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Bicycle accidents in Denmark – the contribution of cyclist behavior, the vehicle and the road

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Abstract

Knowledge on accidents and factors contributing to their occurrence is of key importance for the development of targeted preventive efforts. High levels of underreporting is a well-known challenge particularly for bicycle accidents. Medical records from 4205 cyclists from 2010-2015 were included in this study. The sample included all cyclists registered at the emergency room due to a bicycle accident during the study period. The purpose of the study was to improve knowledge on factors contributing to cyclist accidents based on a qualitative identification of accident factors and underlying factors. When identifying accident factors, we made a distinction between factors related to the condition and behaviour of the cyclist, the road and its surrounding, the bicycle and the other party. We identified 3124 accident factors most of which regarded the other party or the behaviour and condition of the cyclist. However, we also identified damaged roads and poor maintenance of the bicycle as important factors contributing to the occurrence of the bicycle accidents.

Keywords: In-depth analysis, road safety, accident analysis, bicycle accidents.

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1. Introduction

It is claimed that cycling has several individual and societal benefits compared to driving such as increased health and reduction in negative impacts from congestion and pollution. Therefore, attempts to increase cycling has increased substantially internationally over the past decade (Schepers and Heinen, 2013). However, cycling is also known to be related to increased risk of road traffic injury (Elvik, 2009), and related concern for road safety. Although studies show that increasing number of cyclists may not be related to a proportional increase accident numbers (Elvik and Bjørnskau, 2017), knowledge to develop preventive efforts focusing on cyclist safety is relevant. Further, despite a general positive trend regarding road traffic accidents in recent years, accident statistics indicate that this positive trend may not regard vulnerable road users to the same extend (Vejdirektoratet, 2017). In addition, recent research indicates that changes in cycling pattern and frequency may lead to changes in the type and severity of cycling related accidents (Schepers et al., 2017). Thus, although previous studies have identified risk factors such as alcohol (e.g. Andersson and Bunketorp, 2002), riding speed (e.g. Kim et al., 2007), and cycle infrastructure (e.g. Schepers et al., 2015) updated knowledge on accidents and factors contributing to their occurrence remains of key importance for the development of targeted preventive efforts.

High levels of underreporting is a well-known challenge with regard to national crash databases based on police registered information (e.g. Elvik and Mysen, 1999). The level of underreporting varies based on factors such as type of vehicle, level of injury, age and gender, but it is well known that the level of underreporting is particularly high for cycling related accidents. This is also the case in Denmark where the level of underreporting is 90%, which means that the police, for a number of different reasons only registers approximately 10% of the actual cyclist accident. Although medical records are subject to underreporting and bias too, previous studies show that the level of underreporting of cyclist accidents is lower in comparison to cyclist accidents registered by the police (e.g. Watson et al., 2015; Janstrup et al., 2016).

Based on the above the purpose of this study is to get a better understanding of cyclist accidents and the underlying situation-specific factors contributing to their occurrence. The results are relevant for the development of preventive efforts to increase cyclist safety.

2. Method

2.1. Data

The study was conducted in Denmark a Nordic country with approximately 5,7 million citizens. Data derived from medical records from road users during the years 2010-2015 comprise the basis for this study. Aarhus Municipality provided the data, via the University hospital of Aarhus. Aarhus Municipality is a Danish Municipality located in the eastern part of Jutland (see figure 1). Of the 98 Danish municipalities, it has the second largest number of citizens. Nurses collected the data at the hospital based on information provided by the injured road user and medical staff present at the crash scene. The data include accident characteristics; mode types involved, accident situation and accident location (e.g. intersection). Information on accident circumstances are also listed (e.g. condition of the surface, weather condition) along with some road user specific information such as age, gender, helmet use and injury classified according to severity. Finally, the data include a written description of the accident. During the study period, 9446 persons were registered at the emergency room due to involvement in a road traffic accident; of these 4205 were cyclists. Only the 4205 persons visiting the emergency room due to involvement in a road traffic accident as cyclist were included in the study sample.

Fig. 1 The location of Aarhus Municipality

2.2. Analyses

The analysis included two elements. First, we performed a descriptive analysis of the 4205 cases included in the study. Second, we performed a qualitative analysis of the written descriptions of the 4205 cases. For the qualitative analyses, we used an explorative approach that included the following three steps: 1. Careful reading of the written description of each accident with the purpose to get as good an understanding of the incident as possible in order to be able to derive the relevant information about the occurrence of each accident, 2. Identification of accident factors according to four pre-defined main categories (see below), 3. Identification of underlying factors present during or immediately prior to the accident. For each accident, we registered the accident factors and underlying factors in a common database together with information on age, gender and the accident situation.

