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Fall- and collision-related injuries among pedestrians in road traffic environment – A Swedish national register-based study

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ABSTRACT

Objective: To investigate the burden of pedestrian injuries, including pedestrian fall injuries (PFI), compared to other transport-related injuries in Sweden and document their characteristics in terms of demographics, causes, type of injuries, and severity level with a focus on long-term consequences. *Methods:* Data were retrieved from the national Swedish Traffic Accident Data Acquisition register. A total of 361,531 fatalities and injuries were reported by emergency hospitals during 2010–2019, of which 127,804 were pedestrians (35%). We assessed the magnitude of PFIs and conducted comparative analyses to assess differences compared to other types of road users regarding sex, age, severity level, injury circumstances, hospital care, causes of accidents, and type of injuries. *Results:* Pedestrians were the second largest group of traffic-related deaths in Sweden after car occupants and accounted for just over a quarter of all fatal accidents in the road traffic environment. Of the total number of pedestrian fatalities, three out of four have been in collision accidents and the others in fall-related accidents. In terms of injuries, pedestrians were the largest group among all road users, regardless of the type of accident. PFIs accounted for a third of all injuries in the road traffic environment and nearly half of all injuries resulting in permanent medical impairment (i.e., 2.2 times more long-term consequences among PFIs compared to injured car occupants). Females (particularly middle-aged and older) and older adults were overrepresented, and most PFIs occurred on urban and municipal roads. The causes were often related to maintenance (e.g., slippery surfaces such as ice, snow, leaves or gravel together with uneven pavements and roads are the cause three out of four of PFIs). Among collision injuries, the representation was almost equal for sex and age. *Conclusions:* Injuries and fatalities among pedestrians are a considerable issue in the road traffic environment in Sweden. Contrary to other traffic groups, the incidence has not decreased over time, meaning that this issue must be met with specific measures and address the specific risk factors they are associated with. *Practical Application:* Including fall accidents in the definition of traffic accidents increases the chances of getting better information about the accidents and taking preventive measures.

1. Introduction

Although the rates of road traffic fatalities and injuries have declined over the past decade in some continents, the problem continues to increase from a global perspective. Annually, approximately 1.35 million people die and up to 50 million people are injured as a result of a traffic accident in the world (WHO, 2018). Road traffic accidents also account for considerable socio-economic costs in terms of medical expenses and lost production, with costs estimated at 0.4–4.1% of Gross Domestic Product (GDP) in European countries (IRTAD, 2019; Wijnen et al., 2019). As such and as a complement to the UN Sustainable Development Goals (SDG) 3.6 in Agenda 2030, a newly adopted resolution from 2020 UN General Assembly, proclaims a new goal of reducing fatalities and injuries by at least 50% between 2021–2030 (UN, 2020a). In Sweden, the ambition has been greater following the 1997 adoption of a Vision Zero policy regarding fatalities and serious injuries in the road traffic environment. However, while the strategy may

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have contributed to a reduction in the number of fatalities among motor-vehicle accidents (Belin et al., 2012; IRTAD, 2019; Tingvall & Haworth, 1999), the same development cannot be observed among *Vulnerable Road Users (VRU)* (IRTAD, 2019; Värnild et al., 2019; Weijermars et al., 2018; WHO, 2018).

VRUs, as defined by the Intelligent Transport Systems Directive (EU, 2010), have recently been recognized by the World Health Organization (WHO) as a particularly important risk group, as they account for more than half of all fatalities in road traffic worldwide (WHO, 2018). Despite being considered to be one of the prioritized groups in the SDGs of Agenda 2030, some incidents are neglected according to the current general definition of traffic accidents (that requires that at least one vehicle in motion on public roads is included in the incident; Eurostat, 2019). As such, incidents where no other road user was involved and that lead to injury or death are excluded, for example pedestrian falls in the road traffic environment.

Despite not being included in some definitions, there are indications that pedestrian fall injuries (PFIs) account for a considerable number of injuries and fatalities that occur in the road traffic environment (Eurostat, 2019; Methorst et al., 2017; Naci et al., 2009). In Sweden, the authority appointed to lead the road safety work has chosen to include single fall injuries that occur in road environment into the national target adopted by the government. The target is to halve the fatalities and reduce injuries with long-term consequences by at least 25% (Swedish Government, 2020).

To properly prioritize road safety measures, it is important to understand the magnitude and characteristics of the problem. To our knowledge, existing studies on PFIs focus on limited samples in terms of age and location, only study outdoor falls without explicitly focusing on the traffic environment, or do not contextualize PFIs compared to injury events for other types of road users (Björnstig et al., 1997; Duckham, Procter-Gray, & Hannan, 2013; Elvik & Bjørnskau, 2019; Gyllencreutz et al., 2015; Lai et al., 2011; Li et al., 2014; Morency et al., 2012; Naumann et al., 2011; Oxley et al., 2018). Importantly, there are also no studies that describe the outcomes of pedestrian falls in terms of the risk of long-term consequenes (i.e., impairment risk). Given that most PFIs are nonfatal, injury measures based on impairment risk are important complements to fatal injury risk.

The aim of this paper is therefore to investigate and contextualize the burden of pedestrian injuries with fatal or long-term consequences from a Swedish perspective. We address limitations from previous work by using national register data and a contextually relevant definition of long-term injuries according to the national targets in Sweden (to halve the fatalities and reduce serious injuries with long-term consequences by at least 25% (Swedish Government, 2020)). Specifically, we document the magnitude and characteristics of pedestrian injuries, including falls, in terms of demographics, trends, causes, type of injuries, and severity level compared to other types of road users to provide a better basis for priority setting.

2. Materials and methods

2.1. Data collection

2.1.1. STRADA – A national road traffic injury register

This study is based on register data derived from the *Swedish Traffic Accident Data Acquisition* (STRADA), a national information system containing data on traffic accidents and injuries occurring in the Swedish road transport system (for a more comprehensive description of STRADA, see Howard & Linder, 2014)). STRADA contains information regarding accidents based on two separate sources; traffic accident reports provided by the police and medical reports provided by the emergency hospitals. The information contained in the register is pseudonymized (Transportstyrelsen, 2020). This study focuses on hospital data, as this is the only source that includes both the magnitude and severity of injuries. An alternative data source could have been the Swedish National Patient Register that is generally regarded as both valid and reliable (Ludvigsson et al., 2011). However, it has some limitations such as an inability to distinguish between indoor and outdoor cases. Also, there is rarely information about whether the incident occurred in a traffic environment.

Our study focuses on the period 2010 to 2019. Data were limited to this period due to some problems in undercoverage prior to 2010. Fig. 1 shows a flow chart of the number of registered incidents in STRADA, in relation to type of road user, during the time-period. In total, there were 640,578 registered incidents during the 10-year period. Of these, 11,886 were excluded as the incidents occurred outside the road traffic environment (in STRADA, the road traffic environment is defined as a street/road, pedestrian and cycle path, sidewalk, separate car park, market square, public transport stop, or petrol station). About one fifth (141,167) of the incidents involved no injuries or an unknown degree of injury. These were also removed. As such, the total number of fatalities and injuries in the road traffic environment between 2010 and 2019 was 487,525. Of these, 361,531 road traffic injuries or fatalities were reported by the emergency hospitals and hence included in our study because PFI is not reported at all by the police. In terms of pedestrians, 125,283 incidents were registered (after excluding road users who had traveled on skateboards, scooters, inline skates, all types of wheelchairs, or horses).

2.1.2. Coverage

The number of STRADA-affiliated hospitals gradually increased during the study period from 56 of 71 hospitals in 2010 (corresponding to 82% of the population of the catchment area with 9,340,682 inhabitants) to 73 of 74 hospitals in 2015 (corresponding to 97% of the population of the catchment area of 9,851,017 inhabitants). As of 2016, all emergency hospitals in Sweden that have an emergency department and have either an operation or an orthopedic department report to the register. Since 2018, emergency hospitals no longer report deaths to STRADA and therefore we have limited the analysis of deaths to the period 2010–2017.

2.1.3. Measurements

In STRADA, several different metrics are used to quantify injury severity. In terms of fatalities, these are defined as a death that occurred within 30 days from the date of the incident. The cause of death must be related to the injuries sustained in the accident, as decided by the responsible doctor.

