reitano, S. P. Cioffi, M. Altomare, R. Bini, F. Virdis, O. Chiara, and S. Cimbanassi, "Injury Patterns of Electric-Scooter Related Trauma: A Systematic Review With Proportion Meta-Analysis," *The American Surgeon*, vol. 90, no. 6, pp. 1702–1713, June 2024, epub 2024 Mar 26. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/38532248

[49] S. J. Fernstad and J. Johansson, "A task based performance evaluation of visualization approaches for categorical data analysis," in *2011 15th International Conference on Information Visualisation*, 2011, pp. 80–89.

[50] M. L. McHugh, "The Chi-Square Test of Independence," *Biochemia Medica*, vol. 23, no. 2, pp. 143–149, 2013. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/23894860

[51] B. S. Everitt, *The Analysis of Contingency Tables*, 2nd ed., ser. Monographs on Statistics and Applied Probability. London; New York; Melbourne; Madras: Chapman & Hall, 1992, vol. 45.

[52] E. J. Beh and R. Lombardo, *Correspondence Analysis: Theory, Practice and New Strategies*, ser. Wiley Series in Probability and Statistics. Chichester, UK: John Wiley & Sons, 2014, vol. 45. [Online]. Available: https://www.wiley.com/en-us/Correspondence%2BAnalysis%3A%2BTheory%2C%2BPractice%2Band%2BNew%2BStrategies-p-9781118762875

[53] A. C. A. Hope, "A simplified monte carlo significance test procedure," *J. R. Stat. Soc. Series B Stat. Methodol.*, vol. 30, no. 3, pp. 582–598, Sep. 1968.

[54] A. Agresti, "A Survey of Exact Inference for Contingency Tables," *Statistical Science*, vol. 7, no. 1, pp. 131–153, 1992, includes discussion of simulation-based approximate p-values.

[55] M. L. McHugh, "The chi-square test of independence," *Biochem. Med. (Zagreb)*, vol. 23, no. 2, pp. 143–149, 2013.

[56] S. Lê, J. Josse, and F. Husson, "FactoMineR: AnRPackage for multivariate analysis," *J. Stat. Softw.*, vol. 25, no. 1, 2008.

[57] B. Le Roux and H. Rouanet, *Multiple Correspondence Analysis*, ser. Quantitative Applications in the Social Sciences. Thousand Oaks, CA: SAGE Publications, Inc., 2010, vol. 163, part of the "Little Green Book" series.

[58] P. Natarajan, S. K. Sivasankaran, and V. Balasubramanian, "Identification of contributing factors in vehicle pedestrian crashes in chennai using multiple correspondence analysis," *Transp. Res. Procedia*, vol. 48, pp. 3486–3495, 2019.

[59] S. Das and X. Sun, "Factor association with multiple correspondence analysis in vehicle–pedestrian crashes," *Transp. Res. Rec.*, vol. 2519, no. 1, pp. 95–103, Jan. 2015.

[60] L. Fahrmeir, T. Kneib, S. Lang, and B. Marx, *Regression: Models, Methods and Applications*, 1st ed. Berlin, Heidelberg: Springer, 2015, includes parametric and semiparametric regression methods. [Online]. Available: https://doi.org/10.1007/978-3-642-34333-9

[61] "Trafikförsäkring - Transportstyrelsen." [Online]. Available: https://www.transportstyrelsen.se/sv/vagtrafik/fordon/aga-kopa-eller-salja-fordon/trafikforsakring/

[62] I. Isaksson-Hellman, "A study of bicycle and passenger car collisions based on insurance claims data," *Annals of Advances in Automotive Medicine. Association for the Advancement of Automotive Medicine. Annual Scientific Conference*, vol. 56, pp. 3–12, 2012, if Insurance Company P&C Ltd.

[63] "J224_202205: Collision Deformation Classification - SAE International." [Online]. Available: https://www.sae.org/standards/content/j224_202205/

[64] B. van Gils, *Data in Context: Models as Enablers for Managing and Using Data*, ser. Enterprise Engineering Series. Springer, 2023. [Online]. Available: https://doi.org/10.1007/978-3-031-35539-4

[65] Y. Han, Q. Li, W. He, F. Wan, B. Wang, and K. Mizuno, "Analysis of Vulnerable Road User Kinematics Before/During/After Vehicle Collisions Based on Video Records," in *Proceedings of the IRCOBI Conference.* Antwerp, Belgium: International Research Council on the Biomechanics of Injury (IRCOBI), 2017, pp. Paper No. IRC–17–26, iRCOBI Conference 2017. [Online]. Available: https://www.ircobi.org/wordpress/downloads/irc17/pdf_files/26.pdf

