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A novel approach to study the health consequences of road crashes

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ABSTRACT

Introduction: While an association between road crashes and health impairments is well documented, few studies have analysed impairments in relation to crash parameters. The aim of this paper is to describe a novel approach for studying the full complexity of road crashes which allows an analysis of the relationship between crash factors and longer-term health consequences.

Methods: A multidisciplinary team investigated road crashes sampled in a Swedish region. The course of events, road environment and crash configuration were studied at the scene and telephone interviews were conducted with drivers. Road users were queried about their health status 1, 6, and 12 months after the crash. To illustrate a potential use of the collected data, the relationship between crash factors and impairments for car occupants after one month was explored using multiple logistic regression.

Results: The sampled data included 176 crashes, 310 vehicles and 430 people. The most common crash characteristics were: multiple vehicle crashes (62%); posted speed limit of $\geq$ 70 km/h (65%); passenger cars (88%); driver age 25–54 years (60%); male drivers/riders (70%). The example analysis of passenger car occupants showed that having an injury with ISS $\geq$ 1 at the time of crash was a statistically significant predictor for impairment at one month ($p < 0.001$, OR = 25.42, 95% CI: 8.30, 77.81).

Conclusions: The methodology described in this paper provides information about the full spectrum of road crashes and enables novel analyses of unexplored research questions. Based on the data collected so far and the example analysis presented in the paper, recommendations have been made about future data collection. The proposed data collection methodology enables characterisation of crash factors that are associated with long-term health consequences. The ability to timely identify those at risk provides important opportunities for early intervention to reduce long-term health outcomes also from low severity crashes.

1. Introduction

Preventing road crashes with fatal outcomes or serious injury consequences remains the foundation of the Vision Zero system approach to road safety (Larsson et al., 2010). However, with decreasing numbers of fatal crashes in several developed countries (WHO, 2013) it is of increasing importance to understand the emergence and long-term health consequences of less severe crashes. Several studies have shown that even people with low severity injuries, such as those graded at maximum AIS 1 or AIS 2 level on the Abbreviated Injury Scale (AIS) (AAAM, 2008), can experience long-term permanent medical impairment from those injuries (Malm et al., 2008).

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Most previous work related to long-term injury follow-up is based on an individual level rather than crash level. There are three main sources for the selection of cohorts for road crash injury follow-up studies: i) hospital admissions (e.g. Ameratunga et al., 2006; Mayou and Bryant, 2003; Cassidy et al., 2014); ii) injury registries (e.g. Polinder et al., 2015; Tournier et al., 2014); iii) insurance records (e.g. Kenardy et al., 2015; Gustafsson et al., 2014). There is no or little information about crash parameters (e.g. crash configuration, crash severity, vehicle characteristics and crash environment) in these studies. Some of these parameters are known to be strong predictors of major trauma outcome (Buendia et al., 2015), but their relationship with longer-term impairment is less clear.

The aim of this paper is to describe a novel in-depth crash data collection approach and illustrate its potential for the analysis of long-term health consequences of road crashes. In this paper the overall methodology of data collection will be explained and a description of the resulting data outlined. To illustrate how the data collected can be used, an exemplar examination of the relationship of crash related factors and acute injury to health outcomes at one month after the crash is presented for car occupants in low severity crashes.

2. Materials and methods

2.1. Overview of the data collection methodology

The dataset described in this study is referred to as the National In-depth Road Accident Database (INTACT) and originates from in-depth on-scene investigations that are performed at the scene of the crash by trained crash investigators. This dataset is a sample of road crashes in Sweden collected by Chalmers University of Technology. The INTACT methodology was developed in Sweden during 2007 to 2010. The methodology has since been used for crash data collection at a European level in the project Dacota (del Pozo de Dios et al., 2013). A description of the method can be found online (Chalmers University of Technology, 2014). All data was collected by a multidisciplinary team of trained investigators who also performed the case analysis of each case. The process of data collection is described below.

