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Attributable hospital costs, home care costs and risk of long-term sickness benefits following traffic injuries by road user type

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A R T I C L E I N F O

Keywords:
Attributable hospital cost
Attributable home care cost
Attributable risk of long-term sickness benefits
Traffic injury
Vulnerable road users
Case-crossover design

A B S T R A C T

Background: Traffic injuries involving vulnerable road users tend to be forgotten in the political prioritisation in many countries. The underreporting of traffic crashes in vulnerable road users is much higher than that of crashes involving cars. Sometimes, it is even argued that underreported crashes in vulnerable road users are costless. In this study, we aimed to estimate the hospital and home care costs, as well as the risk of long-term sickness benefits, associated with a traffic injury by road user type in the first year after the injury.
Methods: The study used a complete sample of traffic injuries treated in emergency rooms and hospitals in Denmark. We applied a nationwide case-crossover design to the data, comprising 47,242 hospital-registered traffic injuries, of which 14,246 were cyclist injuries and 17,193 were pedestrian injuries, including pedestrian falls. We estimated the attributable hospital and home care costs following the traffic injuries in a two-part model and the excess risk of long-term sickness benefits beyond four weeks in a binomial regression model, taking into account that the data originated from a case-crossover design.
Results: We found that cyclist injuries were as costly as car injuries. Comparing all road users, we found that the most expensive traffic injuries were those of motorcyclists, moped drivers and pedestrians involved in multiparty crashes.
Conclusion: Traffic injuries involving vulnerable road users reach a price level similar to that of car injuries. The underreporting of crashes in vulnerable road users can, however, imply that road authorities choose safety measures that prevent car–car crashes instead of those that prevent crashes involving vulnerable road users, such as single-bicycle crashes or pedestrian falls. The outcome of this lack of knowledge and recognition is a biased prioritisation of the limited resources for road safety work.

1. Introduction

The available resources for road safety work are limited. In some cases, road authorities must choose between safety measures preventing traffic injuries for different road user types. An example is prioritising between the rebuilding of four-lane intersections into roundabouts, which primarily prevent car collisions, and good maintenance of sidewalks and cycle paths during winter, which primarily prevents injuries to vulnerable road users. This prioritisation is often necessary because funds are limited and come from the

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same public coffers for road improvements.

In Denmark, as is the case in other countries, cyclist injuries tend to be forgotten in the political debate because only a few cyclist injuries find their way to police reports compared with motor vehicle injuries (Aertsens et al., 2010; Meltofte et al., 2015; Scholten et al., 2015; Danish Road Directorate, 2018). The underreporting of cyclist crashes in Denmark has been estimated at 86% for severe injuries and 93% for slight injuries, whereas the corresponding figures were 32% and 75% for car injuries (Janstrup et al., 2016). Similar findings of underreporting in police registrations are also well known in other countries (Broughton et al., 2010; Derriks and Mak, 2007; Elvik and Mysen, 1999). Apparently, hospital records of traffic injuries may be less influenced by underreporting and give another picture of injuries, especially amongst vulnerable road users (Meltofte et al., 2015; Statistics Denmark, 2019). Furthermore, pedestrian falls on public roads must be included in traffic safety work even though they are not officially defined today as traffic crashes. In a cost-of-illness (COI) analysis, this underreporting in police reports should also be included. COI is descriptive and often used to shed light on the burden of a disease or, as in this case, the burden of traffic injuries to society and, therefore, the savings that could be made if traffic injuries could be lowered or eradicated (Rice, 1967). This way, COI is useful information for policymakers on how much could be saved, e.g. through the funding of pavement maintenance and other pedestrian facilities, which is often found on the same budget as the funding of safety measures for other road user types (Berg et al., 2016; Elvik and Bjørnskau, 2019).

Police underreporting of crashes amongst vulnerable road users may lead to a trivialisation of the societal costs of their injuries compared with those of other road users, e.g. car users. A calculation of costs based on a hospital sample of traffic injuries would be beneficial. Four recent European studies have estimated the attributable costs of traffic injuries by road user type based on hospital data (Polinder et al., 2016; Devos et al., 2017; Papadakaki et al., 2017; van der Vlegel et al., 2020). Two studies dealt with serious injuries in patients admitted to a hospital ward or an intensive care unit (Papadakaki et al., 2017; van der Vlegel et al., 2020), whereas the two other studies had (almost) complete population-based study populations of both emergency room and hospital-treated traffic injuries (Polinder et al., 2016; Devos et al., 2017). All studies agreed that the economic burden of traffic injuries is considerable, and they presented an implicit ranking of injury costs by road user type. Neither of the studies considered the cost of pedestrian falls.