We defined an accident factor as an aspect of key importance for the occurrence of the accident. When identifying accident factors we distinguished between the following four predefined categories: The behavior and condition of the cyclist, the road and its surroundings, the bicycle and the other party. We decided to choose this approach as it has previously successfully been used when trying to understand factors contributing to road traffic accidents (e.g. Møller and Haustein, 2016; Bjørnskau et al., 2012). If relevant, we identified more than one accident factor in relation to an accidents. In cases where the written description of the accident was missing or the information provided was too limited, to identify an accident factor, we registered it in the database and the accident was not included in further analysis.

When identifying the underlying factor(s) for each accident we used an explorative approach, with no predefined categories. The purpose of the identification of the underlying factors was to register the situation specific circumstances contributing to the occurrence of each accident in order to get a more detailed understanding of specific contributing factors. For instance if the cyclist was identified as the main accident factor the identification of the underlying factor(s) served to identify the specific contributing aspects of the cyclists behavior and/or condition such as attention, illness, violations etc. The same holds for the other main accident categories. Table 1 provides examples of underlying factors in relation to all four main accident categories.

Table 1. Examples of underlying factors for each accident factor category

Accident factor	Example of underlying factors
The behavior and/or condition of the cyclist	The cyclist is drunk
The road and its surroundings	A pothole in the road
The bicycle	The chain comes off
The other party	Not respecting the right of way

With regard to the identification of accident factors and underlying factors, we only identified aspects as factors if the available information provided clear and explicit documentation of the presence. For instance, we only identified alcohol as an underlying factor in cases where it was explicitly noted in the accident description that the cyclist was under the influence of alcohol.

3. Results

In this section, we describe the results of the analysis. First, we provide some general descriptive results regarding the included cases. Second, we present the results regarding the accidents factors and lastly we present the results on the identified underlying factors.

3.1. Descriptive accident characteristics

Of the persons registered at the emergency room due to involvement in a road traffic accident, 4205 (45%) were cyclists. None of the cyclists were involved in the same accident. Out of the 4205 cyclists, 2115 were male (50,3%) and 2081 were female (49,5%). In nine of the observations (0,2%) the gender of the injured cyclist was not registered. The injured cyclists were aged between 0 and 92 with a median age of 30.

The large majority of the cyclist (N = 2916, 69%) were involved in a non-intersection accident, while 1170 (28%) cyclists were involved in an accident occurring in an intersection. Only a small part of the cyclists (N = 119,3%) were involved in accidents involving a pedestrian. Among all the cyclists' accidents, the most frequently occurring

accident situation was single-bicycle accidents. Half (*N* = 2083, 50%) of the cyclists included in the study were involved in a single-bicycle accident. For cyclists injured in accidents occurring in an intersection the most frequent accident situation involved a straight riding cyclist and a right turning motor vehicle (*N* = 531).

With regard to 1271 (30%) of the accident involved cyclists the description of the accident was either missing or the information provided was too limited to identify accident factors. These cases were excluded when identifying the accident factors and underlying factors. Thus, the results regarding accident factors and underlying factors are based on information regarding 2934 cyclists.

3.2. Accident factors

The study identified 3124 accidents factors based on analysis of the written description of the accidents. Table 2 provides an overview of the identified accident factors and their distribution on the four predefined main accident categories. For the large majority (*N* = 2742, 94%) of the accidents we identified only one accident factor. For the remaining 192 (6%) accidents, we identified two accident factors.

Table 2. Overview of the identified accident factors and their distribution on the fours predefined main accident categories.

Accident factor	Other party	Cyclist	Road	Cycle	Total
Other party	949	10	74	2	1035
Cyclist	10	929	98	0	1037
Road	74	98	777	7	956
Cycle	2	0	7	87	96
Total	1035	1037	956	96	3124

As can be seen from table 2 the other party was identified as an accident factor in 1035 (33%) cases, in the majority of which (*N*=949) it was the only identified accident factor. In 86 of the cases in which the other party was identified as an accident factor it was in combination with either the cyclist, the road or the cycle as a second accident factor. Male cyclists were significantly more often injured in an accident in which the cycle was an accident factor χ^2 (1, *N*=96) = 19.92, *p* <.001), whereas women more often were injured in accidents with the other party as an accident factor χ^2 (1, *N*=1035) = 6.73, *p* <.05). We did not find any significant gender differences for the other accident factors.

