sustainability

MDPI

Article

Exploratory Analysis of Pedestrian Road Trauma in Finland

Steve O'Hern [1,2,*], Roni Utriainen [1], Hanne Tiikkaja [1], Markus Pöllänen [1] and Niina Sihvola [3]

1 Transport Research Centre VERNE, Tampere University, 33100 Tampere, Finland; roni.utriainen@tuni.fi (R.U.); hanne.tiikkaja@tuni.fi (H.T.); markus.pollanen@tuni.fi (M.P.)
2 Monash University Accident Research Centre, Clayton, VIC 3800, Australia
3 Finnish Crash Data Institute (OTI), 00180 Helsinki, Finland; niina.sihvola@oti.fi
* Correspondence: steve.ohern@tuni.fi

Abstract: In Finland, all fatal on-road and off-road motor vehicle crashes are subject to an in-depth investigation coordinated by the Finnish Crash Data Institute (OTI). This study presents an exploratory and two-step cluster analysis of fatal pedestrian crashes between 2010 and 2019 that were subject to in-depth investigations. In total, 281 investigations occurred across Finland between 2010 and 2019. The highest number of cases were recorded in the Uusimaa region, including Helsinki, representing 26.4% of cases. Females (48.0%) were involved in fewer cases than males; however, older females represented the most commonly injured demographic. A unique element to the patterns of injury in this study is the seasonal effects, with the highest proportion of crashes investigated in winter and autumn. Cluster analysis identified four unique clusters. Clusters were characterised by crashes involving older pedestrians crossing in low-speed environments, crashes in higher speed environments away from pedestrian crossings, crashes on private roads or in parking facilities, and crashes involving intoxicated pedestrians. The most common recommendations from the investigation teams to improve safety were signalisation and infrastructure upgrades of pedestrian crossings, improvements to street lighting, advanced driver assistance (ADAS) technologies, and increased emphasis on driver behaviour and training. The findings highlight road safety issues that need to be addressed to reduce pedestrian trauma in Finland, including provision of safer crossing facilities for elderly pedestrians, improvements to parking and shared facilities, and addressing issues of intoxicated pedestrians. Efforts to remedy these key issues will further Finland's progression towards meeting Vision Zero targets while creating a safer and sustainable urban environment in line with the United Nations sustainable development goals.

Keywords: pedestrians; road safety; road trauma; Finland; sustainability

Citation: O'Hern, S.; Utriainen, R.; Tiikkaja, H.; Pöllänen, M.; Sihvola, N. Exploratory Analysis of Pedestrian Road Trauma in Finland. *Sustainability* **2021**, *13*, 6715. https://doi.org/10.3390/su13126715

Academic Editor: Haywantee Ramkissoon

Received: 26 May 2021
Accepted: 10 June 2021
Published: 13 June 2021

1. Introduction

Pedestrians are the largest road user group with almost all trips containing a walking component [1,2]. Incorporating more walking into daily life offers a myriad of benefits to the individual [1,3,4]. Walking promotes active living, improves health, is inexpensive, and produces no emissions [3–6]. Walking is also beneficial to the broader community and helps to create attractive, prosperous, and sustainable cities [3,7,8]. Increasing walking participation can assist in realising the United Nations (UN) Sustainable Development Goals, particularly Goal 11, which addresses the need to make cities and human settlements inclusive, safe, resilient, and sustainable [9].

However, despite the benefits of walking, pedestrians represent one of the most vulnerable road user groups. Global road safety statistics estimate that 1.35 million lives are lost each year due to road trauma [10], and statistics from the World Health Organisation estimate that 22% of road deaths involve a pedestrian [2,11]. The need to reduce road trauma is well recognised in key global strategies including the UN Sustainable Development Goals and the Stockholm Declaration on Road Safety [9,12,13]. These strategies set targets to halve the number of fatal and serious road injuries over the next decade. Within these strategies, it is recognised that the need to reduce pedestrian trauma is a longstanding issue that has been difficult to address.

Finnish road safety is guided by the concept of Vision Zero, where the long-term aim is to eliminate road traffic crashes resulting in fatal or serious injuries [14]. To date, there have been some impressive achievements in terms of pedestrian safety in Finland; for example, in 2019, the city of Helsinki recorded no pedestrian deaths. Notwithstanding, in Finland, like most countries in the OECD, pedestrians are over-represented in injury statistics [15–17].

Recently, Malin et al. [15] performed a review of pedestrian trauma reported in police datasets in Finland between 2014 and 2017. Malin et al. identified that subgroups of pedestrians including males and older pedestrians aged over 75 years had the highest rates of injury [15]. Vehicle type, crash location, temperature, and road conditions were also found to be significantly associated with injury severity when considering differences between fatal and serious injuries. Utriainen et al. further identified an increasing proportion of pedestrian injuries, compared to other road users, when considering police-recorded crashes in Finland between 2014 and 2015 [16]. These studies highlight the risk and overrepresentation of pedestrians in high severity and fatal road traffic crashes and provide insight into the issues associated with pedestrian trauma in Finland. However, a limitation of each study is the use of police-reported datasets, which provide only limited information regarding the circumstances of the crash and injury outcomes of the road users. Furthermore, police-reported datasets often underreport cases involving vulnerable road user groups [18,19]. To develop effective countermeasures to reduce pedestrian trauma and ultimately meet the goals of Vision Zero, there is a need to further understand the contributing factors beyond those identified in police reports.