The four European studies used different approaches, which are reflected in the between-study variance of prices. The price of a traffic injury varies by the cost estimation method (Wijnen et al., 2019), the perspective of the study and the types of costs included in the evaluation, e.g. whether productivity costs are included (Rissanen et al., 2017; Wijnen et al., 2017; Wijnen and Stipdonk, 2016). Regarding perspective, the cost of hospitalisation constitutes only a minor part of the societal cost of traffic injuries when the broadest possible perspective is chosen. When a narrower perspective is chosen as in many health economic studies, e.g. a municipality and/or a hospital perspective, the hospital costs constitute a much greater part; in this case, the cost of a traffic injury can be a visualisation of the burden for a hospital, a region or a municipality and is eventually used in prioritisation.

Regardless of perspective, the objective of all policymakers is to prevent traffic injuries, and the pricing of injuries is necessary for prioritising prevention funds in public budgets. This can be done through the use of different economic evaluation tools, such as a cost–benefit analysis in which the effect (of the traffic safety measure) is monetarised and compared to the cost of the measure that prevents traffic crashes. Rationally, one should choose the safety measure with the largest reduction in the number of injuries per spent euro.

Regarding the methods for estimating the costs of traffic injuries, in the national Danish scene, one (important) report on the costs of traffic crashes proceeded without the appropriate use of controls (Danish Road Directorate, 2013). At some point, the report did not consider that the injured could have ended up in societal paid care for reasons other than the traffic crash. Two other Danish studies included controls but did not categorise the cost of traffic injuries by road user type (Kruse, 2015; Nielsen and Andersen, 2014).

The use of suitable controls is key to the proper estimation of the costs, e.g. of traffic injuries (Devos et al., 2017). Devos and colleagues used a case-crossover design for the estimation of direct hospital costs in the first year after the traffic injury; that is, they used the injured themselves as their own control in the year before the injury. The case-crossover design matched important confounders, e.g. individual comorbidity, socioeconomic status and favoured means of transport, along with personal characteristics, e.g. risk-taking behaviour.

In this study, we addressed the direct costs of hospitalisation (both inpatient and outpatient treatment) and the subsequent (municipality) care at home (nursing, cleaning and rehabilitation), along with the risk of long-term sickness benefits in the first year after a traffic injury in Denmark—all evaluated together in a case-crossover design using the injured as their own control. We hypothesised that the estimated costs would be less biased with appropriate control for the favoured use of the means of transportation and personal characteristics, e.g. risk-taking behaviour. We wanted to highlight the differences amongst the costs associated with the various road user groups, including pedestrian falls, and thus allow transportation authorities to include these differences in the prioritisation of different road safety measures.

2. Methods

2.1. Study design, perspective and time horizon

We conducted this study primarily from the perspective of hospitals and municipalities, and the time horizon was one year. We used the case-crossover design for the estimation of the mean hospital and municipality costs of injuries as the difference between the costs in the year after and the year before the injuries. Studies on the acute outcomes of certain exposures to air pollution (e.g. Maclure, 1991) previously used this design, but health economic studies also gained from using this design (Devos et al., 2017; Finkelstein et al., 2005). With reference to Finkelstein and colleagues' methodological work, Devos and colleagues argued that the case-crossover design was in favour of the conventional case-control design.