In the case of injuries, their severity is quantified in two different ways to capture two important perspectives: (a) the risk of permanent medical impairment (long-term consequences), and (b) the severity of the injury in terms of the acute risk of dying (initial outcomes). The risk of long-term consequences is captured by assessing the measure *Risk of Permanent Medical Impairment (RPMI).* This measure has been developed to estimate the risk for a patient of suffering a medical impairment at a specific level 1–3 years after the accident, based on the body part and the severity from the AIS classification of injuries using the method described by Malm et al. (2008). The RPMI metric has been validated in relation to sick leave and perceived quality of life (Elrud et al., 2019; Stigson et al., 2020). The Swedish Transport Administration defines a serious injury in the road traffic environment as an injury that leads to a *PMI of above* 1% (PMI1+) and a very serious injury as an injury that leads to a PMI of above 10% (PMI10+)

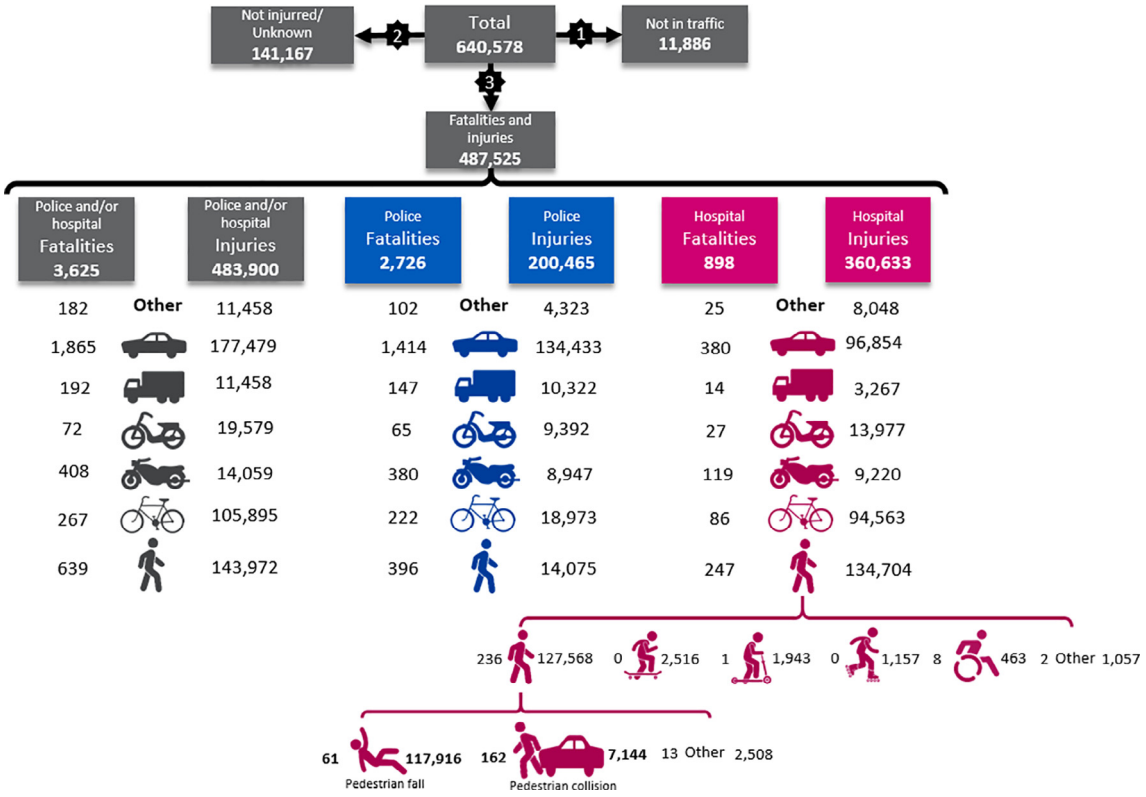

Fig. 1. Number of fatalities and injured by road user category, 2010–2019, STRADA.

(Trafikverket, 2020). The acute risk of dying is captured by the emergency hospitals' injury reporting according to the *Abbreviated Injury Scale (AIS2005, update 2008;* AAAM, 2020). This study includes road users who died or were injured with at least one injury classified as AIS 1 or higher. Given that a person often has more than one injury, the most severe injury is defined according to the *Maximum AIS (MAIS)* (Decker et al., 2016). For the classification of multiple injuries, a weighting according to the *Injury Severity Score (ISS)* was used, which is an estimate of the probability of death (Baker et al., 1974). However, this measurement does not capture the assessment of medical impairment.

Finally, STRADA also contains a number of characteristics in addition to measures of injury, such as information regarding sex, age, location, circumstances, and so forth. This information is also included in the study in order to compare injury characteristics between types of road users.

2.2. Statistical analysis

In order to describe and compare the characteristics of PFIs with other road users, two types of analyses were conducted. First, we analyzed the magnitude of PFIs per 100,000 person-years as well as the characteristics of PFIs in terms of causes, type of injuries, severity level, and comparisons with other types of road users. Secondly, we compared individual- and event-specific characteristics. For the comparison of fatalities and injuries between the groups, one-way analyses of variance (ANOVA) with Bonferroni post-hoc test was used for continuous measurements and Chi-Square with *z*-test for categorical measurements. Since there are many pairwise comparisons, the *p*-values were adjusted using the Bonferroni method. An alpha level set at $p < 0.05$ was considered statistically significant. Rates of injury and fatality are presented per 100,000 person-years. IBM SPSS (version 27) was used for the analysis.

2.3. Ethical considerations

This study was approved by the Regional Ethics Board in Uppsala (DNR 2018/480; with addendum [DNR 2021–10338] approved by the Swedish Ethical Review Authority).

3. Results

As shown in Fig. 2, the number of PFIs has not declined during the study period, in similarity to cyclists. Decreasing trends are seen amongst car occupants and other types of road users such as motorcyclists, moped drivers, or those who travel by truck or bus.

3.1. Fatalities

During the study period (2010–2017), 898 persons were reported by hospitals as fatally injured in the road traffic environment in Sweden (i.e., an average of 112 persons per year; 1,2 per 100,000 person-years). In total, pedestrians were the second largest group after car occupants with 25% of all fatalities. On average, about 8 pedestrians (27% of the pedestrians in total) died annually in falls and 20 in collisions (73% of the pedestrians; Fig. 3).

3.2. Injury severity

On average, regardless of the degree of injury, more than 36,000 people were injured annually in Sweden during the period 2010–2019 (367 per 100,000 person-years). The largest group were pedestrians with an annual average of 127 pedestrians per 100,000 person-years. Of these, almost all (94%) were PFIs. Seventeen times more pedestrians were injured in fall accidents than in collisions accidents.

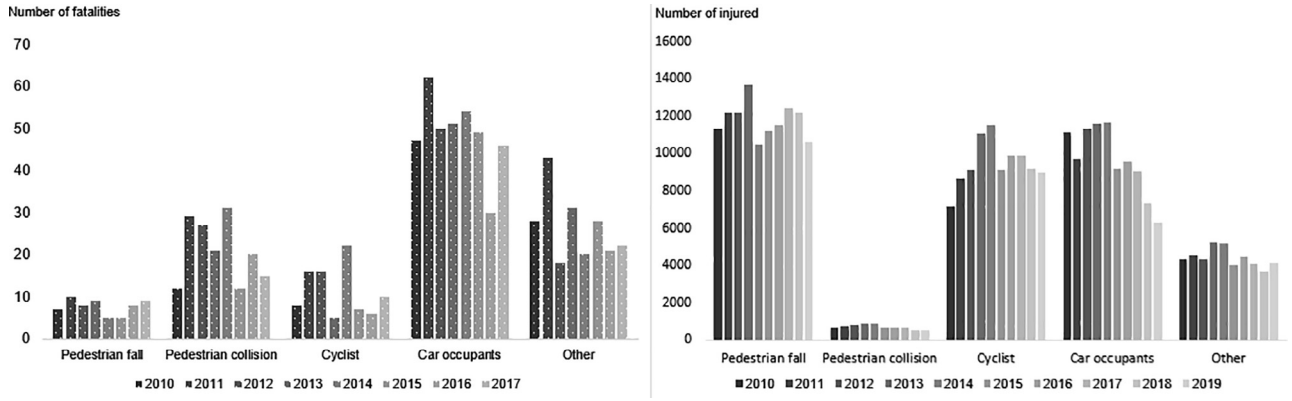

Fig. 2. Number of fatalities and injured by road user category and year. More detailed documentation can be found in Appendix 1.