In Finland, all fatal on-road and off-road motor vehicle crashes are subject to an in-depth investigation in accordance with law 1512/2016 [20]. The Finnish Crash Data Institute "Onnettomuustietoinstituutti" (OTI), which operates as a unit within the Finnish Motor Insurance Centre, coordinates the investigations. Crash investigations are undertaken independently, with the aim of the investigation being to increase road safety, as opposed to investigations being undertaken to assign legal liability. To date, over 15,000 fatal crashes have been investigated [21]. Across Finland, there are 20 teams that investigate crashes in different regions. Each team consists of a police officer, a vehicle engineer, a traffic engineer, a physician, and a psychologist or behavioural scientist. The team adopts a systems approach that aligns with Safe System thinking by considering elements of the road environment, speed, road user behaviour, and vehicle factors during each investigation [21], with each investigation undertaken using a defined methodology detailed in Salo et al. [22].

The aim of this study was to investigate the most recent 10 years of pedestrian cases recorded within the OTI crash dataset. The research provides an updated review of pedestrian trauma in Finland. The analysis identifies events, locations, and demographics that are associated with an increased risk of injury. Cluster analysis is then presented to highlight common crash types and factors most associated with these cases. The findings are discussed in terms of the most prevalent road safety issues that require addressing for Vision Zero targets to be realised in Finland for pedestrians.

2. Methods

2.1. Dataset

Since 1997, all fatal road traffic crashes in Finland involving a pedestrian and caused by a powered vehicle have been investigated by the Finnish Crash Data Institute. The investigation methodology has remained consistent since 2003 [21], which facilitates the investigation of long-term trends in trauma. Each investigation uses a systematic methodology with standardised reports prepared for each case collecting pertinent information regarding the crash. Separate reports are prepared by each member of the investigation team [21]. Risk factors are collected across four main categories: road users, vehicle, environment, and system factors, with recommendations for safety improvements provided for each case. All investigated cases from 2010 to 2019 were included in the analysis where the main person involved was classified as a pedestrian. Permission to undertake the analysis was granted by OTI. Data included all coded variables collected in each investigation. Full-text reports for each case were not examined. Findings are reported at an aggregate level to maintain anonymity.

2.2. Analysis

Analysis involved an exploratory investigation of all cases that resulted in a fatal injury to a pedestrian between 2010 and 2019. Trend data were analysed using log-linear regression to assess estimated annual percentage change and confidence intervals. Comparative analysis was performed using Chi-squared tests (χ^2) to identify differences in prevalence and the influence of various pre-crash conditions between variables of interest. Fisher's exact test was used when individual cell sizes were below 5. Effect size was assessed using Cramer's V statistic (φc).

Two-step cluster analysis was performed to segment crashes into common themes, following the procedure described by Norusis [23]. Clusters were developed iteratively, with the initial cluster considering all variables. Two-step clustering first groups cases into pre-clusters then applies standard hierarchical clustering to form the clusters. The optimal number of clusters was selected using's Schwarz's Bayesian information criterion (BIC), with the number of clusters selected based on the lowest BIC value. Validation of the clusters was performed using three methods: first, the silhouette measure of cohesion and separation is required to be above the level of 0.0, with higher values indicating greater separation between clusters [24]. Next, the predictor importance for each variable was assessed, with variables with a low rating (0.2 or below) removed and clusters reassessed. Finally, Chi-squared, Fisher's exact, and Student t-tests were performed to identify the statistical significance of categorical and continuous variables. Variables were removed from the model and rerun iteratively until the final presented model was identified. A fourth stage of validation is often recommended [25], however was not applicable for this study due to the small sample size with a minimum threshold of 300 cases recommended. The clusters represent cases with common attributes and provide an indication of key pedestrian crash risks. Finally, recommendations from the OTI investigation team regarding each crash were summarised for each of the clusters to elucidate the most pertinent safety recommendations. All data were analysed using IBM © SPSS v.27 with alpha (α) set to 0.05.

3. Results

In total, 281 investigations occurred across Finland between 2010 and 2019. The annual number of cases decreased over the study period from 36 to 13; based on the regression analysis, this represented a statistically significant annual decrease of −7.3% (95% CI −11.5% to −3.2%). However, it is noted that cases are rare, and there is annual fluctuation in the number of cases.

3.1. Investigation Region

Figure 1 classifies case location by the region of investigation. The highest number of cases was recorded in the Uusimaa region (16.4%). The Uusimaa region includes Helsinki; however, a separate investigation team operates in the Helsinki metropolitan region. Combined, the cases from Uusimaa and Helsinki represent one quarter of cases. The next most common investigation locations were Pirkanmaa (11%), which includes the city of Tampere, and Varsinais-Suomi (10.7%), which includes the city of Turku.