2.2. Data

The study used three data sources: (a) hospital (emergency room, inpatient and outpatient) data, including Danish Diagnosis Related Group tariffs, from all of Denmark, with approximately 5.8 million inhabitants (The National Hospital Discharge Registry); (b) municipality home care data from Aalborg Municipality in the North Denmark region, with approximately 220,000 citizens (extracted from the municipality database, done exclusively for this project); and (c) data on the recipients of long-term sickness benefits (the employer pays the first four weeks after an injury) from all inhabitants of Denmark (The DREAM [Registry-based Evaluation of the Scope of Marginalisation] Registry). In Denmark, every individual has a unique civil registration number given to them at birth (or immigration), which encodes each person's gender and date of birth. This 10-digit number is used in most administrative registers, permitting the linkage of individual hospital registrations of traffic injuries with municipality costs and sickness benefit data. The hospital cost data originated from the 2014–2016 period (year of injury: 2015), whereas the municipality and the sickness benefit data came from the 2015–2017 period (year of injury: 2016). We defined the date of treatment of a traffic injury in a hospital (or an emergency room) as the index date of injury. Any subsequent treatment of a traffic injury within 30 days from the index was defined as originating from the index episode. We extracted the cost data for one year before the index date and one year after the index date. From the hospital cost data (a), we excluded the costs of pregnancy, birth and maternity (International Classification of Diseases version 10 [ICD-10] code DO [World Health Organization, 2016]) but included the costs of all other diagnoses plus rehabilitation, both inpatient and outpatient, paid by hospital authorities. Only those who were alive on arrival at the hospital ended up in the register. From (b), we included all costs of home care, cleaning, nursing and rehabilitation paid by the municipality. From (c), we summed up the number of weeks on sickness benefits beyond the first four weeks, thus defining long-term sick leave as absence for more than four weeks.

Our study comprised three samples, one from each data source, but we defined all samples from the hospital data as personal injuries sustained in traffic areas (public roads, including motorways, sidewalks, bike lanes/paths and parking areas). The samples from the three data sources included (1) all registered traffic injuries in the hospital data in 2015; (2) all registered traffic injuries in the hospital data in 2016, sustained by citizens in Aalborg Municipality; and (3) all registered traffic injuries in the hospital data in 2016, involving individuals in the 18–64 age group.

2.3. Statistical analysis

For the analysis of the first-year cost of hospitalisation and municipality care, we used the two-part model, as suggested by Deb and Norton (2018). One part (a logistic regression) models the odds of having a positive (above zero) treatment cost, and the other part models the distribution of the positive costs (Belotti et al., 2015). This distribution is typically right skewed and thus requires a transformation and/or handling in an appropriate statistical distribution. A Box-Cox test on the positive values of the after-injury cost data was indicative of a transformation with the natural logarithm function (coefficient = −0.12 for the hospital costs and coefficient = 0.06 for the cost of care). Conditional on the choice of the transformation, we then performed a modified Park test, suggesting that the gamma distribution was appropriate (coefficient = 1.81 for the cost of hospitalisation and coefficient = 1.92 for the municipality cost of care). The before-and-after-injury data from the same person were repeated measures, and we handled the correlation between these repeated measures through Taylor-linearised variance estimation (Kreuter and Valliant, 2007). Our aim was to predict direct costs by road user category in a model including adjustments for gender and age (four categories: 0–14, 15–34, 35–64 and 65+ years) and whether death occurred during the year of the injury. We made the prediction by estimating the marginal (or incremental) effects of the interaction of the year (one if year of injury, zero if year before) with the road user type (pedestrian fall, pedestrian multiparty, cyclists, mopeds, motorcyclists, car drivers including passengers, miscellaneous including a mix of truck and tractor drivers, along with bus drivers and passengers). We calculated the marginal effects for the average values of the confounder variables and estimated the standard errors of the predictions using the delta method (Belotti et al., 2015). We labelled these marginal effects as attributable costs of traffic injuries.

We analysed the excess risk of needing long-term sickness benefits beyond four weeks in a binomial regression with an identity link, thus facilitating an interpretation of estimates as risk differences in percentage points (McCullagh and Nelder, 1989). As we did above, we adjusted the interaction term between the year and the road user type for gender, age in categories (18–34 and 35–64 years) and a dummy variable indicating whether death occurred in the year of the injury.