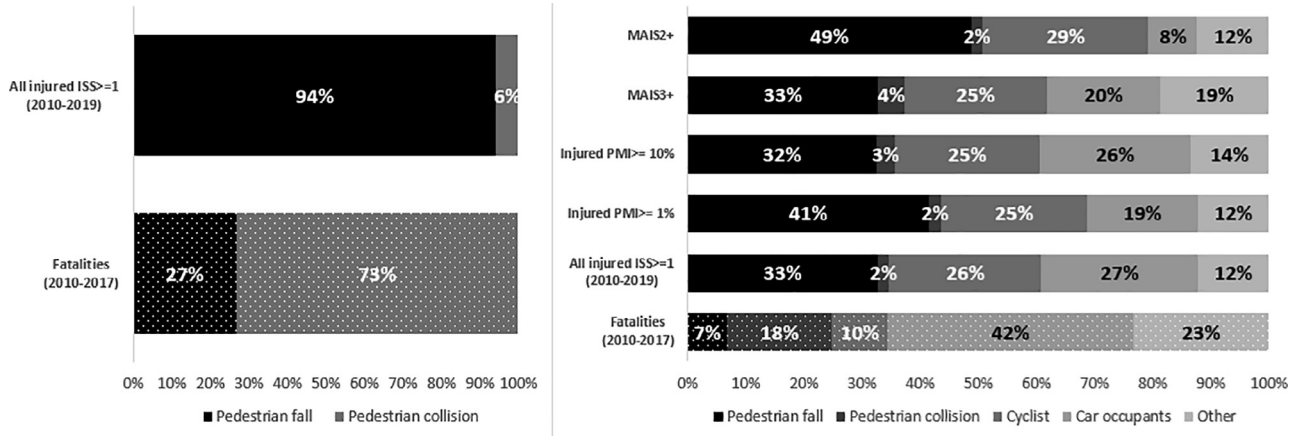

Fig. 3. Proportion of fatalities (2010–2017) and injured (2010–2019) by degree of injuries and road users category.

The distribution between different types of road users and injury severity is presented in Fig. 3. Pedestrians in total (excluding those who travelled on skateboards, scooters, and wheelchairs) accounted for more than a third of the injured (35%). Together with cyclists (26%), the two VRUs categories accounted for almost two-thirds of all injuries in the road traffic environment. Pedestrians also accounted for the largest proportion (43%) of all injured road users with long-term consequences (PMI1+). There were significantly more PFIs with long-term consequences compared to other road users (19 times compared to pedestrian collisions, 1.7 times compared to cyclists and 2.2 times compared to car occupants).

Table 1 shows that every fourth PFI and every fifth pedestrian in collision accidents led to a permanent reduction in PMI1+. For injuries that led to more severe impairment (PMI10+), a significantly higher proportion was seen among pedestrians in collisions compared with other types of road users. In terms of serious initial outcomes (MAIS2+), pedestrians accounted for more than half (51%) of all injuries in the road traffic environment.

3.3. Distribution by sex and age

In terms of individual characteristics, males were clearly over-represented in all catagories, apart from fatal pedestrian collisions where the sex distribution was more equal (Fig. 4). The majority of pedestrian fatalities were males (58%) and 59% were 65 years or older, regardless of sex. The proportion of persons 65 years or older was greater among pedestrians who died in falls (82%).

The proportion of females among injured pedestrians is considerable (69%), not least compared to other types of road users where males generally constitute the large proportion.

The age distribution was also skewed, with 40% of those injured in falls being 65 years or older, regardless of sex. For injured pedestrians in collision accidents, the distribution was more even. Generally, there were considerable differences in the age distribution between injured road users. Fall injuries were more common among the older population, while injuries in bicycle and car accident were more common among the younger population.

3.4. Injury circumstances

As is seen in Table 1, the majority of pedestrians injured in falls suffered an injury in an urban area and on a municipal road. Injuries that occurred during leisure time were common regardless of the type of road user but more common among PFIs. The cause of PFIs varied greatly during the year. Injuries due to slippery surfaces such as ice, snow, or gravel were more common (60%) among PFIs compared to other types of road users. Most pedestrian injuries (77%) occurred during the cold season in Sweden (November 1 to April 30), with an average of 91 injured per 100,000 person-years. On a yearly basis, more than half of all pedestrians were injured in falls due to slips. However, the proportion was significantly greater (73%) during the winter season. The proportion who were injured during the autumn (September 1-November 30), when daylight hours are fewer, was greatest among pedestrian collisions (30%) compared with other types of road users.

3.5. Hospital care

Most PFIs (84%) left the hospital after treatment at the emergency department (i.e., they were not admitted). However, about

Table 1
Number and proportion of fatalities during study period 2010–2017 and injured 2010–2019 after each road user category and characteristic information.

	Fatalities						Injuries					
Road user category	Pedestrian fall	Pedestrian collision	Cyclist	Car occupants	Other	All	Pedestrian fall	Pedestrian collision	Cyclist	Car occupants	Other	All
N (% of all)	**61 (6.8%)**	**162 (18.0%)**	**86 (9.6%)**	**380 (42.3%)**	**209 (23.3%)**	**898**	**117,916 (33%)**	**7144 (2%)**	**94,563 (26%)**	**96,854 (27%)**	**44,156 (12%)**	**360 633**
Per 100.000 person-year	**0.6**	**1.7**	**0.9**	**4.0**	**2.1**	**9.3**	**119.9**	**7.3**	**96.1**	**98.5**	**44.9**	**366.6**
Age. mean (95% CI)	76.2 (71.9–80.5)	59.2 (55.4–63.0)	62.6 (58.2–66.9)	47.2 (44.9–49.5)	41.4 (38.7–44.1)	**51.5 (49.9–53.0)**	56.9 (56.8–57.1)	41.7 (41.2–42.3)	38.2 (38.1–38.4)	36.4 (36.3–36.5)	33.8 (33.6–33.9)	**43.4 (43.3–43.5)**
Age (median)	82	66	65	51	44	**58**	60	38	38	32	27	**43**
Female	31.1%a. b	44.3%b	30.0%a. b	28.5%a	13.3%c	**28.2%**	68.9%a	56.7%b	45.3%c	49.0%d	34.5%e	**53%**
PMI 1%							25.1a	21.5b	18.9c	13.9d	20.0b	**19.7**
PMI 10%							2.4a	3.9b	2.3a	2.3a	2.7c	**2.4**
ISS 1–3							46.9%a	64.6%b	61.3%c	88.9%d	64.2%b	**64%**
ISS 4–8							49.2%a	25.0%b	34.4%c	7.7%d	29.0%e	**31%**
ISS 9-							4.0%a	10.5%b	4.4%c	3.5%d	6.8%e	**4%**
MAIS2+							53.1%a	35.4%b	38.7%c	11.1%d	35.8%b	**36%**
MAIS3+							3.8%a	8.7%b	3.6%c	2.8%d	5.8%e	**4%**
Urban area	83.6%a	60.5%b	73.3%a. b	11.8%c	36.5%d	**37%**	85.2%a	84.0%a	77.2%b	33.9%c	56.4%d	**66%**
Non-urban area	14.8%a	32.9%a	18.9%a	80.2%b	54.5%c	**55%**	9.1%a	10.6%b	15.8%c	58.0%d	34.2%e	**27%**
Government	13.1%a	34.1%b	21.1%a. b	74.0%c	49.3%d	**51.9%**	3.8%a	9.4%b	7.6%c	54.0%d	24.9%e	**21%**
Municipal	63.9%a	48.5%a	63.3%a	9.3%b	29.4%c	**30%**	58.0%a	66.7%b	56.8%c	27.4%d	42.7%e	**48%**
At work or on the way to / from work	1.6%a	4.2%a	8.9%a	6.4%a	6.6%a	**6.0%**	16.9%a	17.5%a	22.3%b	27.7%c	16.5%a	**21.2%**
At school or on the way to / from school	0%	1.2%a	1.1%a	0.5%a	0%	**0.5%**	2.4%a	9.1%b	7.7%c	2.1%d	6.1%e	**4.3%**
At leisure	77.0%a	54.5%b	47.8%b	46.5%b	46.4%b	**50.1%**	69.2%a	56.8%b	57.8%b	50.0%c	62.1%d	**59.9%**
Other / Unknown	21.3%a	40.1%a. b	42.2%a. b	46.5%b	46.9%b	**43.4%**	11.5%a	16.6%b	12.2%c	20.1%d	15.3%b	**14.6%**
Slippery due to snow / ice	21.3%a	2.4%b	0%	9.3%c	2.4%b	**6.3%**	55.9%a	7.5%b	11.1%c	20.6%d	7.1%b	**27.7%**
Slippery because of other things, such as leaves	0.6%a	1.1%a	1.0%a	2.8%a	1%	**1.3%**	7.7%a	3.2%b	16.1%c	7.4%a	20.7%d	**11.3%**
Uneven pavement / road	6.6%a	0%	3.3%a. b	0.8%b	0.5%b	**1.2%**	21.6%a	1.2%b	11.8%c	2.3%d	9.0%e	**11.9%**
Nothing that affected the accident	23.0%a	38.9%a	34.4%a	38.0%a	33.6%a	**35.8%**	15.1%a	64.7%b	46.8%c	50.5%d	45.1%e	**37.6%**
Crossing	3.3%a	16.2%a. b	27.8%b	13.9%a	17.5%a. b	**15.8%**	2.8%a	19.2%b	12.4%c	28.2%d	18.9%b	**14.4%**
Street / Road	26.2%a	73.7%b	53.3%c	85.6%d	73.0%b	**73.4%**	25.7%a	51.5%b	36.9%c	69.4%d	54.9%e	**44.5%**
Walking Area	52.5%a	4.2%b	13.3%b	0%	4.7%b	**6.6%**	53.7%a	9.2%b	44.4%c	0.1%d	15.0%e	**31.3%**
Shared area	18.0%a	6.0%a. b	5.6%a. b	0.5%c	4.7%b	**4.1%**	17.7%a	20.1%b	6.4%c	2.3%d	11.3%e	**9.9%**
Pedestrian crossing and / or bicycle crossing	4.9%a. b	15.0%b	7.8%a. b		2.8%a	**4.5%**	4.4%a	37.2%b	10.7%c	1.5%d	3.1%e	**5.7%**
N (care days)	310	492	371	603	311	**2087**	87,551	14,771	48,351	47,601	40,362	**238,636**
Care days for hospitalized, mean (95% CI)	6.2 (4.5–7.9)	6.5 (4.1–9.0)	6.7 (4.3–9.2)	4.9 (3.5–6.2)	5.2 (3.1–7.3)	**5.7 (4.9–6.6)**	4.9 (4.8–4.9)	6.6 (6.3–7.0)	3.7 (3.6–3.8)	3.5 (3.4–3.6)	4.8 (4.6–4.9)	**4.3 (4.2–4.3)**
<1 day	5	22	8	43	21	**99**	1397	164	1249	2052	676	**5538**
1–30 days	45	49	43	76	37	**250**	16,444	1969	11,574	11,320	7594	**48,901**
>30 days	4	4	7	12	3	**30**	444	129	343	577	405	**1898**
Not hospitalized (outpatient)	7	92	32	258	150	**539**	99,631	4882	81,397	82,905	35,481	**304,296**