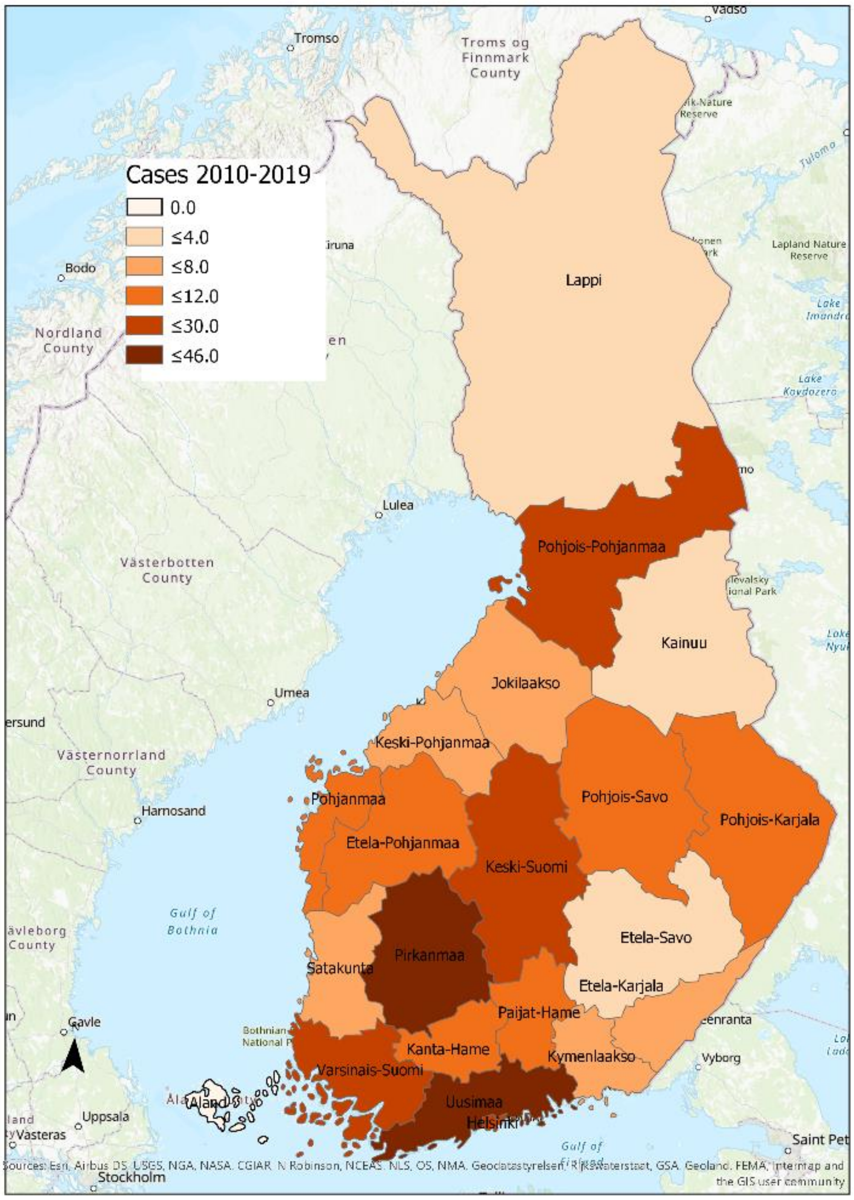

Figure 1. Investigations per region.

When adjusting for population (Table 1), the Pohjanmaa and Kanta-Häme regions had the highest rates of cases per 100,000 population, highlighting the risk of pedestrian trauma even in sparsely populated regions of Finland.

3.2. Pedestrian Characteristics

When considering the demographics of pedestrians (Table 2), females (48.0%) were involved in fewer cases than males (52.0%). The average age of pedestrians was 56.5 years (SD = 24.7) and ranged from 1 to 96 years. Pedestrians aged 75 and older were involved in the most cases compared to other age groupings. When cross-tabulating age and gender, older females represented the most common group, followed by young male adults (χ^2 (5) = 27.8, p < 0.01, φc = 0.32).

Table 1. Pedestrian cases per investigation region 2010–2019.

Region	Number of Cases (281)	%	Population (Estimate as per 31 December 2020)	Cases per 100,000 Population
Uusimaa (excluding Helsinki)	46	16.4	1,045,758	4.40
Pirkanmaa (Tampere region)	31	11.0	519,391	5.97
Varsinais-Suomi (Southwest Finland)	30	10.7	481,403	6.23
Helsinki	28	10.0	656,920	4.26
Pohjois-Pohjanmaa (North Ostrobothnia)	17	6.0	301,264	5.64
Keski-Suomi (Central Finland)	16	5.7	274,778	5.82
Kanta-Häme	12	4.3	170,577	7.03
Päijät-Häme	12	4.3	199,146	6.03
Pohjanmaa (Ostrobothnia)	12	4.3	130,618	9.19
Pohjois-Karjala (North Karelia)	11	3.9	160,341	6.86
Etelä-Pohjanmaa (South Ostrobothnia)	10	3.6	187,679	5.33
Satakunta	8	2.8	216,716	3.69
Pohjois-Savo (North Savo)	8	2.8	243,576	3.28
Keski-Pohjanmaa (Central Ostrobothnia)	8	2.8	117,657	6.80
Kymenlaakso	7	2.5	169,437	4.13
Jokilaakso	7	2.5	121,166	5.78
Etelä-Karjala (South Karelia)	6	2.1	127,721	4.70
Etelä-Savo (South Savo)	4	1.4	139,787	2.86
Kainuu	4	1.4	71,664	5.58
Lappi (Lapland)	4	1.4	176,665	2.26

Table 2. Pedestrian characteristics and use of intoxicants.

Characteristics	Variable	N (281)	%
Gender	Female	135	48.0
	Male	146	52.0
Age group	0–17	18	6.4
	18–34	50	17.8
	35–54	49	17.4
	55–64	31	11.0
	65–74	52	18.5
	75+	81	28.8
Alcohol	Yes	56	19.9
	No	216	76.9
	Not known	9	3.2
Illegal narcotics	Yes	8	2.8
	No	265	94.3
	Not known	8	2.8

Toxicology of pedestrians detected the presence of alcohol in 19.9% of cases, with the presence of alcohol unknown in 3.2% of cases. Male pedestrians were over-represented in cases involving alcohol (82.1%) (χ^2 (2) = 23.8, p < 0.01, φc = 0.29). Narcotics were less prevalent, with the presence of narcotics identified in only eight cases. Young (18–34) and middle-aged (35–54) pedestrians represented the majority of cases involving alcohol (76.7%) and narcotics (87.5%).