We performed all statistical analyses using the software Stata 15 (StataCorp, 2017). All attributable costs were indexed to € (2018 prices) using the Danish inflation rates (net price index) published by Statistics Denmark (2020; https://www.dst.dk/en/Statistik/emner/priser-og-forbrug/forbrugerpriser/nettoprisindeks) and an exchange rate of 1 € = 7.50 DKK. For the comparison with two other European studies using population-based complete hospital samples (Polinder et al., 2016; Devos et al., 2017), an indexation for the year 2018 was made using the harmonised index of consumer prices (Statistics Denmark, 2021; https://www.dst.dk/en/Statistik/emner/priser-og-forbrug/forbrugerpriser/eu-harmoniseret-forbrugerprisindeks-hicp). The Purchasing Power Parities (PPP) was checked to account for price level differences among the three countries, but was not needed.

3. Results

For the purpose of describing a typical extract of traffic injuries from the hospital register in Denmark, we present the distribution of injuries in 2015 by road user type, gender and age at the injury and indicate whether the patient died during the year of the injury (Table 1). Falls, cyclist injuries and car driver injuries were the dominant types of injuries in emergency rooms and hospitals. The cyclist share amounted to 30%, which was higher than the car driver share (24%). There was a 50–50 gender split of injuries; regarding age, children (0–14 years) accounted for 12% of the injuries, and persons 15–34 years old had a noticeable proportion of 35%. Finally, 616 persons from the total of 47,242 injured who were registered alive on arrival at the hospital following their traffic crash died in 2015, indicating an increased mortality of 57% compared with the general population. This increased mortality of the injured varied by age group (22%: 0–14, 474%: 15–34, 187%: 35–64 and 27%: 65+ years old).

In Table 2, we show the estimated attributable hospital costs of traffic injuries by road user type. The attributable cost estimates from the two-part model were adjusted for gender, age and whether death occurred during the year of the injury. Motorcyclist injuries were the most expensive, followed by pedestrians in multiparty traffic crashes and moped drivers. The rest and the major percentage of the injuries had lower costs, just below the average of €1775.

In Table 3, we show the results of the estimation of the municipality costs of care. Similar to the case of hospital costs, the injuries of motorcyclists, moped drivers and pedestrians in multiparty crashes were the most expensive. Cyclist injuries had relatively lower costs than the injuries of car drivers and passengers, but the 95% confidence intervals (CIs) were wide, especially for the latter, suggesting a large variation in severity.

The motorcyclist attributable cost of care was not estimable in the two-part model because all 41 motorcyclists had zero cost of care in the year before the injury (the zero odds of non-zero costs implied that the logistic regression part of the two-part model could not converge). However, the mean cost in the year after the injury of the motorcyclists was €614 (standard error = €255; 95% CI = €113–1114), providing an alternative estimate of the municipality cost of care for this road user type (the data did not allow adjustments for gender, age and death in the current year). The estimate for the miscellaneous category was highly volatile because of one person whose cost of care amounted to €123,333 in the year before the injury; thus, we chose to exclude this outlier from the estimation of the attributable costs of care in Table 3.

Table 4 presents the results of the estimation of the risks of receiving sickness benefits for more than four weeks following a traffic injury, after subtracting the risks before the injury. Here again, motorcyclist injuries showed the highest risk, meaning that one in every six injured individual motorcyclists would receive long-term sickness benefits (number needed to harm [NNH] = 6). Next, the moped driver and miscellaneous injuries showed that one in 13 would receive sickness benefits for more than four weeks. The rest of the injuries, including cyclist and car injuries, were associated with an excess risk close to the mean of all (5.8 percentage points).

In Table 5, we compare our results with those from the Dutch study by Polinder et al. (2016) and the Belgian study by Devos et al. (2017). All three studies used complete population-based samples of hospital and emergency room data. However, the types of costs and the estimation methods differed. Before the comparison, we aggregated our attributable costs of hospitalisation and municipality cost of care and indexed the cost estimates in the Dutch and Belgian studies to € (2018 prices) using the harmonised index of consumer prices (Statistics Denmark, 2021). Table 5 displays to the left the absolute prices by road user type for each country, whereas the three columns to the right show the relative differences (within a country) between the price of an injury of a specific road user type compared with the price of a cyclist injury.

The Dutch and Danish prices were of the same magnitude even though the Dutch estimates were lifetime costs. The Belgian prices were relatively higher by a factor of 2–5 compared with the Danish prices. The Belgian study did not supply an estimate for moped users.