[66] L. X. Pei, H. Chan, L. K. Shum, L. Jae, J. A. Staples, J. A. Taylor, D. R. Harris, and J. R. Brubacher, "Demographic and Clinical Profile of an Inception Cohort of Road Trauma Survivors," *BMC Public Health*, vol. 23, no. 1, p. 1534, 2023, published online 2023-08-12. [Online]. Available: https://doi.org/10.1186/s12889-023-16487-w

[67] A. Miclescu, A. Straatmann, P. Gkatziani, S. Butler, R. Karlsten, and T. Gordh, "Chronic neuropathic pain after traumatic peripheral nerve injuries in the upper extremity: prevalence, demographic and surgical determinants, impact on health and on pain medication," *Scandinavian Journal of Pain*, vol. 20, no. 1, pp. 95–108, 2019, published: December 18, 2019. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/31536038

[68] M. Lindman, L. Jakobsson, and S. Jonsson, "Pedestrians Interacting with a Passenger Car: A Study of Real World Accidents," in *Proceedings of the IRCOBI Conference.* Kraków, Poland: International Research Council on the Biomechanics of Injury (IRCOBI), 2011, pp. Paper No. IRC–11–61, iRCOBI Conference 2011. [Online]. Available: https://www.ircobi.org/wordpress/downloads/irc11/pdf_files/61.pdf

[69] S. Bahrololoom, W. Young, and D. Logan, "Modelling Injury Severity of Bicyclists

in Bicycle-Car Crashes at Intersections," *Accident Analysis Prevention*, vol. 144, p. 105597, 2020. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/32559658

[70] D. M. Mothershed, R. Lugner, S. Afraj, G. J. Sequeira, K. Schneider, T. Brandmeier, and V. Soloiu, "Comparison and Evaluation of Algorithms for LiDAR-Based Contour Estimation in Integrated Vehicle Safety," *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 5, p. 3925 – 3942, 2022, cited by: 2. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85099082935&doi=10.1109%2fTITS.2020.3044753&partnerID=40&md5=613849c0385ed9f284dfa677898b78a4

[71] K. R. Vaghela, D. Velazquez-Pimentel, A. K. Ahluwalia, A. Choraria, and A. Hunter, "Distal Radius Fractures: An Evidence-Based Approach to Assessment and Management," *British Journal of Hospital Medicine (London)*, vol. 81, no. 6, pp. 1–8, 2020, published online June 12, 2020. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/32589543

[72] M. Gabl, R. Arora, and G. Schmidle, "Biomechanics of Distal Radius Fractures: Basic Principles and GPS Treatment Strategy for Locking Plate Osteosynthesis," *Der Unfallchirurg*, vol. 119, no. 9, pp. 715–722, 2016, published in German; original title: Biomechanik distaler Radiusfrakturen. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/27445000

[73] P. Störmann, A. Klug, C. Nau, R. D. Verboket, M. Leiblein, D. Müller, U. Schweigkofler, R. Hoffmann, I. Marzi, and T. Lustenberger, "Characteristics and Injury Patterns in Electric-Scooter Related Accidents—A Prospective Two-Center Report from Germany," *Journal of Clinical Medicine*, vol. 9, no. 5, p. 1569, 2020. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/32455862/

[74] C. de Putter, R. Selles, J. Haagsma, S. Polinder, M. Panneman, S. Hovius, A. Burdorf, and E. van Beeck, "Health-related quality of life after upper extremity injuries and predictors for suboptimal outcome," *Injury*, vol. 45, no. 11, pp. 1752–1758, 2014. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/25150751/

[75] P. Díaz Fernández, M. Lindman, I. Isaksson-Hellman, H. Jeppsson, and J. Kovaceva, "Description of same-direction car-to-bicycle crash scenarios using real-world data from Sweden, Germany, and a global crash database," *Accident Analysis Prevention*, vol. 168, p. 106587, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0001457522000239