Each subscript letter represents a subset of the road user category whose column proportions do not differ significantly from each other at the 0.05 level. That is, those with the same letter do not have a difference, but those with different letters have a statistically significant difference.

16% were hospitalized and the average length of care was almost five days. In total, PFIs who were admitted to hospital stayed for almost 75,000 days during the study period. The proportion of people admitted to the hospital was higher among pedestrians in collision accidents compared to other road users. On average, they remained in hospital for almost a week.

3.6. Injury type

On average, pedestrians sustained 2.4 injuries after a collision and 1.4 injuries after a fall. Fig. 5 illustrates that, regardless of severity, injuries to the upper extremity such as wrist, shoulder, and elbow were more common among PFIs (42%). The most com-

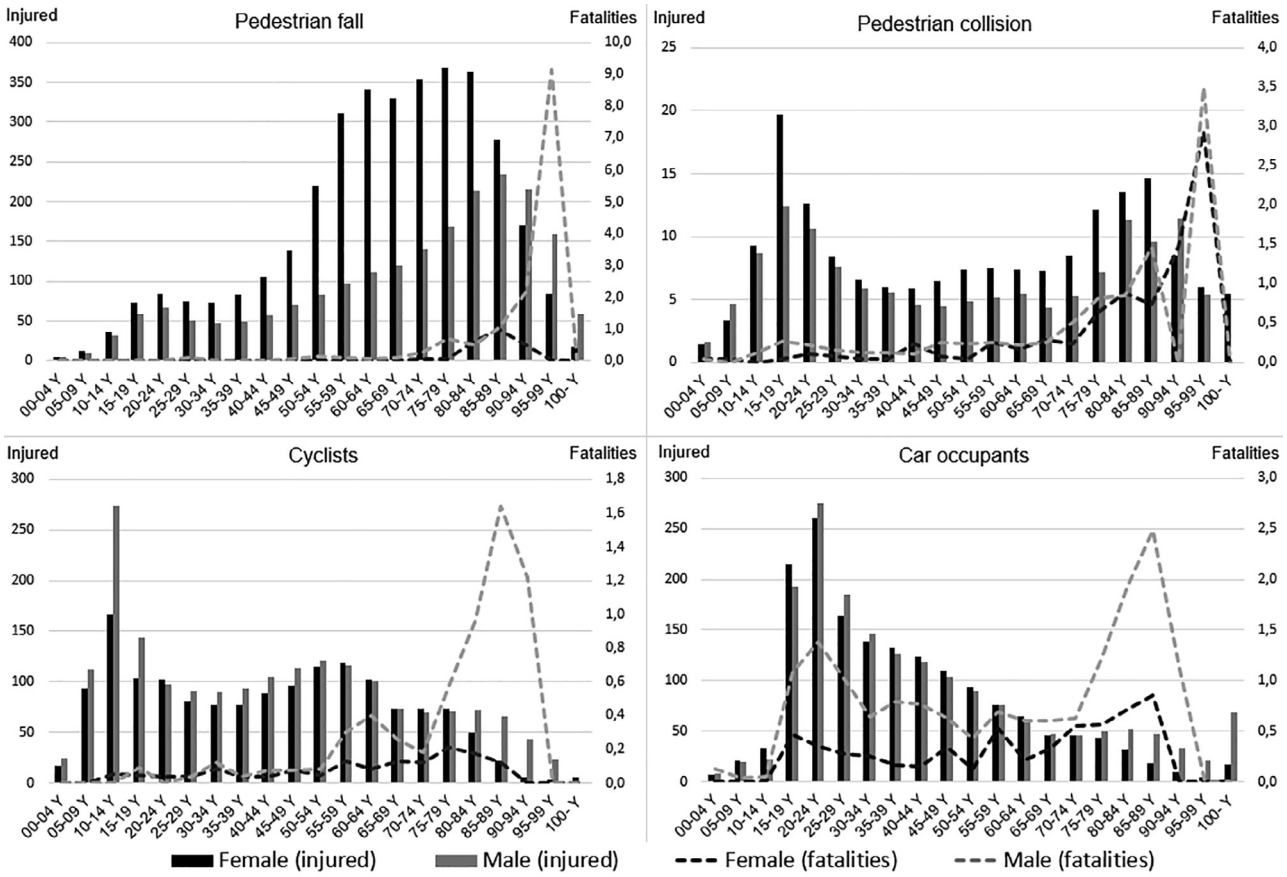

Fig. 4. Number of fatalities (2010–2017) and injured (2010–2019) per 100,000 person-year, age group, and road user category.

mon type of injury among pedestrians in collision accidents were superficial wounds (72%) followed by fractures of the hip, knee and leg (28%). Head injuries were significantly more common among injured pedestrians in collision accidents (13%) compared to other road users (see Appendix 1).

As shown in Fig. 6, 53% of pedestrians in fall accidents with long-term consequences (PMI1% +) had injuries to the upper extremity such as hand, arm, or shoulder. Half of the pedestrians (51%) in collision accidents with long-term consequences (PMI1% +) suffered an injury to the lower extremities such as knee or hip. Head injuries, both initially (Appendix 2) and as a long-term consequence (Fig. 6), were significantly more common among pedestrians in collisions compared to other road users categories.