The relative differences were more pronounced in our Danish study, with motorcyclist injuries being as much as 2.7 times more expensive than cyclist injuries. When car occupants were compared with cyclists, the relative differences in Denmark and the Netherlands were similar, whereas in Belgium, the price of car injuries was estimated at a relatively higher level. In all countries,

Table 1
Description of the sample of all hospital registrations of traffic injuries in 2015 in Denmark.

Variable	N	%
Road user type		
Pedestrian fall	16,343	34.6
Pedestrian multiparty	850	1.8
Cyclist	14,246	30.2
Moped driver	2,361	5
Motorcyclist	898	1.9
Car driver and passengers	11,528	24.4
Miscellaneous	1,016	2.2
Gender		
Male	23,834	50.5
Female	23,408	49.5
Age		
0–14 years	5,527	11.7
15–34 years	16,462	34.9
35–64 years	17,331	36.7
65+ years	7,922	16.8
Died during year of injury		
Yes	616	1.3
No	46,626	98.7
Total	47,242	

Table 2
Estimated attributable hospital costs one year after a traffic injury by road user type (in €, 2018 prices).

Road user type	Estimate*	Standard error	95% confidence interval			N
Pedestrian fall	1,425	83	1,263	–	1,588	16,343
Pedestrian multiparty	3,729	593	2,566	–	4,891	850
Cyclist	1,699	74	1,555	–	1,844	14,246
Moped driver	3,082	386	2,326	–	3,837	2,361
Motorcyclist	4,554	557	3,462	–	5,647	898
Car driver and passengers	1,813	163	1,493	–	2,132	11,528
Miscellaneous	1,284	200	891	–	1,676	1,016
All	1,775	58	1,662	–	1,889	47,242

[*] Adjusted for gender, age and whether the person died during the year of the injury, using the two-part model (logistic regression combined with the generalised linear model [gamma distribution and log link]).

Table 3
Estimated attributable costs of municipality home care in the first year after a traffic injury by road user type (in €, 2018 prices).

Road user type	Estimate[a]	Standard error	95% confidence interval			N
Pedestrian fall	422	177	75	–	769	105
Pedestrian multiparty	547	228	100	–	995	37
Cyclist	184	49	88	–	281	480
Moped driver	832	409	29	–	1,635	73
Motorcyclist	614[b]	255	113	–	1,114	41
Car driver and passengers	385	167	57	–	713	371
Miscellaneous	360	179	8	–	711	34
All	358	66	228	–	488	1,141

[a] Adjusted for gender, age and whether the person died during the year of the injury, using the two-part model (logistic regression combined with the generalised linear model [gamma distribution and log link]).
[b] The effect was not estimable in the two-part model because all 41 motorcyclists had zero cost of care in the year before the injury. Instead, we estimated the effect on raw differences in linear regression on a log scale.

Table 4
Estimated excess risk of receiving long-term sickness benefits (beyond four weeks) after a traffic injury.

Road user type	Estimate[a]	Standard error	95% confidence interval			NNH[b]	N
Pedestrian fall	4.4	0.41	3.6	–	5.2	23	8,258
Pedestrian multiparty	5.5	1.79	2.0	–	9.0	18	504
Cyclist	5.4	0.37	4.7	–	6.2	19	9,454
Moped driver	7.9	0.94	6.1	–	9.8	13	1,402
Motorcyclist	16.0	1.65	12.8	–	19.3	6	826
Car driver and passengers	5.5	0.42	4.7	–	6.4	18	10,049
Miscellaneous	8.0	1.58	4.9	–	11.1	13	715
All	5.8	0.22	5.3	–	6.2	17	31,208

[a] In percentage points; estimated in the generalised linear model (binomial with identity link).
[b] Number needed to harm (injure) to observe one case of long-term sick leave.

Table 5
Attributable health care cost estimates from three European studies (see text) in € (2018 prices) to the left and relative differences to the right with cyclist as the reference.

Road user type	Denmark	Netherlands	Belgium	Denmark	Netherlands	Belgium
Pedestrian fall	1,847	–	–	0.98	–	–
Pedestrian multiparty	4,276	4,271	11,025	2.27	1.50	1.49
Cyclist	1,883	2,844	7,389	1 (ref)	1 (ref)	1 (ref)
Moped driver	3,914	2,697	–	2.08	0.95	–
Motorcyclist	5,168	4,019	10,954	2.74	1.41	1.48
Car occupant	2,198	3,268	11,659	1.17	1.15	1.58

multiparty pedestrian and motorcyclist injuries were more expensive than cyclist injuries.