A

Appendix 1

Table A.1: Frequency table of MCA variables for each type of VRU

Variable	Category	Cyclist	Pedestrian	Scooter	Other
Age	0-16	9	4	4	0
	17-29	14	7	5	0
	30-44	20	6	2	1
	45-65	39	10	2	2
	65+	15	21	0	1
Sex	Female	38	31	4	1
	Male	59	17	9	3
Conflict situation		2	2	0	0
	Backing	0	11	0	0
	Crossing	52	20	9	2
	Door way	3	0	0	0
	Same direction	5	4	0	0
	Turning left	16	4	2	1
	Turning right	19	7	2	1
Service weight	<1199	7	4	0	0
	1200–1499	26	7	5	0
	1500–1999	38	23	2	2
	>2000	14	7	2	1
	Unknown	12	7	4	1
Crossing	No	21	30	5	0
	Yes	76	18	8	4
Speed limit	30	18	12	3	1

Continued on next page

Variable	Category	Cyclist	Pedestrian	Scooter	Other
	40	41	9	6	1
	50	21	15	1	2
	60	4	3	0	0
	70+	5	2	0	0
	Unknown	8	7	3	0
Crash Type	Back	2	3	0	0
	Front	30	5	2	1
	Side	54	20	9	2
	Unknown	11	20	2	1
HitVRU	Back	1	3	0	0
	Frontal	25	3	2	1
	Left	25	5	0	1
	Right	24	9	7	1
	Unknown	22	28	4	1
Ground	no	19	16	3	0
	yes	78	32	10	4
N other	1	88	46	13	4
	2+	9	2	0	0
N car	1	58	39	8	2
	2	17	5	2	1
	3+	22	4	3	1
N deformations	0	59	41	7	3
	1	10	2	3	0
	2	9	3	1	1
	3+	19	2	2	0
Position VRU	Other	0	1	0	0
	Bent	9	1	0	0
	Unknown	12	5	0	0
	Upright	76	41	13	4
Movement of VRU	Other	0	2	0	1
	Cycling ’Slow’	6	0	0	1
	Cycling ’fast’	18	0	4	1

Continued on next page

Variable	Category	Cyclist	Pedestrian	Scooter	Other
	Cyklande, unspecified speed	72	0	9	1
	Walking	0	29	0	0
	Jogging, Ran	0	5	0	0
	Unknown	1	7	0	0
	Standing	0	5	0	0
In. speed car km/h	0	8	1	0	0
	5+	10	1	0	0
	10	5	1	1	1
	15+	1	1	0	0
	20+	3	2	3	0
	30+	6	6	1	0
	50+	1	3	0	0
	Unknown	63	33	8	3
Kinematic VRU	Other	4	2	0	0
	Cycle fall, VRU thrown	13	0	1	1
	Catapulted	18	9	2	0
	Knocked	30	23	5	1
	Unknown	18	8	0	1
	Scooped up on car	14	6	5	1
MAIS	1	21	2	5	1
	2	70	38	8	3
	3	5	7	0	0
	4	1	1	0	0
Severity	1	27	8	6	1
	2	70	39	7	3
	3	0	1	0	0
Side of arm	00	3	2	0	0
	Left	44	19	7	2
	Right	50	27	6	2
ISS	<=5	71	29	11	4
	5<=10	17	13	1	0
	10+	9	6	1	0
Impact to cycle		4	46	0	1

Continued on next page

Variable	Category	Cyclist	Pedestrian	Scooter	Other
	Other	2	0	1	0
	Yes, unknown where	5	0	0	0
	No	3	0	0	2
	Unknown	83	2	12	1
Impact to other	No	96	46	13	4
	Bus shelter	0	1	0	0
	cycle in front	1	0	0	0
	Trailer on car	0	1	0	0