3.3. Injury Characteristics

Three measures of injury were reported for each case: the injury severity, based on Abbreviated Injury Scale (AIS) score, the Injury Severity Score (ISS), and the grouped injury type based on ICD-10 external cause codes (Table 3). ISS scores are grouped as per the classification proposed by Bolorundura et al. [26]. Most cases were found to result in profound injury with an ISS score greater than 25. Four cases resulted in mild injuries despite a fatal outcome for the pedestrian. Injuries most commonly occurred to the head, thorax, or multiple body regions.

Table 3. Injury characteristics.

Characteristics	Variable	N (281)	%
Injury severity	Died immediately	145	51.6
	Died before treatment	29	10.3
	Died within 6 h	43	15.3
	Died within 6–24 h	21	7.5
	Died within 1–7 days	25	8.9
	Died within 7–30 days	16	5.7
	Died in more than 30 days	2	0.7
Injury Severity Score	<9 = Mild	4	1.4
	9–15 = Moderate	3	1.1
	16–24 = Severe	19	6.8
	>/= 25 = Profound	224	79.7
	Not recorded	31	11.0
ICD-10	Injuries to the head	116	41.3
	Injuries to the thorax	51	18.1
	Injuries involving multiple body regions	45	16.0
	Injuries to the neck	18	6.4
	Injuries to the abdomen, lumbosacral region	11	3.9
	Other	16	5.7
	Not recorded	24	8.5

3.4. Road and Environment

Seasonal trends show that the highest proportion of crashes was investigated in winter (December–February) and autumn (September–November) months of the year. In Finland, these times of year have fewer daylight hours; for example, there are as few as 6 h of daylight in December in Helsinki and even fewer in northern parts of the country. Furthermore, an increased proportion of crashes occurred during dark lighting conditions during these seasons (χ^2 (5) = 30.7, $p < 0.01$, $\varphi c = 0.23$) (Figure 2).

When considering the day of the week, 76.9% of cases occurred on weekdays. Saturday had the lowest proportion of cases, with only 9.3%. Crashes most commonly occurred in the afternoon between noon and 6 p.m. (39.9%) (Table 4).

Highways, main streets, and collector streets were the most common road environments for crashes (Table 5). This roughly corresponds with the most common speed environments in Finland, where the standard speed limit on urban roads is 50 km/h and 80 km/h on non-urban roads, while a growing number of cities have adopted 30 and 40 km/h speed limits. The majority of crashes (71.5%) occurred on straight sections of roadway, with intersections (27.0%) and midblock sections of road (45.2%) representing the majority of road cross-sections. Adjacent land use was most often residential, and most crashes occurred when the road surface was dry (56.2%).

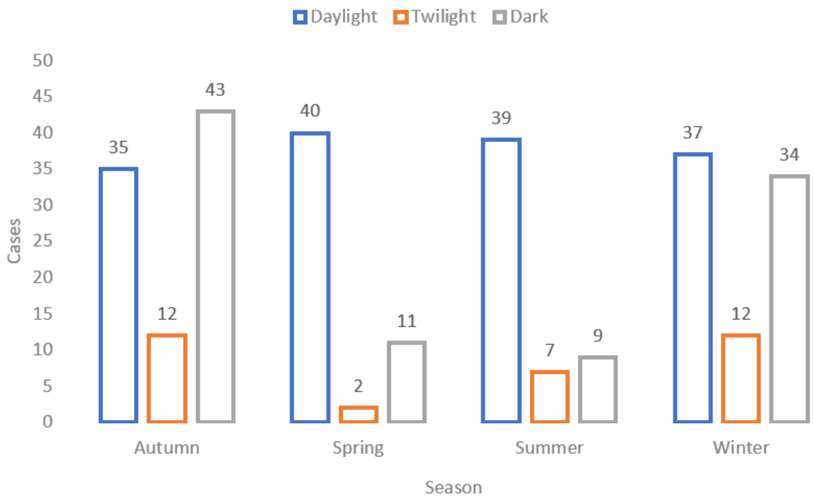

Figure 2. Season vs. daylight condition.

Table 4. Temporal characteristics.

Characteristics	Variable	N (281)	%
Day of week	Monday	52	18.5
	Tuesday	38	13.5
	Wednesday	48	17.1
	Thursday	42	14.9
	Friday	39	13.9
	Saturday	26	9.3
	Sunday	36	12.8
Time of Day	0:00–5:59	36	12.8
	6:00–11:59	83	29.5
	12:00–17:59	112	39.9
	18:00–23:59	50	17.8

Table 5. Road environment characteristics.

Characteristics	Variable	N (281)	%
Road type	Highway	53	18.9
	Main road	13	4.6
	Regional road	30	10.7
	Connecting road	27	9.6
	Main street	47	16.7
	Collector	43	15.3
	Other street	21	7.5
	Private road or area (e.g., yard)	30	10.7
	Light traffic route	14	5.0
	Other	3	1.1
Road alignment	Straight	201	71.5
	Curve	44	15.7
	Other/Not known	36	12.8

Table 5. *Cont.*

Characteristics	Variable	N (281)	%
Road cross-section	Mid-block	127	45.2
	Intersection	76	27.0
	Public transport stop	10	3.6
	Overtaking lane	1	0.4
	Yard area or private grounds	20	7.1
	Road works	2	0.7
	Railway level crossing	10	3.6
	Car park	6	2.1
	Rest area	1	0.4
	Other	27	9.6
	Not known	1	0.4
Adjacent land use	Residential area	123	43.8
	Industrial area	10	3.6
	Trade and service area	63	22.4
	Agriculture and forestry area	70	24.9
	Other/not known	15	5.3
Speed limit (km/h)	≤30	19	6.8
	40	91	32.4
	50	50	17.8
	60	20	7.1
	70	2	0.7
	80	49	17.4
	≥100	27	9.6
	No speed limit	17	6.0
	Not known	6	2.1
Road surface condition	Dry	158	56.2
	Wet	59	21.0
	Snowy	42	14.9
	Only driving tracks clear	14	5.0
	Other/not known	8	2.8

3.5. Crash Mechanisms

Passenger cars were the most common counterpart (47.0%), followed by heavy vehicles (24.9%), light vehicles (7.8%), and buses (7.8%) (Table 6). Only a small number of cases involved collisions with bicycles (3). Collisions most commonly occurred when the pedestrian was crossing the road or when walking on the roadway. A number of crashes also occurred with pedestrians lying on the roadway. It is noted that cases involving suicide or suspected suicide are included in the dataset.