The dataset of road crashes was sampled from crashes in the city of Gothenburg and the six surrounding councils during two years from 1st September 2012 to 31st August 2014. A team of crash investigators were on stand-by to travel directly to the crash scene if notified by the emergency services. The shift schedule was planned with the aim of collecting a random sample of crashes in a two-year period with an expected number of 180 investigated crashes in total. Three shift types: morning (7 a.m. to 2 p.m.), afternoon (2–9 p.m.) and night (9 p.m. to 7 a.m.) were distributed evenly throughout the year and each shift type had the same frequency for each day of the week.

The investigation team received notifications about a crash as soon as an ambulance and the rescue services were called to the scene. Crashes involving at least one passenger car, truck or bus were investigated (therefore, e.g. single motorcycle crashes were excluded). There were no restrictions with respect to injury severity, i.e. all injury severity crashes and non-injury crashes were investigated. Data about the course of events, the road environment and the crash configuration was collected at the scene as well as from witness statements and briefings from the police and the rescue services. The police record of the crash was retrieved and the damaged vehicles were inspected by the team experts. Thorough inspection of passenger cars after the crash were restricted to those of year model 2003 and later as the ECE R94 regulation (UNECE, 2013) requiring an offset barrier test at 56 km/h was enforced to new vehicle registrations from 1 October 2003. Details such as the name and telephone number of involved road users were often obtained directly at the scene or later from the police, to prepare for interviews and injury follow-up. Overall, the collected data includes information from all phases of a crash i.e. pre-crash conditions, in-crash injury outcomes, pre-hospital care and long-term health consequences. These aspects will be described in detail below. The study was approved by the Regional Ethical Review Board in Gothenburg.

2.1.1. Data collection about pre-impact conditions

Data about pre-impact conditions concerning the driver's fitness to drive and the event leading up to the crash were collected after the crash event by telephone interviews with drivers, riders and/or pedestrians. An interview pro-forma (English version available at Chalmers University of Technology, 2012) was used for consistency and the interviews were performed as soon as possible after the crash. Each interview took approximately 30 minutes to conduct. To understand the course of events and the contributing factors to the crash, a computerised reconstruction was performed using the software PC-Crash (DSD, 2010). From this reconstruction, several crash severity measures (such as the impact speed and Delta-V, the change of velocity during the crash) were derived. Identification of the contributing factors to the crash was then performed by trained researchers according to the Driver Reliability Error Analysis Methodology (DREAM) (Ljung Aust et al., 2012). The results from the reconstruction are not reported in this manuscript. Results from the DREAM analysis have been presented previously (Kovaceva et al., 2015).

2.1.2. Data collection of in-crash injury outcomes and pre-hospital care

Once a written consent was obtained from the injured people, the medical records from the ambulance and hospital treatments were gathered. The medical record from the hospital includes injury diagnoses and was used to code in-crash injury outcomes using the Abbreviated Injury Scale (AAAM, 2008). From the AIS codes the Injury Severity Score (ISS) (Baker et al., 1974) was calculated. From the ambulance medical record, the patients' vital signs (systolic blood pressure, pulse rate, respiratory rate and the level of consciousness according to the Glasgow Coma Scale) were recorded. Additional pre-hospital treatment data collected included information about the rescue performed at the crash scene, the treatment during transport and the acute care at the hospital. These details enable further analysis about the pre-hospital treatment. However, such analysis will not be reported in this manuscript.

2.1.3. Data collection of health status after the crash

One month after the crash, the involved road users were mailed a description of the research study together with a consent form requesting access to medical records and the long-term injury follow-up questionnaire with a reply-paid envelope. One separate page of the questionnaire contained general questions about the road user such as their role in the crash (e.g. driver, passenger, and/or rider) as well as age, gender, height and weight. The injury follow-up questionnaire contained six pages of questions concerning the physical impairments due to the injuries in the crash and general impairments due to the crash (defined below), as well as questions related to health care and absence from work.

A 'physical impairment' was defined as an impairment due to an on-going physical injury obtained in the crash. The respondent marked the impairments on a figure of a human body and specified the impairments on a list adjacent to the figure. A 'general impairment' was defined as a general health issue e.g. headache, anxiety or sleep disorder that did not directly relate to any physical injury. The presence or absence of general impairments was evaluated on the basis of responses to 31 yes/no questions about specific health issues.