Table A.2: Frequency table for VRUs with intricate UEIs

	Cyclist (n=111)		Pedestrian (n=62)		Scooter (n=15)		Other (n=4)		Total (n=192)	
Variable	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Age										
0–16	10	9.01	5	8.06	5	33.33	0	0.00	20	10.42
17–29	15	13.51	10	16.13	6	40.00	0	0.00	31	16.15
30–44	23	20.72	6	9.68	2	13.33	1	25.00	32	16.67
45–64	44	39.64	13	20.97	2	13.33	2	50.00	61	31.77
65+	19	17.12	28	45.16	0	0.00	1	25.00	48	25.00
Sex										
Male	63	56.76	20	32.26	11	73.33	3	75.00	97	50.52
Female	48	43.24	42	67.74	4	26.67	1	25.00	95	49.48
Conflict situation										
Reversing	0	0.00	12	19.35	1	6.67	0	0.00	13	6.77
Straight Crossing Path	61	54.95	27	43.55	10	66.67	2	50.00	100	52.08
Dooring	4	3.60	0	0.00	0	0.00	0	0.00	4	2.08
Opposite direction	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Same direction	5	4.50	4	6.45	0	0.00	0	0.00	9	4.69
Turning left	18	16.22	7	11.29	2	13.33	1	25.00	28	14.58
Turning right	21	18.92	10	16.13	2	13.33	1	25.00	34	17.71
Unknown	2	1.80	2	3.23	0	0.00	0	0.00	4	2.08
Service weight of car										
<1199	8	7.21	5	8.06	0	0.00	0	0.00	13	6.77
1200–1499	28	25.23	9	14.52	5	33.33	0	0.00	42	21.88
1500–1999	47	42.34	28	45.16	4	26.67	2	50.00	81	42.19
>2000	15	13.51	10	16.13	2	13.33	1	25.00	28	14.58
Unknown	13	11.71	10	16.13	4	26.67	1	25.00	28	14.58
Traffic environment										
Urban	96	86.49	43	69.35	15	100.00	4	100.00	158	82.29
Rural	12	10.81	6	9.68	0	0.00	0	0.00	18	9.38
Unknown	3	2.70	13	20.97	0	0.00	0	0.00	16	8.33
Crossing										
Roundabout	13	11.71	5	8.06	3	20.00	0	0.00	21	10.94
Intersection	71	63.96	22	35.48	6	40.00	4	100.00	103	53.65
No	24	21.62	34	54.84	6	40.00	0	0.00	64	33.33
Unknown	3	2.70	1	1.61	0	0.00	0	0.00	4	2.08
Speed limit										
30 km/h	21	18.92	16	25.81	5	33.33	1	25.00	43	22.40
40 km/h	47	42.34	12	19.35	6	40.00	1	25.00	66	34.38
50 km/h	23	20.72	19	30.65	1	6.67	2	50.00	45	23.44
60 km/h	4	3.60	4	6.45	0	0.00	0	0.00	8	4.17
70 km/h	5	4.50	0	0.00	0	0.00	0	0.00	5	2.60
80+ km/h	2	1.80	3	4.84	0	0.00	0	0.00	5	2.60
Unknown	9	8.11	8	12.90	3	20.00	0	0.00	20	10.42
Crash type										
Back	2	1.80	3	4.84	0	0.00	0	0.00	5	2.60
Front	34	30.63	6	9.68	3	20.00	1	25.00	44	22.92
Side	63	56.76	31	50.00	9	60.00	2	50.00	105	54.69
Unknown	12	10.81	22	35.48	3	20.00	1	25.00	38	19.79
Hit VRU										
Back	1	0.90	3	4.84	0	0.00	0	0.00	4	2.08
Frontal	29	26.13	3	4.84	3	20.00	1	25.00	36	18.75
Left	27	24.32	8	12.90	0	0.00	1	25.00	36	18.75
Right	29	26.13	12	19.35	7	46.67	1	25.00	49	25.52
Unknown	25	22.52	36	58.06	5	33.33	1	25.00	67	34.90
Ground										
Yes	93	83.78	45	72.58	11	73.33	4	100.00	153	79.69
No	18	16.2	17	27.42	4	26.67	0	0.00	39	20.31
N other										
1	100	90.09	60	96.77	15	100.00	4	100.00	179	93.23
2+	11	9.91	2	3.23	0	0.00	0	0.00	13	6.77
N car										
1	67	60.36	50	80.65	9	60.00	2	50.00	128	66.67
2	18	16.22	6	9.68	3	20.00	1	25.00	28	14.58
3+	26	23.42	6	9.68	3	20.00	1	25.00	36	18.75
Number of deformations										
0	67	60.36	50	80.65	8	53.33	3	75.00	128	66.67
1	12	10.81	5	8.06	3	20.00	1	25.00	21	10.94
2	10	9.01	4	6.45	2	13.33	0	0.00	16	8.33
3+	22	19.82	3	4.84	2	13.33	0	0.00	27	14.06

Table A.3: Regression for Equation (3.1) with hand as reference level for arm region, age reference set to 45-64, the conflict situation reference is Turning Left, Hit VRU reference as front and number of impacts to car as 1.