Finally, we estimated the aggregated cost of all traffic injuries for each road user type through multiplication of the first (Danish) column (hospital and municipality care) to the left in Table 5 by the number of injuries per road user type in Table 1. The aggregated costs and proportions of the total amount were as follows: pedestrian falls: €30.2 million (30%), pedestrian multiparty injuries: €3.6 million (4%), cyclist injuries: €26.8 million (26%), injuries of moped drivers: €9.2 million (9%), MC driver injuries: €4.6 million (5%) and injuries in car occupants: €25.3 million (25%). The miscellaneous category comprised 2% of the cost, thus adding up to a total of €101.5 million for hospitalisation and municipality care in the first year after a traffic injury.

4. Discussion

In this study, we estimated the hospital costs in Denmark in the first year after a traffic injury by road user type, with data from a case-crossover design, through the application of an appropriate statistical two-part model. Our results confirm that the most vulnerable (unprotected) road users sustain more serious and expensive injuries. The predicted attributable cost of a car injury is not much higher than that of a cyclist injury, and pedestrians who fall are associated with mean hospital expenses at a level similar to those of car crash victims.

We found that motorcyclists, pedestrians in multiparty traffic crashes and moped drivers were especially associated with high hospital costs. We also estimated the municipality costs of care in Aalborg, one of the largest Danish municipalities. Aalborg's costs of care showed that the same road user types had the highest costs in the municipality, similar to those in the hospital. Regarding the excess risk of ending up on long-term sickness benefits after a traffic injury in Denmark, the risk particularly increased amongst motorcyclists, of whom one out of six injuries resulted in long-term sickness benefits.

The aggregated attributable cost of the traffic injuries in pedestrians in multiparty crashes and powered two-wheelers constituted a proportion of 18% of the total bill of hospitalisation and municipality care in Denmark. Even though these injuries are the most expensive, they are not the most frequent. When aggregating the cost per road user type, taking into account the frequencies of the various injury types, we identified the top three as follows: pedestrian falls (30% of the total cost), cyclist injuries (26%) and injuries in car occupants (25%). This result clearly demonstrates that the societal costs of pedestrian falls and cyclist injuries are not negligible from the perspective of hospitals and municipalities. Increased public focus can help explain these somewhat hidden prices of traffic injuries.

Motorcyclist injuries are expensive because the riders are relatively unprotected and drive fast along with cars and trucks on the road. Mopeds are less fast but inherit some dangers from motorcycles, which is probably why we observe their higher attributable costs. The high costs of moped crashes have also been found in a US study, which additionally detected the high prevalence of drunk driving amongst moped drivers involved in crashes (Ode et al., 2018). A European report on the safety of powered two-wheelers (mopeds and motorcycles) did not find any pronounced problems related to drunk driving but mentioned too high speeds and many junction crashes, in which turning motor vehicles overlook powered two-wheelers (Morris et al., 2019). The report pointed out that single-vehicle crashes, in which the drivers lost control of the vehicles, are significant contributors to the vast number of fatal and serious injuries in powered two-wheelers. Cyclists also face a high risk of single crashes (Schepers et al., 2015), but their speed is generally lower, thus implying a relatively lower but not negligible price of injury. Car drivers and passengers are more protected inside the vehicle, which may compensate for the risk associated with a higher speed, leaving injuries in car occupants at a price level only slightly higher than that of cyclists. This finding may seem surprising, but the Dutch study by Polinder et al. (2016) also found a relative difference between cyclist and car injuries of the same magnitude as ours. The Belgian study by Devos et al. (2017) reported a much larger relative difference between injuries in cyclists and car occupants, suggesting that international differences could be at play. The Netherlands and Denmark have modal splits in favour of cycling, and from the data descriptions in the Dutch and Belgian papers, it can be seen that more cyclist injuries were treated in emergency rooms and hospitals in the Netherlands and Denmark than in Belgium, where a large proportion of the treated injuries involved car occupants. Somehow, Belgians face more serious car injuries, maybe because of the high speed involved.