The injury follow-up instrument used to measure the health outcome was based on that used by the Traffic Injury Register in earlier studies (Olofsson et al., 2012; Jakobsson et al., 2003; Andersson et al., 1997). The inclusion criteria for follow-up were that the person needed to be known by name and have a Swedish address and be able to respond to questions in Swedish. If no response was received after four weeks a reminder was mailed to the non-respondents. If either physical or general impairments were reported in the preceding follow-up a new questionnaire was sent six and twelve months after the crash. No incentives to respond were given.

2.2. Data analysis

The sampling plan described in Section 2.1 was designed to yield a random sample of crashes occurring in and around Gothenburg. In order to detect potential statistically significant differences between the sample and the crash population, the proportion of sampled crashes in each shift was compared with the whole population of crash notifications by shift times during the study period, using a chi-square test.

As the follow-up component was an 'opt in' design, the distribution of key characteristics of the follow-up sample was compared to those who did not opt in to examine any potential bias in the follow-up sample. This was achieved by comparing road users in terms of road user classification (driver/rider, passenger), age, gender, and injury status between participants who opted in to the follow-up component and those who did not. For consistency with previous work (Kovaceva et al., 2015) the age of the respondents in all crashes was categorised into seven groups: 0–17, 18–24, 25–34, 35–44, 45–54, 55–64 and 65+. The statistical significance of any differences was tested using the chi-square test. The post-hoc Marascuilo procedure was applied to identify pairs of age groups with significantly different response rates.

To give a descriptive overview of the crashes in the dataset, frequencies of the following variables are presented.

Crash related variables include 'Crash type', 'Posted speed limit', and 'Number of vehicles in crash'. Crashes were categorised according to three crash types; single vehicle crashes, multiple vehicle crashes where the vehicles travelled in the same direction (e.g. rear-end crashes), and multiple vehicle crashes where the vehicles were not heading in the same direction (e.g. head-on and junction crashes). In this study, the prevailing speed limit is defined as the maximum sign posted speed limit (in case two roads with different speed limits intersect).'Posted speed limit' was categorised into three groups: less than 70 km/h, equal to 70 km/h and higher than 70 km/h. It is important to note that the speed limit is not necessarily the driving speed of the vehicles at the time of crash. The group < 70 km/h typically involved a crash on an urban road while the group > 70 km/h typically involved a crash on a rural road. Crashes on roads with a 70 km/h limit included both rural and urban crashes.

Vehicle related variables include 'Vehicle type' and the 'Passenger car year model' for passenger cars. The vehicle year model was categorised into three groups: pre-2003, 2003 to 2007 and 2008 and later. The lower cut-point was selected due to that detailed vehicle inspection was conducted for passenger cars from year model 2003 as explained in Section 2.1.

Road user related variables include 'Age group', 'Gender' and 'Road user class' (driver or passenger), 'Transportation', and 'Injury severity'. 'Transportation' specifies whether or not road users were transported from the crash scene by ambulance. 'Injury severity' was categorised into four groups using the injury severity score (ISS); ISS 0 = uninjured; ISS 1–3 = minor injuries; ISS 4–8 = moderate injuries and ISS ≥ 9 = serious injuries. The moderate injury group is included to distinguish individuals suffering maximum AIS 2 injuries from those suffering maximum AIS 1 injuries.

3. Results

3.1. The sample of all crashes

The sampling procedure for the crash dataset resulted in 176 investigated crashes. The sample of investigated crashes was not statistically different from all crash notifications (n = 2 373) during the collection period in terms of time of crash during the day ($\chi^2 = 0.17$, $p = 0.70$). The crashes involved 310 vehicles operated by a driver or a rider with a total of 430 people involved. Table 1 presents the crash characteristics for selected variables. Table 2 shows the road user characteristics and the injury levels of all road users (n = 430) and drivers/riders (n = 310) separately.