3.6. Cluster Analysis

Using the crash characteristic, cluster analysis was undertaken, using the methodology outlined in Section 2, to group crashes and identify common themes amongst crashes based on the similarity of variables. Four unique clusters were identified (silhouette value 0.2, BIC = 390.7). A summary of the most common variables for each cluster is included in Table 7. Each cluster is then discussed, including the most common road safety recommendations proposed by the investigation teams for addressing cases within each cluster.

Table 6. Collision counterparts and mechanism.

Characteristics	Variable	N (281)	%
Counterpart	Passenger cars	132	47.0
	Light vehicles	22	7.8
	Heavy vehicles	70	24.9
	Bus	22	7.8
	Motorcycle	1	0.4
	Light motorcycle	2	0.7
	Moped	4	1.4
	Tram	2	0.7
	Train	10	3.6
	Bicycle	3	1.1
	Multiple vehicles	4	1.4
	Other	9	3.2
Mechanism	Pedestrian crossing	141	5.3
	Pedestrian emerging from behind stationary vehicle	6	2.1
	Pedestrian stationary on road	30	10.7
	Pedestrian walking in direction of traffic	15	5.3
	Pedestrian walking towards traffic	17	6.0
	Pedestrian on footway or traffic island	4	1.4
	Rollover crash on the road	21	7.5
	Collision with train	10	3.2
	Passenger entering or leaving vehicle	3	1.1
	Reversing crash	1	0.4
	Collision into traffic island	2	0.7
	Collision with an obstacle on the road	1	0.4
	Running off to right on straight section of road	1	0.4
	Collision with animal	1	0.4
	Other pedestrian crash	28	8.9

Table 7. Cluster analysis summary.

Variable	Cluster 1 (28.6%)	Cluster 2 (27.9%)	Cluster 3 (25.7%)	Cluster 4 (17.8%)	*p*-Value
Age (mean)	68.5	57.9	54.9	38.2	≤ 0.05
Gender	Female (69.6%)	Male (58.4%)	Male (50.7%)	Male (75.5%)	≤ 0.05
Alcohol detected for pedestrian	No (88.6%)	No (88.3%)	No (80.3%)	Yes (61.2%)	≤ 0.05
Collision counterpart	Car (59.5%)	Car (50.6%)	Car (40.8%)	Heavy vehicle (51.0%)	≤ 0.05
Season	Winter (36.7%)	Winter (36.4%)	Spring (29.6%)	Autumn (44.9%)	≤ 0.05
Light conditions	Daylight (65.8%)	Daylight (57.1%)	Daylight (71.8%)	Dark (81.6%)	≤ 0.05
Time of day	12:00–17:59 (55.7%)	12:00–17:59 (51.9%)	12:00–17:59 (39.4%)	0:00–5:59 (55.1%)	≤ 0.05
Road type	Collector (41.8%)	Highway (32.5%)	Private road or area (38.0%)	Highway (57.1%)	≤ 0.05
Speed limit	40 km/h (63.3%)	80 km/h (44.2%)	40 km/h (43.7%)	100 km/h (32.7%)	≤ 0.05
Crash mechanism	Pedestrian on crossing (27.8%)	Pedestrian otherwise crossing road (48.1%)	Other pedestrian crash (25.4%)	Pedestrian stationary on road (42.9%)	≤ 0.05

3.6.1. Cluster 1: Older Adults at Crossings

Cluster 1 represented 28.6% of cases and was characterised by pedestrians crossing at intersections. Crashes were typically in 40 km/h speed environments (63.3%) on collector roads with the pedestrian hit by a turning car. Typically, cases involved older female adults (M = 68.5 yrs) and occurred in daylight conditions (65.8%) in the afternoon (55.7%). The most common recommendations from the investigation teams for these crashes were increased emphasis on driver behaviour and training to predict potential collisions, installation of traffic signals at pedestrian crossings, advanced driver assistance (ADAS) technologies to assist with pedestrian detection, and increasing the number of crosswalks to facilitate pedestrian movements.

3.6.2. Cluster 2: Crossing in High-Speed Environments

Cluster 2 represented 27.9% of cases and was characterised by crashes in 80 km/h speed environments and highways. These crashes commonly involved males (m = 57.9 yrs) crossing the road away from a pedestrian crossing. Crashes most often occurred in daylight conditions in the afternoon; however, 26% occurred when it was dark. Common safety recommendations provided by the investigation team included construction or widening of pedestrian facilities, improvements to street lighting, increased emphasis on driver behaviour and training, and the use of reflection material in clothing or fixed reflectors.

3.6.3. Cluster 3: Off-Street Environments

Cluster 3 represented 25.7% of cases and was characterised by crashes on private roads or in parking facilities. As such, these cases were associated with lower speed environments or the speed limit was not recorded by the investigation team. Crashes involved males and females evenly with an average age of 54.9 years. Recommendations for these cases included ADAS technologies to assist with pedestrian detection such as forward radar and reversing devices to assist drivers when parking, reducing the complexity of city driving environments, providing more guidance to drivers, and the use of crosswalk facilities that encourage drivers to adjust their speed, for example, a raised crosswalk.