Arm Region	Variable	Estimate	Std. Error	Z-value	P-value
Elbow	(Intercept)	-1.875	1.265	-1.482	0.138
Elbow	Age 0-16	-0.196	1.358	-0.144	0.885
Elbow	Age 17-29	0.004	0.967	0.005	0.996
Elbow	Age 30-44	-0.752	0.914	-0.822	0.411
Elbow	Age 65+	0.393	0.945	0.416	0.677
Elbow	Backing	1.070	1.842	0.581	0.561
Elbow	Crossing	1.056	1.013	1.042	0.297
Elbow	Door way	-15.069	0.000	$-2{,}1\times10^{6}$	0.000
Elbow	Same direction	27.241	0.816	33.402	0.000
Elbow	Turning right	-0.510	1.210	-0.422	0.673
Elbow	Hit VRU Back	0.021	2.177	0.010	0.992
Elbow	Hit VRU Left	1.445	1.037	1.393	0.164
Elbow	Hit VRU Right	1.139	1.144	0.996	0.319
Elbow	Hit VRU Unknown	0.595	1.093	0.544	0.586
Elbow	Impact Car 2	0.491	0.852	0.576	0.565
Elbow	Impact Car 3+	-1.101	1.003	-1.098	0.272
Forearm	(Intercept)	-3.007	1.702	-1.767	0.077
Forearm	Age 0-16	3.175	1.332	2.383	0.017
Forearm	Age 17-29	1.029	1.315	0.782	0.434
Forearm	Age 30-44	-21.552	0.000	$-1{,}0\times10^{7}$	0.000
Forearm	Age 65+	1.029	1.248	0.824	0.410
Forearm	Backing	0.632	1.773	0.356	0.722
Forearm	Crossing	-0.590	1.078	-0.547	0.584
Forearm	Door way	-10.833	906.393	-0.012	0.990
Forearm	Same direction	-7.513	—	—	—
Forearm	Turning right	-32.665	—	—	—
Forearm	Hit VRU Back	-13.005	0.001	-1.9×10^{5}	0.000
Forearm	Hit VRU Left	2.128	1.546	1.376	0.169
Forearm	Hit VRU Right	2.618	1.619	1.618	0.106
Forearm	Hit VRU Unknown	2.589	1.511	1.714	0.087
Forearm	Impact Car 2	1.315	1.055	1.246	0.213
Forearm	Impact Car 3+	-0.994	1.392	-0.714	0.475
Shoulder	(Intercept)	-0.281	0.880	-0.319	0.750
Shoulder	Age 0-16	-1.771	1.286	-1.377	0.168
Shoulder	Age 17-29	-0.407	0.784	-0.519	0.603
Shoulder	Age 30-44	-0.902	0.723	-1.247	0.213
Shoulder	Age 65+	0.012	0.757	0.016	0.987
Shoulder	Backing	1.426	1.433	0.995	0.320
Shoulder	Crossing	0.407	0.752	0.541	0.588
Shoulder	Door way	0.342	1.634	0.209	0.834
Shoulder	Same direction	24.939	0.776	32.153	0.000

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Table A.3 – continued from previous page

Arm Region	Variable	Estimate	Std. Error	Z-value	P-value
Shoulder	Turning right	-0.535	0.835	-0.641	0.522
Shoulder	Hit VRU Back	-0.832	1.825	-0.456	0.649
Shoulder	Hit VRU Left	-0.344	0.814	-0.422	0.673
Shoulder	Hit VRU Right	1.424	0.781	1.825	0.068
Shoulder	Hit VRU Unknown	0.733	0.765	0.959	0.338
Shoulder	Impact Car 2	0.499	0.733	0.681	0.496
Shoulder	Impact Car 3+	0.636	0.622	1.022	0.307
Wrist	(Intercept)	1.555	0.881	1.765	0.078
Wrist	Age 0-16	-0.271	0.973	-0.279	0.781
Wrist	Age 17-29	-0.494	0.836	-0.591	0.555
Wrist	Age 30-44	-0.739	0.724	-1.021	0.307
Wrist	Age 65+	-1.323	0.869	-1.522	0.128
Wrist	Backing	0.986	1.633	0.604	0.546
Wrist	Crossing	0.226	0.795	0.285	0.776
Wrist	Door way	-0.660	1.678	-0.393	0.694
Wrist	Same direction	24.051	0.943	25.495	0.000
Wrist	Turning right	-0.535	0.868	-0.616	0.538
Wrist	Hit VRU Back	-30.797	0.000	-5.5×10^9	0.000
Wrist	Hit VRU Left	-1.260	0.806	-1.563	0.118
Wrist	Hit VRU Right	-0.243	0.776	-0.314	0.754
Wrist	Hit VRU Unknown	-0.791	0.768	-1.030	0.303
Wrist	Impact Car 2	-1.964	0.953	-2.060	0.039
Wrist	Impact Car 3+	-1.363	0.741	-1.840	0.066