4. Discussion

In spite of VRUs being the most common traffic injury and entailing a high cost for society, traditional traffic safety work tends to focus on injured motorists or VRUs in collision with motorists. One potential reason for the lack of interest in PFIs is the lack of a consistent and clear definition of fall accidents in the road traffic environment. The fact that a vehicle must be involved in a collision in order for it to be counted as a road traffic accident (Eurostat, 2019) has inadvertently eliminated PFIs from official statistics. In turn, this may have led to the responsibility for pedestrian traffic falling between several instances, with no one taking overall responsibility. In order to overcome this and reduce injuries with long-term medical consequences and fatalities, a clear definition of pedestrian accidents and injuries in the road traffic environment is required as well as high-quality data.

In this first nationwide scientific study on accidents in the road traffic environment among pedestrians, with a focus on PFIs and their relation to other road user categories, we find that during 2010–2019, over 125,000 individuals (128/100,000 person-years) died or required emergency medical treatment. Whether this number or rate is high or not is difficult to assess as there are few comparable studies. Specifically, previous studies are limited in terms of age, location, studying all falls outdoors, or without comparing to other road user categories (Björnstig et al., 1997; Duckham, Procter-Gray, & Hannan, 2013; Elvik & Bjørnskau, 2019; Li et al., 2014; Morency et al., 2012; Naumann et al., 2011; Oxley et al., 2018). However, regardless, pedestrians now account for the second largest group of traffic-related deaths in Sweden, with higher rates among pedestrians in collisions compared to fall accidents. Similarly, in terms of injuries, pedestrians are the largest group among all road users injured in the road traffic environment, regardless of the degree of injury, a result similar to previously reported studies (Ahnlund, 2008; Methorst et al., 2017).

Perhaps most importantly, every fourth PFI leads to permanent disability according to the injury measure PMI 1%. The proportion is even higher according to MAIS, where more than half receive injuries with MAIS 2+. Diagnoses leading to impairment differ to some extent from injuries classified as AIS2+ or AIS3+. There is a particular need to consider certain diagnoses which lead relatively often to long-term consequences at AIS1 level degrees from injuries. VRUs in urban areas, including PFIs, are found at lowered thresholds for injury or impairment levels compared to vehicle occupants. In addition, there are diagnoses that more rarely lead to impairment among higher levels of AIS (Tingvall et al., 2013). Among the more severe injury outcomes, both initial outcomes (MAIS33+) and long-term consequences (PMI10+), pedestrians in

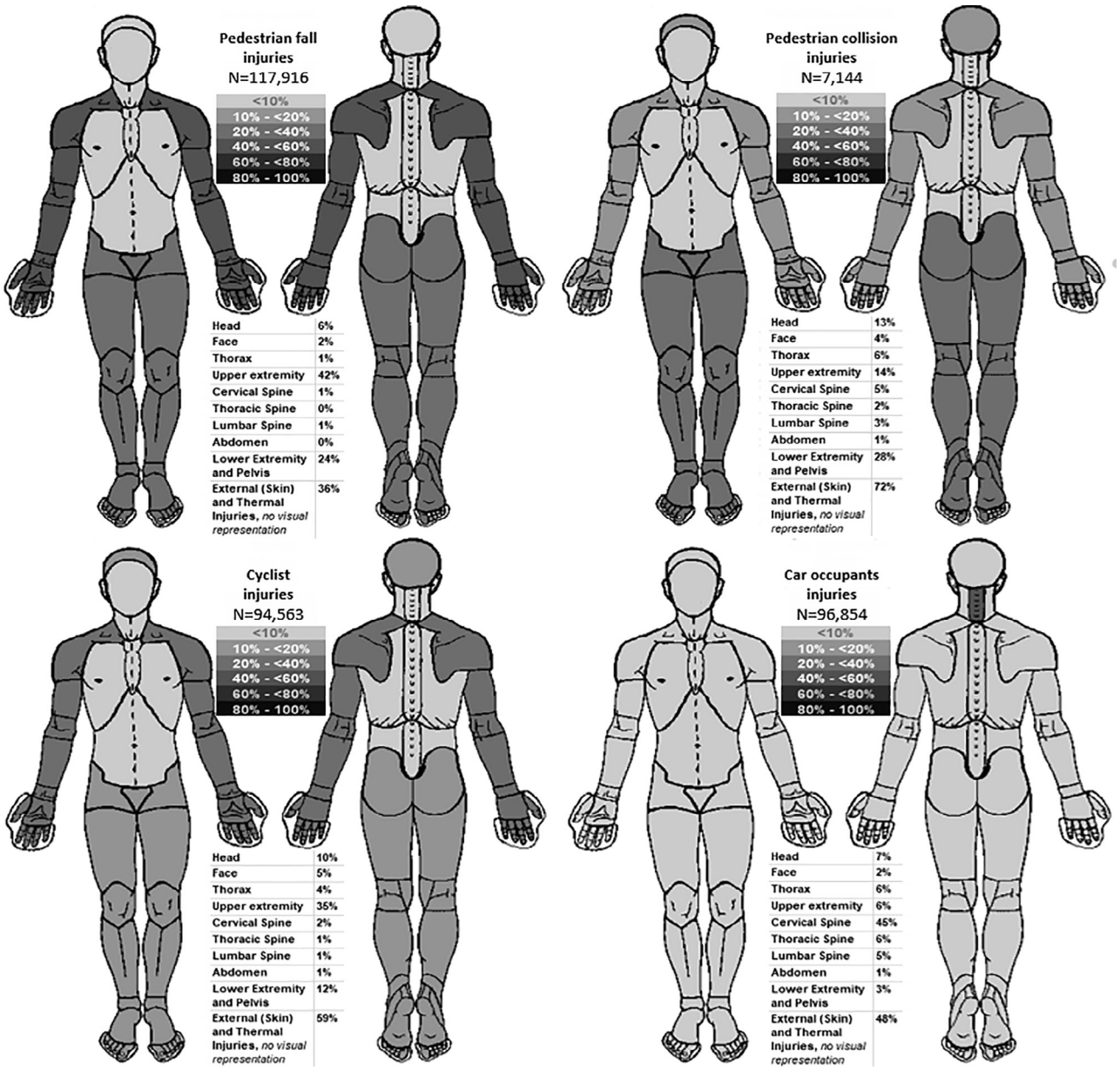

Fig. 5. The proportion of injuries after road users category and body part, 2010–2019). A person can have injuries to several body parts.

motor-vehicle collisions were a more affected group than PFIs, which is not surprising given the larger amount of energy in the incident. However, although they are more affected, our study shows that PFIs are up to 17 times more common than pedestrian injuries due to collisions, regardless of the degree of injury. This is significantly higher than the results shown in previous studies (Methorst et al., 2017). The difference between the two studies may indicate the success of road safety measures for VRUs such as vehicle improvements and the road traffic environment combined with lower speeds in urban areas, thereby reducing the number of collisions (Ballesteros et al., 2004; Oxley et al., 2013; Strandroth et al., 2011).

Our results show that, on average, pedestrians suffered more injuries in collision accidents than in falls, in accordance with other studies (Hu & Klinich, 2014). While injuries most commonly occurred to the upper extremities, hip and lower extremities were also common. Although hip fractures are generally not defined as a serious injury, from a long- to medium-term perspective they have a high mortality rate within one year after a fracture (Mellner et al., 2020). Also, they lead to serious consequences such as poor health and loss of life activities (LeBlanc et al., 2011; Lyles et al., 2007). As such, these injuries should also be taken seriously. In relation to other road users, head injuries among pedestrians in collision accidents led to more long-term consequences (PMI1+), a result supported by Fredriksson, Rosén, and Kullgren (2010).