3.6.4. Cluster 4: Intoxication

Cluster 4 represented 17.8% of cases and was associated with pedestrians with recordings of alcohol in toxicology reporting. Cases commonly involved younger males (m = 38.2 yrs). Crashes were most often in highway environments with speed limits of 100 km/h with around a third of cases involving a pedestrian laying on the roadway. Crashes were most common in the morning hours before 6 a.m. while it was either dark (81.6%), or twilight (18.4%). Recommendations included increased street lighting, ADAS technologies for vehicles, and guidance and health support for people using the road environment under the influence of alcohol and drugs, including education on the dangers of substances and their interactions.

4. Discussion

Pedestrians are a vulnerable road user group. In order to meet road safety targets such as Vision Zero and the UN Sustainable Development Goals [9,14], there is a need to address their specific road safety requirements. Previous research in Finland has demonstrated an increasing proportion of road traffic crashes resulting in injuries to pedestrians [16], highlighting the need for further investigation of this issue. Similarly, global road safety statistics highlight the high proportion of road traffic crashes involving vulnerable road users.

This study presents an exploratory and cluster analysis of fatal pedestrian crashes between 2010 and 2019 that were subject to in-depth investigations. The analysis highlighted the high number of pedestrian crashes focused in populous city regions of Finland, with a prevalence of crashes in residential areas. This is somewhat expected and aligns with previous analysis highlighting increased pedestrian trauma in urban areas and locations with increased pedestrian activity, such as arterial roads and shopping districts [27]. However, when adjusting for population, the highest rates of trauma were in sparsely populated regions of Finland, yet the absolute number of cases was low, highlighting the need to also consider non-urban and rural areas when implementing pedestrian safety measures.

Key at-risk groups identified in the analysis align with Finnish and international research [2,15,27]. The highest number of cases involved pedestrians over the age of 75, in line with previous analysis by Malin, who identified a heightened rate of serious and fatal injuries amongst older adults [15]. The findings of cluster analysis indicate that many cases involving older pedestrians occur at pedestrian crossings in low-speed environments. Recommendations from the investigation teams suggest the installation of pedestrian-operated signals to improve priority for pedestrians. However, crossing green phases need to be designed to allow for slower walking speeds of the elderly to ensure safety [27]. Other recommendations to improve pedestrian safety at crossings include shortening crossing distances through the use of medians or kerb outstands, passive detection to increase the time allocated to pedestrians or to only call vehicle phases when needed, and raised crosswalks and intersections [2,28].

The analysis also identified pedestrians under the influence of alcohol as a high-risk group. The inclusion of toxicology in the in-depth crash investigation assists in the quantification of the extent of this issue. Furthermore, this study provides added insight into this at-risk group through cluster analysis and identified cases to often involve younger male pedestrians, with collisions most commonly occurring in high-speed road environments at night. Research from Tennessee in the United States of America found similar patterns amongst alcohol-affected pedestrians [29] while also noting that the share of alcohol-affected pedestrians increased with injury severity. Education campaigns to inform pedestrians of the dangers associated with the road environment, particularly when under the influence of alcohol and narcotics, were recommended by the investigation team, while modifications to signal phases have previously been found to improve safety for intoxicated pedestrians [30].

When considering vehicle factors in the collision, passenger cars were the most prominent counterpart. Heavy vehicles were over-represented in cases with one quarter of cases involving a heavy vehicle, despite representing only 7.8 percent of vehicle kilometres travelled in Finland [31]. Heavy vehicles pose an added risk to pedestrians even at lower speeds, due to the incompatibility between pedestrians and heavy vehicles when considering their size, mass, and kinetic energy in the event of a collision [32]. Furthermore, research suggests that the average size and mass of heavy vehicles have been increasing in Finland as a result of changing legislation allowing larger vehicles [33]. However, this is likely to be coupled with increased safety improvements to heavy vehicles, and there is conjecture regarding the road safety implications of these newer heavy vehicles, particularly if they result in fewer heavy vehicles on the roadway. Furthermore, ADAS technologies are likely to reduce the risk of pedestrian trauma by reducing human error associated with many vehicle collisions [34].

Lowering vehicle speeds is another proven method of reducing the risk of pedestrian trauma. A recent meta-analysis by Hussain et al. estimated that the risk of a fatal injury was 13% at an impact speed of 40 km/h, and this reduced to 5% at 30 km/h [35]. Similar relationships have also been identified when examining serious injuries [36,37]. Within the analysis, the high proportion of cases that occurred in 40 and 50 km/h zones could be reduced by lowering posted speed limits. Lower vehicle speeds not only reduce kinetic energy in collisions but also increase driver time to react and reduce required braking distances in the event of a potential collision [38].

A unique element to the pattern of injury in this study is the seasonal effects. Finland is characterised by highly variable seasons. Winter months are cold, with snow and few daylight hours, while summer months are temperate with long days. The influence of season, lighting conditions, and road surface conditions were all highlighted in the analysis. Higher rates of crashes, particularly involving older pedestrians, were observed in winter months and during dark conditions. Previous research has identified the association between adverse weather conditions, poor lighting, and injury severity [39], with findings highlighting this issue in other Nordic countries. Improvements to street lighting were a commonly recommended road safety countermeasure identified by the investigation teams to reduce the risk of pedestrian trauma, with findings from previous reviews of the literature indicating that road lighting is associated with a reduction in crashes in darkness [39].