Of the 310 drivers and riders, 208 (67%) were interviewed. Of the 102 drivers and riders that were not interviewed, 42 (41%) had unknown contact details and 60 (59%) declined participation or were never reached by the team investigators. As described in the methods, this interview focused on the pre-impact conditions concerning the driver or rider's fitness to drive and the events leading

Table 1
Crash characteristics (selected variables) of investigated crashes (n = 176).

	n	%
Crash type		
Multiple vehicles same direction	58	33%
Multiple vehicles other	51	29%
Single vehicle crash	67	38%
Posted speed limit		
< 70 km/h	61	35%
= 70 km/h	72	41%
> 70 km/h	43	24%
No of vehicles in crash		
1	67	38%
2	92	52%
3–6	17	10%
Vehicle type[a]		
Passenger cars	273	88%
Trucks	24	8%
Motorcycles	8	3%
Other[b]	5	2%
Passenger car year model[c]		
< 2003	90	33%
2003–2007	78	29%
> 2007	94	34%
Unknown	11	4%

[a] Vehicles involved in 176 crashes (n = 310).
[b] Includes one tractor, one tram and three buses.
[c] Only presented for passenger cars (n = 273).

Table 2
Characteristics and injury outcomes of all road users (n = 430) and drivers/riders (n = 310) involved in the investigated crashes.

	All road users		Drivers/riders	
	n	%	n	%
Age group				
0–17	19	4%	0	–
18–24	52	12%	40	13%
25–34	84	20%	60	19%
35–44	72	17%	66	21%
45–54	73	17%	63	20%
55–64	41	10%	34	11%
65–87	37	9%	25	8%
Unknown	52	12%	22	7%
Gender				
Male	261	61%	217	70%
Female	133	31%	82	26%
Unknown	36	8%	11	4%
Injury severity				
ISS 0 (uninjured)	250	58%	181	58%
ISS 1–3	76	18%	62	20%
ISS 4–8	11	3%	8	3%
ISS ≥ 9[a]	4	1%	2	1%
Unknown	89	21%	57	18%
Transportation				
No ambulance	282	66%	201	65%
Ambulance (incl. helicopter)	110	26%	78	25%
Unknown	38	9%	31	10%

[a] All individuals in this group sustained maximum AIS 3 injuries.

up to the crash. There was no statistically significant difference by gender and age group distribution between those interviewed and those not interviewed. Drivers or riders in the oldest age group (65–87 years) had a higher interview rate (92%) compared to the other groups (63–78%).

Of all road users in the sample, 90 of 430 people did not fulfil the inclusion criteria for the follow-up study. As 54 of the remaining 340 road users had unknown ISS level at the time of the crash they were excluded from the respondent population comparison analysis. Of the remaining 286 people, 130 (45%) responded to the follow-up at one month and the remaining did not respond (n = 136) or declined to participate (n = 20). Road user class ($\chi^2 = 1.51$, $p = 0.22$) and gender ($\chi^2 = 2.20$, $p = 0.14$) were not

Table 3
Distribution of impaired people by age group among respondents to the health survey (n = 130).

	No impairment (n = 78)	Impairment[a] (n = 52)
Age group		
0–17	6	1
18–24	3	9
25–34	10	6
35–44	12	14
45–54	16	7
55–64	11	5
65–87	20	10

[a] Self-reported impairment of which 9 reported solely physical problems, 29 both physical and general problems and 14 solely general problems.

statistically different between those who responded and those who did not; however, the null hypothesis of equal response rates in all age groups was rejected ($\chi^2 = 36.82$, $p < 0.001$). Using the post-hoc Marascuilo procedure, it was found that the response rate is significantly higher ($p < 0.05$) in the age group 65+ (83%) than in the other groups (28–46%), except for the age group 0–17 (50%, $p = 0.53$) and age group 35–44 (59%, $p = 0.39$). No statistically significant difference was found between the other age groups with this test. The null hypothesis of equal response rates was also rejected for injury status where 62% of injured people and 38% of uninjured people responded ($\chi^2 = 14.89$, $p < 0.001$). In Table 3 the number of those reporting impairment or not are presented for the one month follow-up.