In terms of sex and age, pedestrian morbidity and mortality differ considerably to other traffic-related incidents. Traditionally, males are overrepresented in traffic-related morbidity and mortality, however, amongst pedestrians, females are overrepresented. Also, in PFIs, those 65 years or older are clearly overrepresented. Previous studies have shown that the risk of falls increases with age, especially for females (Elvik & Bjørnskau, 2019; Gyllencreutz et al., 2015; Morency et al., 2012; Naumann et al., 2011). Given the projected increase in the percentage of elderly people in the population of high-income countries (OECD, 2003), this clearly shows the importance of this issue for countries in similar

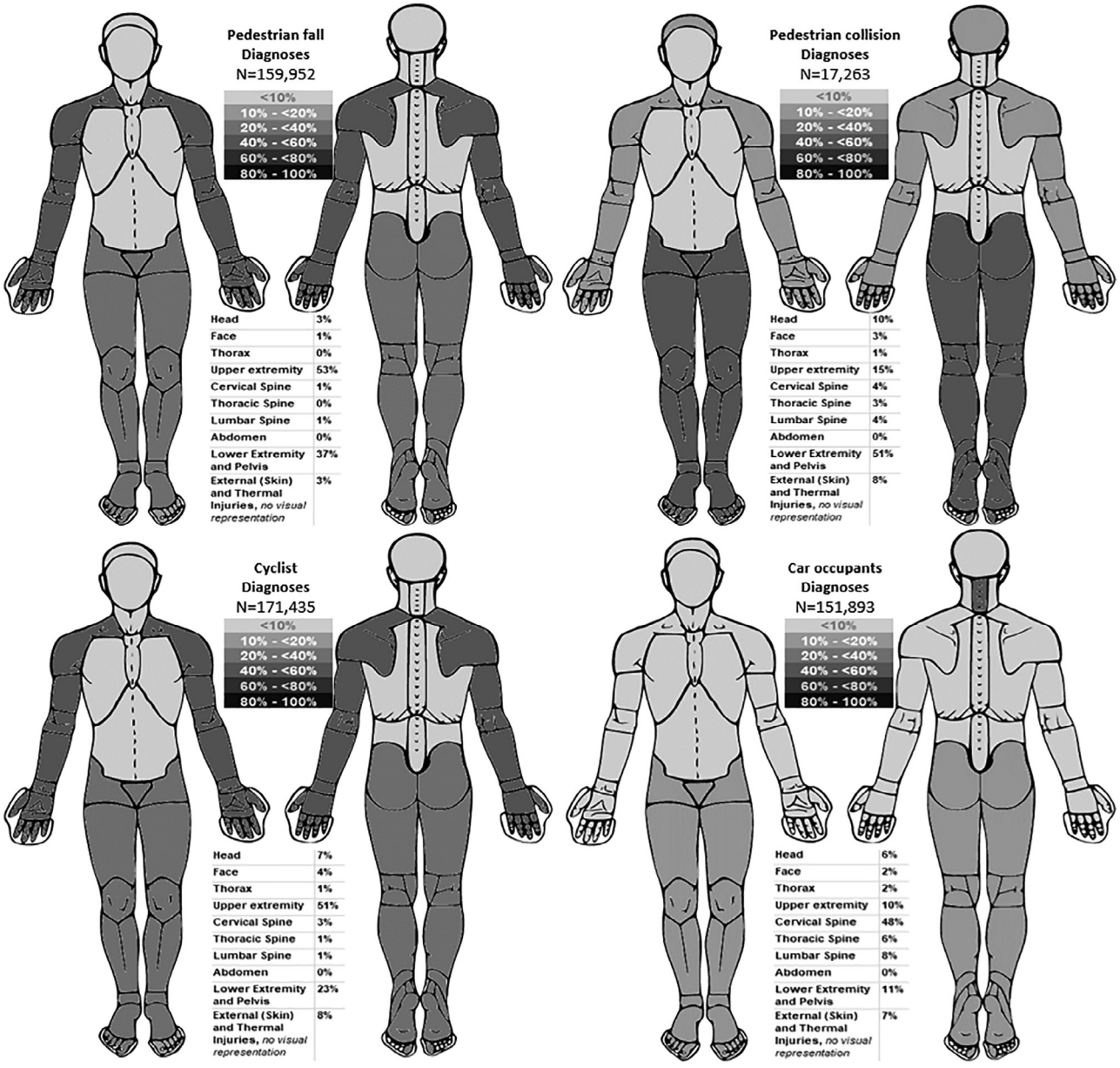

Fig. 6. The proportion of diagnoses leading to PMI1 + after road users category and body part, 2010–2019). A person can have injuries to several body parts.

demographic situations. The significantly older age amongst injured pedestrians, compared to other road users, is problematic when comparing risk. Ideally, time- or distance-related risk measurements would be used when comparing morbidity or mortality rates. However, the knowledge regarding pedestrians' time or distance spent travelling is limited and underreported, not least with regards to age (Sammer et al., 2018). This element needs to be studied further as are factors related to increased knowledge about which groups can be affected by fall accidents. Variables such as gender, ethnicity, class, and disability would provide additional dimensions to the consequences of fall accidents.

Given the results in this study, it is clear that the current definition regarding which accidents are included in the definition of road traffic accidents should perhaps be reassessed. The current definition, based on the Vienna Convention on Road Traffic from 1968, was formulated at a time when collision- and motor-vehicle-related accidents dominated the traffic-related injury and fatality panorama. However, the situation is now very different and, as such, we would argue that PFIs should now be defined as pedestrians who fall in public spaces outdoors without colliding with other road users, in accordance with Methorst (2021). This would include these incidents in the official statistics and thereby adhere to Objective 11 of the Sustainable Development Goals, entailing that by 2030, people will have access to safe, affordable, accessible, and sustainable transport systems (UN, 2020b). By taking such a holistic view and including PFIs in the official statistics, more targeted measures may be needed and developed in order to reduce injuries among VRUs.

In terms of interventions, a systematic review of multifaceted interventions (e.g., information, education, environmental modification, and personal protection such as safe footwear) at the population level showed reductions in fall-related injuries between 6% and 75% (McClure et al., 2005). Also, urban planning, where the road system is adapted to human abilities and limitations (Schepers et al., 2017), can reduce rates (e.g., through the International Road Assessment Program (iRAP) which could be important

to introduce; WHO, 2018). From a maintenance perspective, slipping on leaves, gravel, etc., are important aspects to address (Lai et al., 2011) and this study suggests that slippery surfaces such as ice, snow, leaves, or gravel together with uneven pavements and roads are the cause of three out of four PFIs.

The risk of ice or snow in snow-rich countries has been reported previously (Bergland et al., 2003; Duckham, Procter-Gray, Hannan, et al., 2013; Elvik & Bjørnskau, 2019; Gyllencreutz et al., 2015; Morency et al., 2012; Pajala et al., 2008) and requires specific interventions. Studies have shown that the risk of being injured as a pedestrian in winter is as low as in summer if winter conditions such as ice and snow are eliminated (Elvik et al., 2019), and the individual-level anti-slip devices (e.g., ice cleats) can reduce the risk of PFIs and increase the amount of walking (Berggård & Johansson, 2010; McClure et al., 2005; McKiernan, 2005). From a societal perspective, the spread of hot sand (Niska, 2013), distribution of ice cleats to older adults (Bonander & Holmberg, 2019), or ground heating of roads and sidewalks (thereby reducing ice and snow by 60%; Öberg et al., 1998; Öberg, 2011), are interesting alternatives that should be investigated further.

Strengths and limitations

To our knowledge, this paper is the first to report on the magnitude and characteristics of PFIs on a national level and compare these injuries to other types of road users over several years. The STRADA register offers a unique opportunity to study this problem using data reported by every emergency hospital in Sweden. The register data contains detailed information on the characteristics and severity of injuries from a large number of injury events (n = 361,531), and should represent an almost complete account of traffic injury events that occurred in Sweden between 2010 to 2019 that have come to the attention of emergency departments. While we have mentioned that there was some undercoverage during the first few years included in our analysis, it is important to keep in mind that there may be additional measurement errors present in the data. For instance, some injured individuals may not seek treatment and some events may not have been reported to STRADA because of, for example, shortages in hospital staff.

An additional limitation to our study is that the results are specific to Swedish conditions. The results – especially those related to falls due to slippery road conditions – may not be generalizable to countries located in warmer regions. While we expect that the results should be generalizable to countries with a similar road traffic environment and climate, it would be of considerable interest to see how well our results can be reproduced in other countries.

5. Conclusion

Pedestrians are a large vulnerable group in the road traffic environment. Despite this, the knowledge regarding injuries to this group is largely unknown as PFIs are not included in the official statistics on road traffic injuries. Contrary to other traffic groups, injuries and fatalities have not decreased, meaning that they must be met with measures that specifically address the risk factors they are associated with, such as age and slipping on gravel, leaves, snow, etc. on streets and sidewalks in urban areas. Focusing only on classic approaches that work for vehicle-related accidents seems to be ineffective for VRUs and therefore new strategies are required.

Declaration of Competing Interest

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

Acknowledgments

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Appendix

Appendix 1

Number of fatalities during study period 2010–2017 and injured 2010–2019 after each road user category and degree of injury as well as care time.