While street lighting may improve driver detection of pedestrians, it does not address other common human factor issues such as distracted driving. Another common recommendation from the crash investigation teams was the implementation of ADAS technologies, which can assist with pedestrian detection and reduce the consequences of human error while driving. ADAS was recommended both for crashes on-road and for crashes that occurred in private areas such as car parks or parking garages. Notwithstanding these technologies' potential to improve pedestrian safety, they do not mitigate the need for appropriate design of parking and pedestrian crossing facilities or the need to encourage and educate drivers regarding how to safely interact with vulnerable road users.

This study provides insight into pedestrian trauma in Finland; however, it is not without limitations. Firstly, the analysis has utilised case data, but not in-depth case files collected by the investigation team. Extension of the analysis to include the full case reports could provide greater information about cases and allow for further understanding of the contributing factors of collisions. However, this further analysis would require reading case reports, which was beyond the scope of this analysis. Notwithstanding, these reports should be considered for further research.

The implications of COVID-19 have resulted in significant changes in peoples' travel behaviour [40,41]. While the analysis included in this report was for the years 2010 to 2019 and did not include periods when Finland was subject to mobility restrictions, it may be difficult to compare these findings to future analysis, particularly if mobility patterns change post-COVID-19. Some research suggests that this may result in an increased reliance on private vehicular travel, and as such, it is possible that pedestrian trauma could increase due to the non-linear relationships between vulnerable road user trauma and exposure to vehicular traffic [42].

Notwithstanding, the findings highlight key road safety issues to address for pedestrian trauma in Finland, including provision of safer crossing facilities for elderly pedestrians, improvements to parking and shared facilities, and addressing issues of intoxicated pedestrians. Addressing these key issues will further Finland's progression towards meeting Vision Zero targets while creating a safer and sustainable urban environment in line with UN sustainability goals.

Author Contributions: Conceptualisation, S.O., R.U., H.T., M.P., and N.S.; methodology, S.O., M.P., and N.S.; formal analysis, S.O., H.T., R.U., M.P., and N.S.; data curation, S.O., R.U., H.T., and N.S.; writing—original draft preparation, S.O., R.U., H.T., N.S., and M.P.; writing—review and editing, S.O., R.U., H.T., N.S., and M.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data are available by request from OTI.

Conflicts of Interest: NS is employed by OTI, who provided access to the data utilized in this study.

References

1. WHO. *Pedestrian Safety: A Road Safety Manual for Decision-Makers and Practitioners*; WHO: Geneva, Switzerland, 2013.
2. Zegeer, C.V.; Bushell, M. Pedestrian crash trends and potential countermeasures from around the world. *Accid. Anal. Prev.* **2012**, *44*, 3–11. [CrossRef]
3. WHO. *Global Age-Friendly Cities: A Guide*; World Health Organization: Geneva, Switzerland, 2007; ISBN 9241547308.
4. O'Hern, S.; Oxley, J. Understanding travel patterns to support safe active transport for older adults. *J. Transp. Heal.* **2015**, *2*. [CrossRef]
5. Barton, J.; Hine, R.; Pretty, J. The health benefits of walking in greenspaces of high natural and heritage value. *J. Integr. Environ. Sci.* **2009**, *6*, 261–278. [CrossRef]
6. Rabl, A.; De Nazelle, A. Benefits of shift from car to active transport. *Transp. Policy* **2012**, *19*, 121–131. [CrossRef]
7. Rafiemanzelat, R.; Emadi, M.I.; Kamali, A.J. City sustainability: The influence of walkability on built environments. *Transp. Res. procedia* **2017**, *24*, 97–104. [CrossRef]
8. Kato, H. Effect of Walkability on Urban Sustainability in the Osaka Metropolitan Fringe Area. *Sustainability* **2020**, *12*, 9248. [CrossRef]
9. Desa, U.N. *The Sustainable Development Goals Report*; United Nations: San Francisco, CA, USA, 2018.