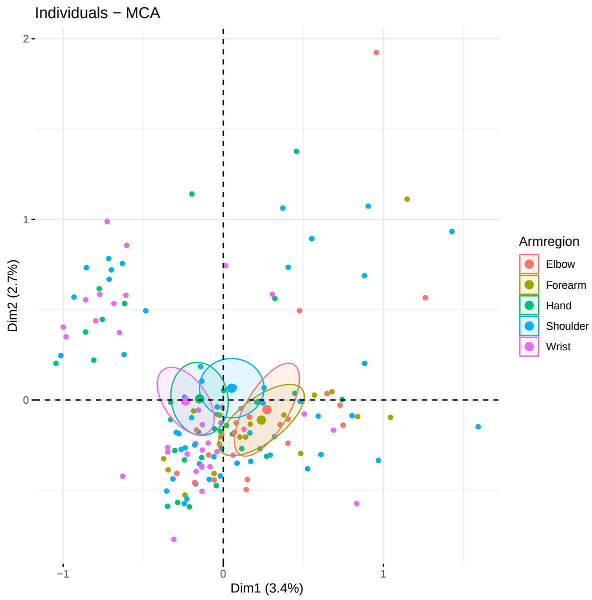

Figure A.1: MCA for arm region among all VRUs with sinlge intricate UEIs

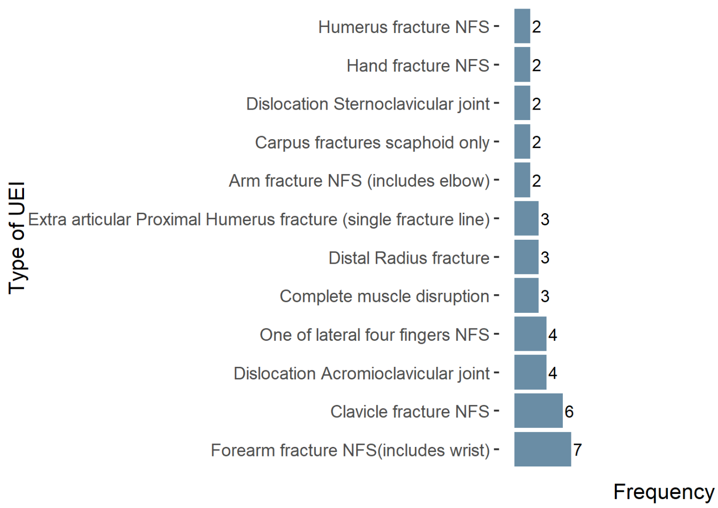

Figure A.2: Overview of the twelve most common UEIs among pedestrians