Road user category	Year	N Fatalities	N Injured	N Diagnoses	N PMI1%	N PMI10%	N ISS 1–3	N ISS 4–8	N ISS 9-	N MAIS3+	N MAIS2+	N Cared (<1 day)	N Cared (1–30 days)	N Cared (>30 days)	N Care days
Pedestrian fall	2010	7	11,345	15,086	3039	287	4846	5994	505	484	6499	75	1649	26	9433
	2011	10	12,207	16,218	3118	303	5620	6042	545	524	6587	147	1866	18	10,035
	2012	8	12,170	16,598	3100	305	5575	6039	556	536	6595	104	1901	18	10,430
	2013	9	13,657	18,790	3404	326	6486	6623	548	511	7171	139	2175	24	11,178
	2014	5	10,506	14,819	2486	234	5371	4717	418	400	5135	109	1535	17	8629
	2015	5	11,234	15,028	2766	250	5479	5358	397	386	5755	170	1505	19	7564
	2016	8	11,536	15,386	2866	261	5493	5630	413	400	6043	167	1410	12	7709
	2017	9	12,467	16,829	3100	287	5893	6110	464	450	6574	160	1565	14	8158
	2018	*	12,211	16,543	3145	278	5530	6237	444	432	6681	172	1576	8	7674
	2019	*	10,583	14,655	2650	243	4961	5207	415	392	5622	154	1262	6	5344
	Total	**61**	**117,916**	**159,952**	**29,673**	**2775**	**55,254**	**57,957**	**4705**	**4515**	**62,662**	**1397**	**16,444**	**162**	**86,154**
Pedestrian collision	2010	12	672	1658	132	22	452	162	58	48	220	17	163	9	1406
	2011	28	715	1732	153	26	467	170	78	65	248	26	217	13	1582
	2012	26	830	2165	184	36	542	175	113	95	288	24	257	8	1773
	2013	21	895	2227	205	41	539	258	98	86	356	21	289	16	2151
	2014	30	853	2193	191	37	551	204	98	79	302	21	255	17	2145
	2015	12	682	1650	154	31	436	167	79	63	246	7	199	9	1532
	2016	20	687	1534	140	20	452	173	62	50	235	12	153	12	1296
	2017	13	696	1526	138	22	462	170	64	51	234	15	174	5	1069
	2018	*	573	1373	124	18	365	159	49	37	208	13	137	3	828
	2019	*	541	1205	115	18	346	145	50	45	195	8	125	4	825
	Total	**162**	**7144**	**17,263**	**1535**	**270**	**4612**	**1783**	**749**	**619**	**2532**	**164**	**1969**	**96**	**14,607**
Cyclist	2010	7	7170	13,767	1395	186	4362	2431	377	315	2808	61	940	23	8046
	2011	16	8632	16,016	1605	202	5381	2852	399	317	3251	113	1240	12	4894
	2012	16	9124	16,491	1674	199	5772	2981	371	301	3352	136	1200	9	4430
	2013	4	11,071	20,515	2106	260	6778	3825	468	378	4293	174	1577	19	6180
	2014	20	11,503	20,787	2141	259	7156	3816	531	425	4347	162	1534	21	6330
	2015	7	9129	15,846	1737	206	5599	3173	357	296	3530	143	1119	15	4611
	2016	6	9869	17,480	1880	215	5967	3467	435	356	3902	127	1133	16	4684
	2017	10	9884	17,103	1890	219	6026	3448	410	343	3858	116	1056	16	4554
	2018	*	9170	17,069	1787	195	5486	3309	375	307	3684	87	928	8	3627
	2019	*	9011	16,361	1751	196	5403	3213	395	336	3608	130	847	7	3399
	Total	**86**	**94,563**	**171,435**	**17,966**	**2138**	**57,930**	**32,515**	**4118**	**3374**	**36,633**	**1249**	**11,574**	**146**	**50,755**
Car occupants	2010	46	11,152	18,459	1520	256	9852	871	429	340	1300	295	1264	42	5411
	2011	61	9688	15,357	1354	224	8556	780	352	288	1132	271	1297	38	5469
	2012	50	11,302	18,449	1586	260	10,003	870	429	339	1299	336	1536	26	5652
	2013	48	11,609	18,856	1567	260	10,367	845	397	321	1242	338	1509	30	5549
	2014	53	11,629	18,100	1630	267	10,366	854	409	316	1263	274	1518	33	5966
	2015	49	9167	13,762	1293	207	8178	706	283	222	989	145	1022	21	4178
	2016	28	9569	14,454	1358	218	8527	711	331	266	1042	154	1050	24	4153
	2017	45	9059	13,570	1293	201	8099	686	274	227	960	94	836	18	3871
	2018	*	7352	11,570	1095	172	6467	603	282	228	885	99	746	15	3192
	2019	*	6327	9316	928	143	5657	491	179	141	670	46	542	14	2290
	Total	**380**	**96,854**	**151,893**	**13,624**	**2209**	**86,072**	**7417**	**3365**	**2688**	**10,782**	**2052**	**11,320**	**261**	**45,731**
Other	2010	28	4337	9855	863	130	2773	1203	361	313	1564	59	795	30	4440
	2011	43	4552	9458	926	134	2861	1320	371	308	1691	90	942	26	4806
	2012	18	4354	8815	864	114	2810	1251	293	248	1544	82	806	17	3963
	2013	31	5239	10,410	1007	129	3413	1476	350	299	1826	96	978	19	4648
	2014	20	5206	10,591	1061	157	3291	1500	415	361	1915	83	1017	36	5831
	2015	28	4022	7734	820	106	2573	1185	264	227	1449	47	683	22	3779
	2016	20	4481	8277	898	119	2859	1347	275	232	1622	70	700	18	3582
	2017	21	4088	7811	799	97	2665	1166	257	223	1423	59	637	20	3453
	2018	*	3711	7627	710	85	2438	1051	222	187	1273	46	520	17	2909
	2019	*	4166	7951	813	90	2659	1300	207	177	1507	44	516	8	2275
	Total	**209**	**44,156**	**88,529**	**8761**	**1159**	**28,342**	**12,799**	**3015**	**2575**	**15,814**	**676**	**7594**	**213**	**39,686**
Total		**898**	**360,633**	**589,072**	**71,558**	**8551**	**232,210**	**112,471**	**15,952**	**13,771**	**128,423**	**5538**	**48,901**	**878**	**236,933**

* = The emergency hospitals have stopped reporting deaths to STRADA.

Appendix 2

Number of injured per body part, MAIS and road user category, 2010–2019. *observation: the sum of the respective columns is not equal to the number of injured persons in the group because a person may have suffered injuries to several body parts.*