10. Janstrup, K.H. *Road Safety Annual Report 2017*; Technical University of Denmark: Lyngby, Denmark, 2017.
11. WHO. *Global Status Report on Road Safety 2018*; WHO: Geneva, Switzerland, 2019.
12. Griggs, D.; Stafford-Smith, M.; Gaffney, O.; Rockström, J.; Öhman, M.C.; Shyamsundar, P.; Steffen, W.; Glaser, G.; Kanie, N.; Noble, I. Sustainable development goals for people and planet. *Nature* **2013**, *495*, 305–307. [CrossRef]
13. Mohan, D.; Jha, A.; Chauhan, S.S. Future of road safety and SDG 3.6 goals in six Indian cities. *IATSS Res.* **2021**, *45*, 12–18. [CrossRef]
14. Huuskonen, M. In Proceedings of the Vision Zero Summit 2019, Helsinki, Finland, 12–14 November 2019.
15. Malin, F.; Silla, A.; Mladenović, M.N. Prevalence and factors associated with pedestrian fatalities and serious injuries: Case Finland. *Eur. Transp. Res. Rev.* **2020**, *12*, 1–17. [CrossRef]
16. Utriainen, R.; Pöllänen, M.; Liimatainen, H. Road safety comparisons with international data on seriously injured. *Transp. Policy* **2018**, *66*, 138–145. [CrossRef]
17. Buehler, R.; Pucher, J. Trends in walking and cycling safety: Recent evidence from high-income countries, with a focus on the United States and Germany. *Am. J. Public Health* **2017**, *107*, 281–287. [CrossRef]
18. Boufous, S.; de Rome, L.; Senserrick, T.; Ivers, R.Q. Single-versus multi-vehicle bicycle road crashes in Victoria, Australia. *Inj. Prev.* **2013**, *19*, 358–362. [CrossRef]
19. O'Hern, S.; Oxley, J. Fatal cyclist crashes in Australia. *Traffic Inj. Prev.* **2018**, *19*, S27–S31. [CrossRef]
20. LVM Act on the Investigation of Road and Off-Road Accidents. Available online: https://www.finlex.fi/fi/laki/alkup/2016/20161512 (accessed on 3 March 2021).
21. Onnettomuustietoinstituutti (OTI). *Liikenneonnettomuuksien Tutkintamenetelmä 2003*; Onnettomuustietoinstituutti (OTI): Helsinki, Finland, 2018.
22. Salo, I.; Parkkari, K.; Sulander, P.; Keskinen, E. In-Depth on-the-Spot Road Accident Investigation in Finland. In Proceedings of the 2nd International Conference on ESAR "Expert Symposium on Accident Research"; Bundesanstalt für Straßenwesen: Hannover, Germany, 2007; pp. 28–37.
23. Norušis, M.J. *IBM SPSS Statistics 19 Statistical Procedures Companion*; Prentice Hall: Upper Saddle River, NJ, USA, 2012; Volume 496.
24. Tkaczynski, A. Segmentation using two-step cluster analysis. In *Segmentation in Social Marketing*; Springer: Berlin/Heidelberg, Germany, 2017; pp. 109–125.
25. Hair, J.F. *Multivariate Data Analysis: A Global Perspective*, 7th ed.; Prentice Hall: Upper Saddle River, NJ, USA, 2009.
26. Bolorunduro, O.B.; Villegas, C.; Oyetunji, T.A.; Haut, E.R.; Stevens, K.A.; Chang, D.C.; Cornwell III, E.E.; Efron, D.T.; Haider, A.H. Validating the Injury Severity Score (ISS) in different populations: ISS predicts mortality better among Hispanics and females. *J. Surg. Res.* **2011**, *166*, 40–44. [CrossRef] [PubMed]
27. O'Hern, S.; Oxley, J.; Logan, D. Older adults at increased risk as pedestrians in Victoria, Australia: An examination of crash characteristics and injury outcomes. *Traffic Inj. Prev.* **2015**, *16*, S161–S167. [CrossRef] [PubMed]
28. Candappa, N.; Stephan, K.; Fotheringham, N.; Lenné, M.G.; Corben, B. Raised crosswalks on entrance to the roundabout—a case study on effectiveness of treatment on pedestrian safety and convenience. *Traffic Inj. Prev.* **2014**, *15*, 631–639. [CrossRef]
29. Hezaveh, A.M.; Cherry, C.R. Walking under the influence of the alcohol: A case study of pedestrian crashes in Tennessee. *Accid. Anal. Prev.* **2018**, *121*, 64–70. [CrossRef]
30. Lenné, M.G.; Corben, B.F.; Stephan, K. Traffic signal phasing at intersections to improve safety for alcohol-affected pedestrians. *Accid. Anal. Prev.* **2007**, *39*, 751–756. [CrossRef] [PubMed]
31. Statistics Finland Finnish Road Statistics. Available online: https://www.stat.fi/til/tiet/2020/tiet_2020_2021-04-15_tie_001_en.html (accessed on 26 May 2021).
32. Elvik, R. Why some road safety problems are more difficult to solve than others. *Accid. Anal. Prev.* **2010**, *42*, 1089–1096. [CrossRef]
33. Liimatainen, H.; Pöllänen, M.; Nykänen, L. Impacts of increasing maximum truck weight–Case Finland. *Eur. Transp. Res. Rev.* **2020**, *12*, 1–12. [CrossRef]
34. Thomas, P.; Morris, A.; Talbot, R.; Fagerlind, H. Identifying the causes of road crashes in Europe. *Ann. Adv. Automot. Med.* **2013**, *57*, 13.
35. Hussain, Q.; Feng, H.; Grzebieta, R.; Brijs, T.; Olivier, J. The relationship between impact speed and the probability of pedestrian fatality during a vehicle-pedestrian crash: A systematic review and meta-analysis. *Accid. Anal. Prev.* **2019**, *129*, 241–249. [CrossRef]
36. Rosen, E.; Stigson, H.; Sander, U. Literature review of pedestrian fatality risk as a function of car impact speed. *Accid. Anal. Prev.* **2011**, *43*, 25–33. [CrossRef]
37. Elvik, R.; Vadeby, A.; Hels, T.; van Schagen, I. Updated estimates of the relationship between speed and road safety at the aggregate and individual levels. *Accid. Anal. Prev.* **2019**, *123*, 114–122. [CrossRef]
38. Bahrololoom, S.; Young, W.; Logan, D. Modelling injury severity of bicyclists in bicycle-car crashes at intersections. *Accid. Anal. Prev.* **2020**, *144*, 105597. [CrossRef]
39. Johansson, Ö.; Wanvik, P.O.; Elvik, R. A new method for assessing the risk of accident associated with darkness. *Accid. Anal. Prev.* **2009**, *41*, 809–815. [CrossRef]
40. Laverty, A.A.; Millett, C.; Majeed, A.; Vamos, E.P. COVID-19 presents opportunities and threats to transport and health. *J. R. Soc. Med.* **2020**, *113*, 251–254. [CrossRef] [PubMed]

41. Beck, M.J.; Hensher, D.A.; Wei, E. Slowly coming out of COVID-19 restrictions in Australia: Implications for working from home and commuting trips by car and public transport. *J. Transp. Geogr.* **2020**, *88*, 102846. [CrossRef] [PubMed]
42. Elvik, R. The non-linearity of risk and the promotion of environmentally sustainable transport. *Accid. Anal. Prev.* **2009**, *41*, 849–855. [CrossRef] [PubMed]