4. An example analysis relating health outcomes to crash factors

As mentioned in the introduction, it might be important to relate long-term health outcomes of road users to crash factors, but no sufficiently detailed data has been available to support such an analysis. The methodology of data collection presented in this paper has the potential to address this and related questions. In this section, an example analysis is presented that demonstrates one possible use of the methodology; the relationship of crash related factors and acute injury to health outcomes at one month after the crash is investigated for car occupants in low severity crashes. Instead of providing an exhaustive analysis of this question with definite conclusions, the primary goal with this example is to demonstrate the potential of the data collection methodology and provide ideas and methods for analysing the resulting data.

4.1. Methods and data - example analysis

From the INTACT dataset, occupants in passenger cars from the age of 15 responding to the follow-up questionnaire were selected, and a statistical model was built to relate their health status at one month after the crash to crash factors. Individuals of 15 years of age and above were selected because the questionnaire was addressed to them directly while for those younger than 15 it was sent to the parents. The dependent variable was the binary outcome of health status of the participant at one month after the crash, categorised as ‘impairment’ (physical or general) or ‘no impairment’. In this example, common crash descriptive parameters from the crash scene that could be accessed by paramedics and medical personnel were selected. Many of these have been found as predictors of injury in previous research (e.g. Buendia et al., 2015).

From Table 1 the variables ‘Crash type’ and ‘Passenger car year model’ were included. ‘Crash type’ was collapsed into multiple and single vehicle crash. ‘Passenger car year model’ was collapsed into < 2003 and ≥ 2003. Additionally, ‘Vehicle impact’ was introduced detailing if the car experienced single or multiple impacts. ‘Airbag deployment’ anywhere in the car was selected because in this dataset there are many low severity crashes and the fact whether an airbag was deployed or not gives an indication to paramedics of the crash severity. Of the 113 responding car occupants two were excluded due to unknown airbag deployment. Four occupants were in cars with no fitted airbag; they were included in the not deployed group.

From Table 2, ‘Age’, ‘Gender,’ ‘Road user class’ and ‘Injury severity’ were selected. Age was considered as a continuous variable and ‘Injury severity’ was collapsed into ISS ≥ 1 (injured) and uninjured.

A univariate analysis was performed for each variable to examine the association between each predictor and the outcome. A conservative approach of including factors of $p \leq 0.25$ was applied to build the multivariable model, and pairwise associations between the independent variables were checked to avoid the simultaneous inclusion of correlated variables. The analysis included 111 car occupants between the ages of 15–87 who responded to the follow-up survey at one month. The logistic regression was performed in IBM SPSS Statistics v23. Odds ratios with 95% confidence intervals were generated for all variables in the models.

4.2. Results - example analysis

Of the 111 passenger car occupants, 45 (42%) reported impairments at one month. Thirty-three (30%) reported physical impairment, of which 25 reported both physical and general complaints. Twelve occupants (11%) reported only general complaints. Thirty-seven (79%) of those reporting impairment (n = 45) had an acute injury (ISS ≥ 1) coded after the crash.

Table 4
Univariate analysis results for car occupant respondents aged 15–87 at one month (n = 111). The outcome variable is self-reported impairment (physical and/or general).

	No impairment (n = 66)	Impairment[a] (n = 45)	β	*p*	Exp(β)	95% CI
Crash type						
Multiple vehicles[b]	54	31			1.00	
Single vehicle crash	12	14	0.71	0.12	2.03	0.84, 4.94
Passenger car year model						
≥ 2003[b]	51	30			1.00	
< 2003	15	15	0.53	0.22	1.70	0.73, 3.96
Vehicle impact						
Single impact[b]	39	24			1.00	
Multiple impacts	27	21	0.23	0.55	1.26	0.59, 2.71
Airbag deployment[c]						
Not deployed[b]	55	28			1.00	
Deployed	11	17	1.11	0.01	3.04	1.25, 7.35
Age	66	45	− 0.02	0.16	0.99	0.96, 1.01
Gender						
Male[b]	41	23			1.00	
Female	25	22	0.45	0.25	1.57	0.73, 3.38
Road user class						
Passenger[b]	15	10			1.00	
Driver	51	35	0.03	0.95	1.03	0.41, 2.55
Injury severity						
Uninjured[b]	54	8			1.00	
ISS ≥ 1	12	37	3.04	0.00	20.81	7.75, 55.87

[a] Dependent variable (outcome). 'Impairment' includes any impairment (physical and/or general).
[b] Reference variable.
[c] Any airbag deployed in the car. 'Not deployed' include four cars not fitted with airbags.