Our study provided indicators for the prioritisation of funds by road user category through appropriate modelling of cost data. We estimated attributable costs and risks in the Danish context, whose results cannot be directly transferred to another country. However, we argue that the results can be used for the purpose of prioritisation in international contexts because road user injuries are somehow ranked in a similar way in countries with approximately the same traffic composition. In Table 5, we have compared our results with those of two other European studies with similar complete nationwide hospital and emergency room samples and with a categorisation of costs by road user type (Polinder et al., 2016; Devos et al., 2017). The Dutch and Danish prices were of the same magnitude, even though the Dutch estimates were lifetime costs and model based. The model of Polinder et al. (2016) was based on an aggregation of the different costs of various scenarios using average tariffs of, e.g. a hospital bed per day, and the probabilities of different scenarios, e.g. chance of nursing home admission. The distribution of traffic injuries by road user type was obtained from a representative hospital sample of both inpatient and outpatient treatments. The Dutch study included a few more cost components than our study did, e.g. visits to general practitioners and medication. The absolute differences between countries can also be explained by the fact that systems of reimbursement of hospital costs and health insurance vary across Europe, affecting the price levels in different countries (Drummond and Pang, 2005). This circumstance may explain why the Belgian estimates of first-year attributable health care costs are notably higher than our estimates. Devos et al. (2017) may have also included more cost components of hospitalisation than we did. The statistical method and the sampling of hospital-treated traffic injuries of the Belgian study by Devos et al. (2017) were close to ours. As an alternative to the comparison of the absolute prices, we compared the Dutch and Belgian studies on the relative differences between the different road user types in Table 5. When these differences in costs per road user injury are used as a means in prioritisation between safety measures, e.g. for the prevention of a cyclist injury compared with the prevention of a motorcyclist injury, different weights are given to the road user types in different countries. In Denmark, powered two-wheelers and pedestrians in multiparty crashes are the most expensive, whereas in Belgium, car injuries are the costliest. As mentioned above, these differences could be attributed to the variation in the composition of traffic and speed, e.g. a larger proportion of the traffic on motorways.

Our study provided the attributable costs of two types of pedestrian injuries—both falls and injuries in multiparty crashes. Pedestrians injured in multiparty crashes are vulnerable parties, often subjected to severe injuries, and thus spend more for hospital treatment and the subsequent home care, as evident from both results. Pedestrian falls have not been on the agenda until recently, mainly because police authorities do not register them. However, researchers have pointed out the need for more focus on these injuries (Elvik and Bjørnskau, 2019). The present study demonstrated the costs of pedestrian falls in both hospital and municipal care, as well as long-term sickness benefits, strongly suggesting that falls cannot be ignored if the intention is to add up all the costs in relation to personal injuries in traffic areas that are under the control of local transportation authorities.

The attributable risk estimates of receiving long-term sickness benefits (beyond the employer-paid first four weeks after the traffic injury) in Table 4 show a slightly different picture than the attributable cost estimates. Still, powered two-wheelers are associated with the highest excess risk, as in the case of hospitalisation and home care costs. However, pedestrian multiparty injuries are associated with an excess risk of long-term sickness benefits about the size of the risk of cyclists and car occupants, whereas pedestrians in falls experience an average risk of long-term sickness benefits that is considerably lower than the rest. The estimation of the attributable risk of receiving sickness benefits was done on the sample restricted to 18- to 64-year-old traffic victims because they are the only group that can receive sickness benefits paid by the government/municipality. We argue that it is the older pedestrians who experience the most serious falls/multiparty crashes, and when they are removed from the sample, another *cheaper* pattern for pedestrians emerges.

A comparison of our estimates with those of the mentioned report by the Danish Road Directorate (2013) revealed similar first-year hospital costs. However, the report only included hospital costs during the first half-year after the injury, which left some of the bill unaccounted for in the report, according to Devos et al. (2017). Regarding the municipality cost of care, our estimate constituted 58% of the estimated cost in the report (Danish Road Directorate, 2013). Another Danish study using matched controls found that first-year medical costs (hospital, drugs, fees of the general practitioner, psychologist, chiropractor and others) amounted to €1,208, which is 32% lower than our estimate (Kruse, 2015). One possible explanation for this discrepancy could be that Kruse's study was based on a pool of hospital- and police-registered injuries, of which the latter did not necessarily imply medical care. We performed extra registry mergers, which revealed that only approximately 60% of all police-registered injuries were found in the hospital records in 2016.