With regard to age, we divided the cyclists into the following age groups: 0-8, 9-17, 18-29, 30-45, 46-65, 66+. The largest group was cyclists aged 18-29 year old. 38% (*N* = 1198) of the cyclists were in this age group (see table 3). As can be seen from table 3, the road was the most frequently identified accident factor for cyclists aged 66 years or older and the second most frequently identified accident factors for the 9-17 and the 46-65 year old cyclists. For the accidents involving the youngest cyclists (0-8 years old), we most frequently identified the cyclist as the accident factor, whereas we most frequently identified the other party as the accident factor for accidents involving cyclists aged 18-29 and 30-45. Significant differences in the age distribution in the accident categories was found.

Table 3. The age distribution of the injured cyclists by main accident category.

Age	Other party		Cyclist		Road		Cycle		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%
0-8	10	25.0	21	52.5	9	22,5	0	0	40	100
9-17	48	18.9	102	40.3	91	35.9	12	5,1	253	100
18-29	481	40.2	361	30.1	313	26.1	43	3.6	1198	100
30-45	218	35.6	190	31.1	182	29.7	22	3.6	612	100
46-65	241	29.4	282	34.4	278	34.0	18	2.2	819	100
66+	37	18.3	81	40.1	83	41.1	1	0.5	202	100
Total	1035	-	1037	-	956	-	96	-	3124	-

3.3. Underlying factors

For all accidents for which it was possible to identify a main accident factor we identified one or more underlying factors whenever possible. Table 4 provides an overview of identified underlying factors within each main accident factor category.

Table 4. Overview of underlying factors by main accident category.

Accident factor	Underlying factor	Total	%
Cyclist	Alcohol	262	25
	Attention	257	25
	Speed	112	11
	Handling the cycle	94	9
	Clothing etc.	90	9
	Crowd	85	8
	Violations	50	5
	Loss of control	46	4
	Unknown	21	2
	Illness	20	2
	Total	1037	100
Road	Slippery	306	32
	Curbstone	231	24
	Design	121	13
	Objects on the road	117	12
	Road surface	79	8
	Road works	53	6
	Weather	25	3
	Crossing animal	22	2
	Unknown	2	0
	Total	956	100
Cycle	Bicycle chain	43	45
	Various bicycle defects	31	32
	Brakes	16	17
	Gear	6	6
	Total	96	100

For accidents where we identified the cyclist an accident factor, alcohol (25%) and attention (25%) were the most frequently occurring underlying factors. Interestingly, in 9% of these cases clothing, bags carried in the hands by the cyclist or the like was the underlying factor. In addition crowding (being squeezed/squeezing another road user from the side) was identified as the underlying factor in 8% of the cases.

For the cases where we identified the road as an accident factor we most frequently identified slippery roads (due to water or ice) as the underlying factor. Cyclists hitting the curbstone was the second most frequently occurring underlying factor (24%). We also identified objects on the road (12%) and road maintenance (6%) as underlying factors but less frequently.

The cycle was the least frequently identified accident factor. Never the less, the analysis revealed that poor maintenance of the cycle is a contributing factor in relation to cycling related person injury. Among the cases where we identified the cycle as an accident factor, the bicycle chain falling off (45%) was the most frequently identified underlying factor. Brake defects accounted for 17% of the underlying factors and defects related to the

gears accounted for 6%. In addition to this, a number of different cycle defects such as breaking of the saddle or frame, or wheels falling off, collectively accounted for 32% of the underlying factors in this category.

4. Discussion

Based on medical records the purpose of this study is to get a better and more detailed understanding of the factors contributing to cyclist accidents. The study included data on 4205 cyclists registered at the emergency room due to involvement in a cyclist accident in the study period (2010-2015). Although it was not possible to identify accident factors in 30% of the cases due to missing information, the analysis of the remaining cases proved that the medical records included valuable information of high relevance for the understanding of factors contributing to cycling accidents. In 33% of the accidents, we identified the other party as an accident factor. Due to limited information of the other party the possibility to perform additional analysis of underlying factors was very limited and therefore left out in this study. For the remaining cases the cyclist were the most frequently identified accident factor (33%), the road (the second most frequently identified factor and the cycle the least frequently identified accident factor. The underlying factors identified in relation to these accidents contributed with valuable information about the specific factors present in the situation in which the accident occurred. Overall, the results show that the behavior and condition of the cyclist him-/herself is a key contributing factor in cyclist accidents. However, the results also showed that the condition of the road is of key importance particularly for older and younger cyclists. Bicycle defects was only an accident factor in a smaller number of accidents, but never the less indicate that better maintenance of bicycles holds a potential for improving cyclists safety. In the following sections, we discuss key findings, limitations, and the relevance of the results for preventive efforts.