The results of the univariate analysis, presented in Table 4, revealed that both airbag deployment (anywhere in the car) and injury status were significantly associated with reported impairment at one month after the crash.

The analysis of pairwise associations showed that airbag deployment (anywhere in the car) and injury severity are significantly correlated ($p < 0.001$) as well as Crash type and Passenger car year model ($p < 0.05$). Therefore, Crash Type, Age, Gender, and Injury Severity were entered into to the multivariable model, whose results are presented in Table 5.

This analysis found that acute injury was the only significant predictor for health outcomes at one month when controlling for the other variables ($p < 0.001$, OR = 25.42, 95% CI: 8.30, 77.81).

4.3. Discussion - example analysis

The selected data analysis of car occupants and their health consequences related to crash factors is a demonstration of how the dataset can be used. For this exemplar analysis, a subset of collected variables easily accessible by paramedics and medical personnel were chosen. The INTACT dataset includes details of approximately 1000 variables associated with the crash environment, the vehicles and the road users. While no crash factors were identified as predictors of impairment in this example case, it is possible that other variables might be.

In the univariate analysis presented in Table 4 airbag deployment anywhere in the car and having an acute injury at the time of the crash (ISS ≥ 1) are the only significant predictors. However, it was found that these variables are statistically significantly correlated, presumably due to both variables being correlated to the severity of the crash. Therefore, airbag deployment was excluded

Table 5
Multivariable analysis results for car occupant respondents aged 15–87 at one month (n = 111). The outcome variable is self-reported impairment (physical and/or general).

	df	β	*p*	Exp(β)	95% CI
Crash type					
Single vehicle crash/Multiple vehicles[b]	1	0.75	0.22	2.13	0.63, 7.12
Age[a]	1	0.00	0.74	1.00	0.98, 1.04
Gender					
Female/Male[b]	1	0.97	0.08	2.63	0.90, 7.71
Injury severity					
ISS ≥ 1/Uninjured[b]	1	3.24	0.00	25.42	8.30, 77.81

[a] Years at time of crash.
[b] Reference variable.

from the subsequent modelling. The multivariate analysis concluded that even though 8 out of the 62 uninjured individuals did report impairment one month after the crash, having a coded injury at the time of crash is the only significant variable ($p < 0.001$) for the current sample when controlling for the other variables.

It should also be kept in mind that the low number of participants in the follow-up study may have resulted in insufficient power to detect any significant associations between the examined crash factors and impairment. However, with sufficient power and exploration of more of the available variables, this type of analysis could provide valuable information to clinicians. The ability to identify those at risk of long-term impairment during the acute post-crash phase would provide important opportunities for early intervention to reduce long-term health problems from low severity crashes.

5. Discussion

The dataset presented in this paper is part of a Swedish strategic investment in research infrastructure. The novelty of this in-depth crash study was that crashes of all severities could be included and data from the whole crash sequence from the pre-crash phase to long-term injury consequences is collected. The road users were queried about their health status before the crash, what happened during the crash event and their health status up to 12 months after the crash. One study that has a similar approach is the Crash Injury Research and Engineering Network (CIREN) in the U.S. (Scarboro and Mccullough, 2005). However, the CIREN study focuses on newer cars (maximum 10 years) and severe injuries (MAIS 3+).