4.1. *Strengths*

The large dataset of all hospital-registered traffic injuries was population-based and complete, so this was a major strength of the study. In the sense that the underreporting is thought to be lower for hospital data than for police data, we can provide a much better picture of how traffic injuries are distributed nationwide (Janstrup et al., 2016).

Linkage was possible such that the hospital sample could be found in both the municipality data and the transfer payment database, which meant that the three types of costs could be evaluated from the same study base of hospital-registered traffic injuries. The quality of the data also implied that information on road user type and confounders was available for analysis.

4.2. *Limitations*

No categorisation according to severity was possible because no proper conversion tool between the ICD-10 diagnoses used in Denmark and any injury severity score was available. This was not a problem for the comparison with the key report from the Danish Road Directorate, which did not also categorise injuries according to severity. Nonetheless, it would have been appropriate to group injuries based on severity, as done in similar studies (e.g. Devos et al., 2017). Transportation authorities may focus on the prevention of severe injuries and, therefore, need a tool for prioritisation amongst countermeasures for injuries by road user type, with minor cases excluded.

The case-crossover design is only appropriate within a short time horizon, such as one or two years, because the year before the injury may not act as an appropriate control for the development in costs of care and transfer payments from the long-term perspective. Again, persons may be involved in other crashes or retire early for reasons other than traffic injuries. From the long-term perspective, applying the propensity score-matching method for the selection of controls would be beneficial. Kruse's (2015) Danish study used this method, along with Nielsen and Andersen's (2014) report, for the prediction of the long-term outcome of a traffic injury regarding the cost of social benefits. However, those studies were not done by road user category and thus cannot be used for prioritisation in that sense.

The sample size available for the estimation of the municipality cost of care was limited (n = 1142), but we chose to present the results because of the scarce registry-based data on this type of expense. We found that the ranking of costs amongst road users was very similar to that of the hospital costs.

The distribution of weeks on sickness benefits in this dataset was truncated by default at four weeks. We were unable to draw any conclusion on the need for sickness benefits of less than four-week durations. Therefore, we chose not to model the long-term use of sickness benefits in weeks because zero in this context could mean two things: either a true zero of no sickness benefit or a positive number of weeks truncated to zero because it was below four weeks. The Danish population's background prevalence of long-term sickness benefits in the year before the injury was 11.8% in contrast to 17.7% in the year after the injury, giving an excess probability of 5.9 percentage points, similar to the adjusted estimate in Table 4. This background prevalence might seem high, but the comparable estimate for 18- to 64-year-old patients in the Danish population who had received sickness benefits was 11.1% in 2016. However, the prevalence also included persons on maternity and paternity leave, which cannot be distinguished from *true* sickness in this data material (Statistics Denmark, 2019). For this reason, the case-crossover design is necessary if we want to capture and adjust for the natural variations in and out of transfer payments.

5. Conclusions

This study provided hospital and home care attributable costs and risk (of long-term sickness benefits) estimates by road user category based on hospital data in the first year after a traffic injury—estimates that can help transportation authorities have a more accurate picture of injury costs by road user type. Comparing all road users, we found that the most expensive traffic injuries were those sustained by motorcyclists, moped drivers and pedestrians involved in multiparty crashes. In summary, however, pedestrians who fall and cyclists who sustain injuries in Denmark during one year contributed the most to the total bill to be paid after traffic injuries in hospitals and municipalities. We showed that crashes involving vulnerable road users are often as costly as car crashes. The underreporting of crashes in vulnerable road users can imply that road authorities choose safety measures that prevent car–car crashes instead of those that prevent crashes involving vulnerable road users, such as single-bicycle crashes or pedestrian falls. The outcome of this lack of knowledge and recognition is a potentially biased prioritisation of the limited resources for road safety work.

Author statement

Anne Vingaard Olesen: Writing - Original Draft; Formal analysis. Karin Dam Petersen: Supervision; Writing – Review & Editing. Harry Spaabæk Lahrmann: Supervision; Writing – Review & Editing.

Declaration of competing interest

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

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