In line with existing knowledge on road traffic accidents the study confirmed that the behavior and condition of the road user, in this case the cyclist, is a key contributing factor (e.g. Rothengatter, 1997). Alcohol impairment was (together with attention) the most frequently identified factor, which indicates that preventive efforts aiming to prevent cycling while under the influence of alcohol as previously suggested by Andersson and Bunketorp (2002) are still highly relevant. In addition to alcohol impairment, the study found other violations such as riding in the wrong side of the road or riding without bike lights during dark hours to be contributing to the occurrence of the accidents.

Previous studies show that errors predict crashes as well as near crashes among cyclists (e.g. Twisk et al., 2015; Puchades et al., 2017). The results of this study adds on to the existing knowledge based on a detailed understanding of the specific types of errors such as clothing and bags getting stuck in the wheel by mistake, feet slipping on the pedal when trying to get on/off the bicycle, braking mistakes etc. Unfortunately, information about cycling skills and experience was not available in this study. Additional studies including such information is therefore relevant to improve the understanding of the contribution errors and their reasons in relation to cyclist accidents. Never the less, the results of this study clearly shows the relevance of increasing cyclists' awareness of the importance of relevant clothing and safe ways to carry bags etc. when cycling.

The qualitative and explorative approach used in this study led to identification of previously underexposed accident factors such as the condition of the road. Our results show that the condition of the road is a key contributing factor in cyclist accidents as 31% of the accident factors identified were related to the road and its condition. In line with our results, a few previous studies show that roads with a surface in bad condition may lead to traffic disruption and increased accident risk (e.g. Pulugurtha et al., 2013; Corazza et al., 2016), and that the majority of cyclist accidents are related to the road condition and design (e.g. NHTSA, 2012). Our results show that the condition of the road is a particularly important accident factor among the oldest (66+ years old) and younger (9-17 years old). This indicates that the road condition is of particular importance for less stable/secure cyclists, who due to factors such as inexperience of physical impairment are less capable of compensating for unexpected turbulence caused by damaged roads. However, additional studies are needed to verify this.

Half (50%) of cyclists included in the study were injured in a single-bicycle accident. This is in line with the results of a previous study by Beck et al. (2016), but a bit below the share found in other studies using non police-registered road traffic accident data (e.g. Schepers et al., 2014). Single-bicycle accidents are generally known to be suffering from a high underreporting level in police registration based accident information (e.g. Aslop and Langley, 2001; Langley et al., 2003). Based on the data available in the study it was not possible to calculate exact levels of underreporting, as it was not possible to verify if an accident registered at the emergency room was also registered by the police and vice versa. However, a comparison of the number of cyclist accidents registered by

the police (data provided by the Danish Road Directorate) and the emergency room in Aarhus Municipality during the years of 2010 and 2015 indicated that underreporting is indeed an issue, particularly with regard to single-cyclist accidents. In total 4205 cyclist accidents were registered by the emergency room while only 1052 accidents were registered by the police. For single cyclist accidents the difference was even more pronounced as only 48 accidents were registered by the police compared to the 2083 accidents registered by the emergency room. Overall, the results of this study clearly show that the use of medical records is relevant when trying to get a better understanding of cyclists' accidents and contributing factors.

In connection to this study, as in any other study, it is relevant to be aware that the quality of the results strongly dependents on the quality of the data on which the analysis is based (Imprialou and Quddus, 2017). In this study, the results are based on information registered by the hospital staff with no possibility to verify the accuracy of the information provided. It has been shown that some inconsistency between road traffic accident information registered by the police and by hospital staff exists (e.g. Lopez et al., 2000), partly due to the different purpose for which the data is collected e.g. civil claims and trauma treatment which may bias the data (Imprialou and Quddus, 2017). Further, similarly to other studies including qualitative data (see Aust et al., 2012; Møller and Haustein, 2016) some variation with regard to the type of information and level of detail provided in the data was found. These variations may stem from a number of known and unknown sources e.g. time pressure on the side of the hospital staff and social desirability (Lajunen et al., 1997) on the side of the injured cyclist influencing him/her to leave out certain types of information and prioritize inclusion of other. However, such bias most likely also influences other road accident data sources and are difficult to control for.

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