The full dataset of 176 crashes is representative of the crash population in the given geographical area in terms of morning, afternoon or night crashes. The representativeness of the crashes in terms of other crash related factors such as crash type, vehicle type or injury severity etc. was not investigated in the present study. The dataset contains both injury and non-injury crashes and very few severely injured road users and no fatalities. This is in line with the actual proportions of crash severities in the region but makes it difficult to analyse high severity crashes due to the small sample size. There is a lack of pedestrian and cyclist crashes and therefore this dataset should be used solely for analysis of motor vehicle crashes. The reason may be that the criteria for the notification of crash investigators require that both the rescue service and an ambulance are sent to the scene and rescue service is not always needed in a vehicle to pedestrian/cyclist crash.

The interview data is an important input for the crash reconstructions and identification of crash contribution factors for drivers (Kovaceva et al., 2015), and it also includes important information about the road users before the crash. Data on the pre-crash status of the participants includes information about the driver's state at the time of crash, e.g. if they experienced a difficult life event before the crash, how they slept the preceding nights and so on. Such information could be included in future studies of the longer-term health consequences. As a high number of people reported impairments of a general nature despite low initial injury severity, further investigation of the relationship between pre-crash status and health outcomes may be warranted.

Of the 430 people involved in the crashes presented in this dataset, 89 had unknown injury severity because of several different reasons. Some people could not be identified either by the police nor the project investigation team (mostly passengers). Others were involved in crashes while carrying out illegal activities and therefore could not be followed up. Lastly, some were identified but did not consent to have their medical status included in the study. The consent form was included in the first follow-up envelope sent one month after the crash. This approach might need to be revised to increase the level of consent to retrieve the medical records. One possible improvement could be to separate the consent form from the follow-up questionnaire.

The participation rate in the one-month follow-up of health outcomes is considered relatively low for this type of study. This is likely because the follow-up was designed as a postal survey. Bauman et al. (2016) suggest that additionally to sending a follow-up questionnaire reminder in case of non-response, sending a post-card before first questionnaire could increase participation. People with injuries in the crash were more likely to respond. Having the symptom under investigation has previously shown to increase the response rate (Dunn et al., 2004). This may indicate that non-injured people do not experience any health issues and therefore are less motivated to respond. Potential sources for bias associated with this low response rate were examined, as discussed below.

Neither the road user class nor the gender between respondents and non-respondents were significantly different between respondents and non-respondents. However, there are differences in the age distribution of the respondents and the non-respondents. The comparison of response rates with the post-hoc Marascuilo procedure shows that the response rate from people 65 years and older (83%) was significantly higher than the response rate in the other age groups (which are between 28% and 46%), except for the age groups 0–17 and 35–44. These age groups also had lower response rates (50% and 59%, respectively), but the difference was not statistically significant. Since the most common age in Sweden for retiring is 65, the results indicate that pensioners may be more likely to respond to injury follow-up questionnaires than people of other ages.

As described in Section 2.1.3 the injury follow-up instrument used to measure the health outcome in this study was based on that used in earlier studies. That instrument was developed by medical practitioners but has not yet been validated with clinical outcomes. The outcome variable used in this study was 'any impairments' (physical or general). This study does not take any psychosocial, socio-economic or geographical participant data into account. Further analysis is needed to understand if the respondents in this study report similar psychological impairments to those reported in other studies (Mayou and Bryant, 2003; Cassidy et al., 2014).

The potential of the data collection method for addressing new research questions was demonstrated by an example analysis in Section 4. This analysis found that acute injury was the best predictor for health outcomes at one month even when controlling for crash factors. Furthermore, the example analysis shows that data collected with the proposed methodology allows for an investigation of the effect of crash factors on long-term health impairment. However, in order to have sufficient power, a larger sample size may be required. This might be achieved by collecting more crashes and/or increasing the response rate to the health outcome follow-up.

6. Conclusions

The in-depth data collection methodology presented in this paper allows for detailed analysis of research questions regarding the crash contributing factors, injury outcome and health consequences of road crashes. The data is a sample of the crash population, including both injured and uninjured crash participants, in one region in Sweden. An example analysis demonstrates how this data could be used to predict passenger car occupants' health status one month after the crash, although more detailed analyses may require larger samples and/or higher response rates. Injury and crash prevention researchers would benefit from greater collaboration with public health researchers and enhanced linkage of data sources; in particular, the inclusion of some crash factors in long-term follow-up studies.

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