		Pedestrian fall			Pedestrian collision			Cyclist			Car occupants			Other			All		
Body part	MAIS	N	column % per body part	column % total	N	column % per body part	column % total	N	column % per body part	column % total	N	column % per body part	column % total	N	column % per body part	column % total	N	column % per body part	column % total
Face	1	1450	54,9%	1,2%	85	27,2%	1,2%	2316	51,9%	2,4%	747	47,6%	0,8%	422	41,2%	1,0%	5020	50,2%	1,4%
	2	1069	40,5%	0,9%	129	41,3%	1,8%	1721	38,6%	1,8%	503	32,0%	0,5%	373	36,4%	0,8%	3795	37,9%	1,1%
	3	106	4,0%	0,1%	73	23,4%	1,0%	343	7,7%	0,4%	225	14,3%	0,2%	152	14,8%	0,3%	899	9,0%	0,2%
	4	9	0,3%	0,0%	17	5,4%	0,2%	53	1,2%	0,1%	66	4,2%	0,1%	53	5,2%	0,1%	198	2,0%	0,1%
	5	6	0,2%	0,0%	8	2,6%	0,1%	29	0,6%	0,0%	29	1,8%	0,0%	25	2,4%	0,1%	97	1,0%	0,0%
Thorax	1	900	53,0%	0,8%	75	17,3%	1,0%	1166	34,4%	1,2%	2031	33,3%	2,1%	642	23,3%	1,5%	4814	33,5%	1,3%
	2	616	36,3%	0,5%	130	30,0%	1,8%	1425	42,0%	1,5%	2453	40,2%	2,5%	944	34,2%	2,1%	5568	38,7%	1,5%
	3	154	9,1%	0,1%	161	37,2%	2,3%	684	20,2%	0,7%	1282	21,0%	1,3%	897	32,5%	2,0%	3178	22,1%	0,9%
	4	18	1,1%	0,0%	50	11,5%	0,7%	93	2,7%	0,1%	247	4,0%	0,3%	195	7,1%	0,4%	603	4,2%	0,2%
	5	9	0,5%	0,0%	17	3,9%	0,2%	26	0,8%	0,0%	93	1,5%	0,1%	83	3,0%	0,2%	228	1,6%	0,1%
Thoracic Spine	1	180	38,6%	0,2%	50	31,4%	0,7%	192	32,9%	0,2%	4120	75,7%	4,3%	374	37,9%	0,8%	4916	64,4%	1,4%
	2	239	51,3%	0,2%	50	31,4%	0,7%	271	46,5%	0,3%	921	16,9%	1,0%	343	34,8%	0,8%	1824	23,9%	0,5%
	3	39	8,4%	0,0%	38	23,9%	0,5%	90	15,4%	0,1%	302	5,6%	0,3%	186	18,9%	0,4%	655	8,6%	0,2%
	4	4	0,9%	0,0%	16	10,1%	0,2%	23	3,9%	0,0%	52	1,0%	0,1%	43	4,4%	0,1%	138	1,8%	0,0%
	5	4	0,9%	0,0%	5	3,1%	0,1%	7	1,2%	0,0%	46	0,8%	0,0%	40	4,1%	0,1%	102	1,3%	0,0%
Abdomen	1	2	5,4%	0,0%	-	-	-	143	28,8%	0,2%	16	2,2%	0,0%	24	4,6%	0,1%	185	9,9%	0,1%
	2	19	51,4%	0,0%	27	31,4%	0,4%	198	39,9%	0,2%	288	39,8%	0,3%	189	36,1%	0,4%	721	38,7%	0,2%
	3	11	29,7%	0,0%	34	39,5%	0,5%	104	21,0%	0,1%	266	36,8%	0,3%	182	34,8%	0,4%	597	32,0%	0,2%
	4	5	13,5%	0,0%	18	20,9%	0,3%	43	8,7%	0,0%	115	15,9%	0,1%	84	16,1%	0,2%	265	14,2%	0,1%
	5	-	-	-	7	-	0,1%	8	-	0,0%	38	-	0,0%	44	-	0,1%	97	-	0,0%
External (Skin and Thermal Injuries)	1	34,864	82,9%	29,6%	3927	76,0%	55,0%	45,695	81,5%	48,3%	42,398	90,6%	43,8%	21,068	80,3%	47,7%	147,952	83,9%	41,0%
	2	6527	15,5%	5,5%	890	17,2%	12,5%	9114	16,3%	9,6%	3111	6,6%	3,2%	4009	15,3%	9,1%	23,651	13,4%	6,6%
	3	612	1,5%	0,5%	284	5,5%	4,0%	1102	2,0%	1,2%	1032	2,2%	1,1%	925	3,5%	2,1%	3955	2,2%	1,1%
	4	53	0,1%	0,0%	52	1,0%	0,7%	126	0,2%	0,1%	181	0,4%	0,2%	152	0,6%	0,3%	564	0,3%	0,2%
	5	23	0,1%	0,0%	15	0,3%	0,2%	42	0,1%	0,0%	79	0,2%	0,1%	76	0,3%	0,2%	235	0,1%	0,1%
Cervical Spine	1	817	75,0%	0,7%	256	70,7%	3,6%	1516	67,7%	1,6%	41,566	96,1%	42,9%	2951	84,1%	6,7%	47,106	93,4%	13,1%
	2	194	17,8%	0,2%	59	16,3%	0,8%	540	24,1%	0,6%	1209	2,8%	1,2%	351	10,0%	0,8%	2353	4,7%	0,7%
	3	66	6,1%	0,1%	29	8,0%	0,4%	143	6,4%	0,2%	373	0,9%	0,4%	131	3,7%	0,3%	742	1,5%	0,2%
	4	7	0,6%	0,0%	11	3,0%	0,2%	20	0,9%	0,0%	72	0,2%	0,1%	35	1,0%	0,1%	145	0,3%	0,0%
	5	5	0,5%	0,0%	7	1,9%	0,1%	19	0,8%	0,0%	41	0,1%	0,0%	39	1,1%	0,1%	111	0,2%	0,0%
Head	1	4401	64,8%	3,7%	380	42,4%	5,3%	5522	60,4%	5,8%	4647	73,5%	4,8%	1970	56,6%	4,5%	16,920	63,5%	4,7%
	2	1712	25,2%	1,5%	278	31,0%	3,9%	2624	28,7%	2,8%	961	15,2%	1,0%	904	26,0%	2,0%	6479	24,3%	1,8%
	3	512	7,5%	0,4%	172	19,2%	2,4%	782	8,6%	0,8%	489	7,7%	0,5%	421	12,1%	1,0%	2376	8,9%	0,7%
	4	109	1,6%	0,1%	46	5,1%	0,6%	146	1,6%	0,2%	157	2,5%	0,2%	118	3,4%	0,3%	576	2,2%	0,2%
	5	53	0,8%	0,0%	20	2,2%	0,3%	64	0,7%	0,1%	69	1,1%	0,1%	69	2,0%	0,2%	275	1,0%	0,1%
Lumbar Spine	1	534	62,9%	0,5%	105	42,7%	1,5%	318	47,9%	0,3%	3197	66,5%	3,3%	445	45,4%	1,0%	4599	60,9%	1,3%
	2	269	31,7%	0,2%	82	33,3%	1,1%	268	40,4%	0,3%	1187	24,7%	1,2%	328	33,5%	0,7%	2134	28,3%	0,6%
	3	43	5,1%	0,0%	40	16,3%	0,6%	56	8,4%	0,1%	338	7,0%	0,3%	142	14,5%	0,3%	619	8,2%	0,2%
	4	2	0,2%	0,0%	13	5,3%	0,2%	17	2,6%	0,0%	61	1,3%	0,1%	36	3,7%	0,1%	129	1,7%	0,0%
	5	1	0,1%	0,0%	6	2,4%	0,1%	5	0,8%	0,0%	28	0,6%	0,0%	29	3,0%	0,1%	69	0,9%	0,0%
Lower Extremity and Pelvis	1	9438	33,1%	8,0%	452	23,0%	6,3%	3502	32,1%	3,7%	780	26,7%	0,8%	2435	33,1%	5,5%	16,607	32,2%	4,6%
	2	15,514	54,5%	13,2%	1103	56,2%	15,4%	5742	52,6%	6,1%	1268	43,4%	1,3%	3663	49,8%	8,3%	27,290	52,9%	7,6%
	3	3506	12,3%	3,0%	334	17,0%	4,7%	1633	15,0%	1,7%	698	23,9%	0,7%	1110	15,1%	2,5%	7281	14,1%	2,0%
	4	13	0,0%	0,0%	52	2,7%	0,7%	32	0,3%	0,0%	127	4,3%	0,1%	96	1,3%	0,2%	320	0,6%	0,1%
	5	4	0,0%	0,0%	20	1,0%	0,3%	9	0,1%	0,0%	48	1,6%	0,0%	53	0,7%	0,1%	134	0,3%	0,0%
Upper extremity	1	9018	18,2%	7,6%	216	22,4%	3,0%	8355	25,5%	8,8%	2461	46,4%	2,5%	3159	26,0%	7,2%	23,209	23,0%	6,4%
	2	40,196	81,0%	34,1%	603	62,5%	8,4%	23,768	72,6%	25,1%	2228	42,0%	2,3%	8188	67,5%	18,5%	74,983	74,4%	20,8%
	3	383	0,8%	0,3%	103	10,7%	1,4%	535	1,6%	0,6%	467	8,8%	0,5%	612	5,0%	1,4%	2100	2,1%	0,6%
	4	11	0,0%	0,0%	34	3,5%	0,5%	67	0,2%	0,1%	115	2,2%	0,1%	122	1,0%	0,3%	349	0,3%	0,1%
	5	3	0,0%	0,0%	9	0,9%	0,1%	20	0,1%	0,0%	36	0,7%	0,0%	56	0,5%	0,1%	124	0,1%	0,0%
Total number of injured		117,916			7144			94,563			96,854			44,156			360,633		

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