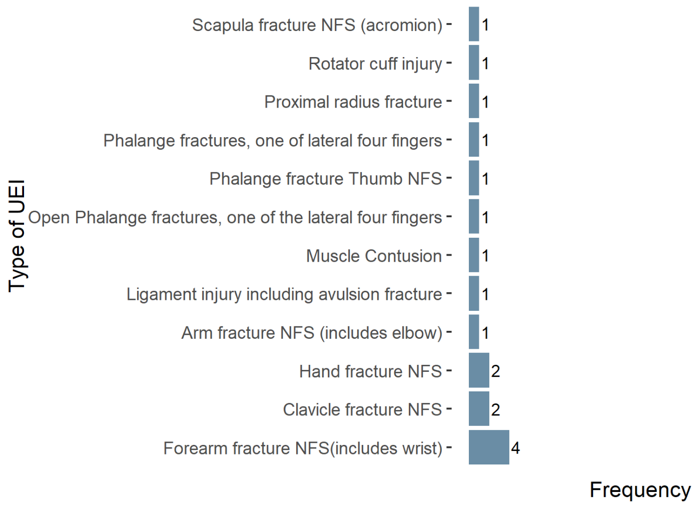

Figure A.3: Overview of the twelve most common UEIs among scooter riders

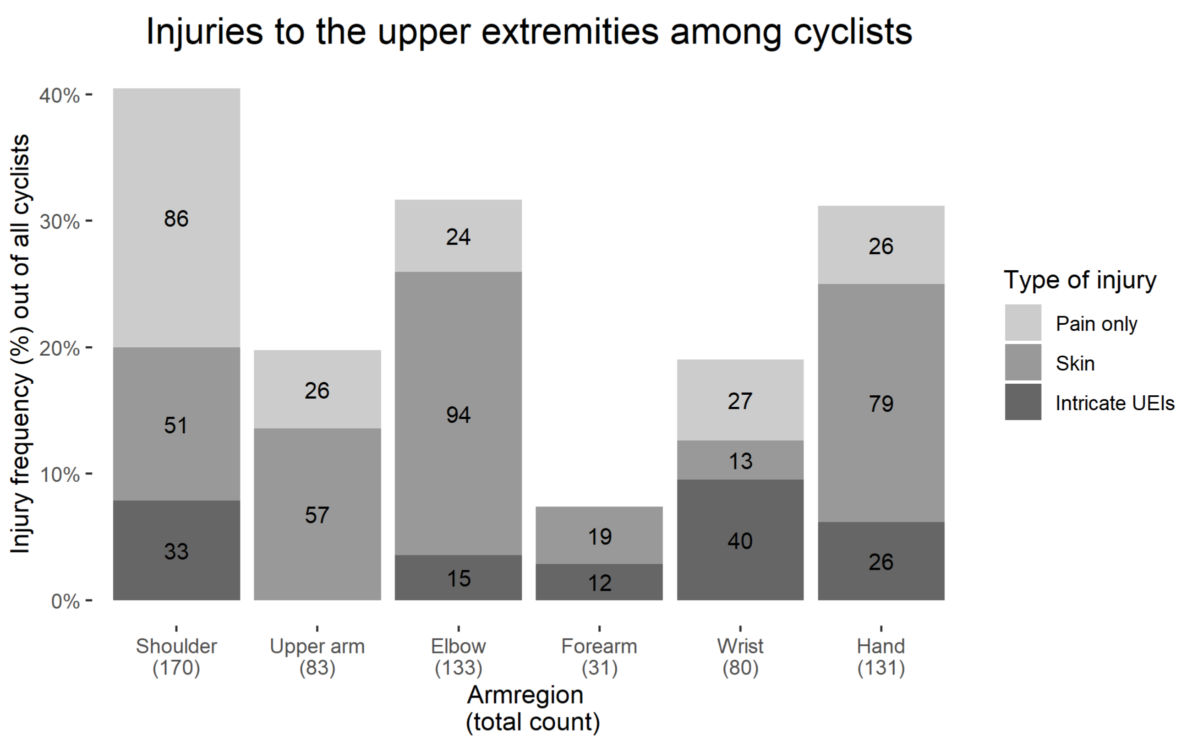

Figure A.4: Frequency of each injury type found in the arm region among cyclists for all UEIs.

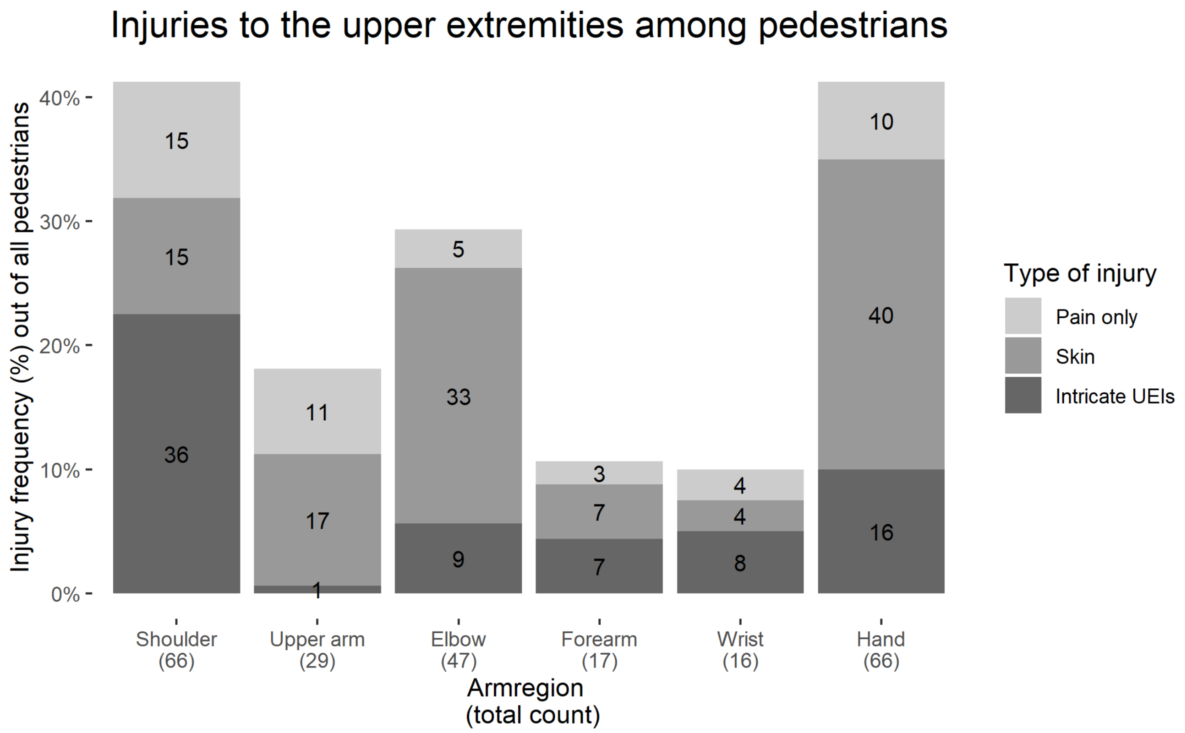

Figure A.5: Frequency of each injury type found in the arm region among pedestrians for all UEIs .

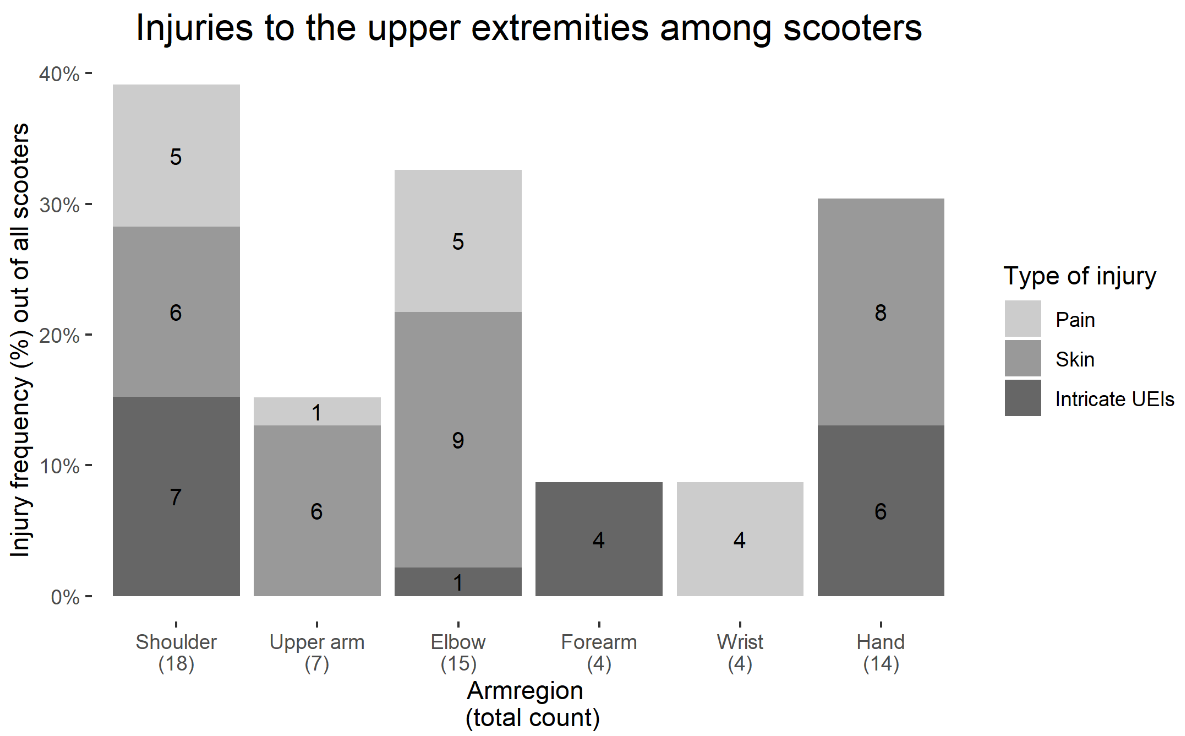

Figure A.6: Frequency of each injury type found in the arm region among scooter riders for all UEIs.

Department of Mechanics and Maritime Sciences
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

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