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E-bike safety: Individual-level factors and incident characteristics

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Abstract

As electrically assisted bicycles (e-bikes) become more widespread, the number of crashes in which they are involved is also growing. We used data from a survey of 685 e-bike users in Denmark to examine the factors which contribute to perceived e-bike safety and involvement in safety critical incidents. Using regression analyses, we demonstrated that riding style and e-bike attitude played a crucial role in both perceived safety and involvement in safety critical incidents. Age and female gender were negatively associated with perceived safety. 29% of participants had experienced at least one safety critical incident that they believed would not have happened on a conventional bike. The most frequent explanation offered for these situations was that other road users had underestimated the speed of the e-bike, followed by rider problems regulating e-bike speed. Older cyclists were more likely to report problems maintaining balance due to the weight of the e-bike. Preventive measures discussed include awareness campaigns and making it easier to distinguish e-bikes from conventional bicycles to address the problem of underestimation of speed. We also identified a need to familiarise with the e-bike before using it in demanding traffic situations.

Keywords:

e-bike, road safety, perceived safety, cycling accident, risk factor

1. Introduction

Electrically assisted bicycles (e-bikes) are becoming more common in many western countries. They account for more than 15% of total bicycle sales in Switzerland and the Netherlands (Fishman & Cherry, 2015), about 12% in Austria and Germany (VSSÖ, 2015; ZIV, 2015), and about 8% in Denmark (Danske Cykelhandlere, 2016). From a health-perspective, it is most relevant to look at the effects the e-bike has on physical activity and traffic safety. In relation to physical activity, most studies from Western countries indicate that e-bike access increases the number and distance of bike trips, at least partly at the expense of car trips, so that the effects are all in all positive (e.g.: Fyhri & Fearnley, 2015; Haustein & Møller, 2016; Hiselius & Svenssona, 2014).

In this paper, we focus on safety-related aspects of the e-bike. Various methods have been used to investigate, whether e-bike users are more likely to be involved in safety critical traffic incidents than users of conventional bikes, or if they are involved in more or different types of crashes.

Studies comparing the type and frequency of crashes involving e-bikes and conventional bikes based on data registered by the police have produced somewhat contradictory results. A German study found that although e-bikers were not more likely to be involved in crashes than conventional bike users, they were more likely to be injured or killed (Lawinger & Bastian, 2013), whereas another German study found no difference in either crash frequency or severity (Otte et al., 2014). Two studies based on Swiss crash data also produced slightly different results: Weber et al. (2014) found that e-bike crashes tended to be more severe than those involving conventional bikes, whereas Schmitt et al. (2014) found no significant difference in crash severity. An increase in the volume of e-bike crash data is needed to clarify the picture.

A study based on emergency department data and survey data from the Netherlands found that e-bikers were more likely to be involved in a crash that required hospital treatment than conventional bike users but found no difference in crash severity (Schepers et al., 2014).

The first studies based on “naturalistic cycling” data also produced mixed findings. Schleinitz et al. (2014) concluded that e-bike users in Germany were no more likely than conventional cyclists to be involved in

safety critical situations, whereas Dozza et al. (2015) concluded from data collected in Sweden that e-bikers experience more critical incidents, but with lower severity and that e-bike users were more likely to experience dangerous interactions with motorised vehicles than conventional cyclists. The latter was attributed to the probable underestimation of e-bikes' greater speed by other road users. Confirmation for this interpretation comes from a recent study that has shown that car drivers accept shorter time gaps in front of an approaching bicycle when the bicycle is an e-bike though not being aware of the bicycle type (Petzhold et al., 2015). The authors suggest that the observed difference in posture and the lower pedalling frequency on an e-bike is responsible for the misinterpretation of speed.

A naturalistic cycling study conducted in the USA that focused on safety-relevant behaviour, such as riding the wrong way or violating traffic signs, did not detect significant differences between e-bike users and conventional cyclists, with the exception of the difference in speed (Langford et al., 2015). Other studies have also reported that cyclists on e-bikes ride at higher speeds (e.g. Dozza et al., 2015; Schleinitz et al., 2015; Vlakveld et al, 2015), which may result in a higher severity of e-bike crashes but may also result in a more homogenous speed among cyclists (due to electric support of the slower cyclists) and hence safer cycling (Vlakveld et al., 2015).

An Austrian survey (Jellinek et al., 2013) found that about 4% of e-bike users had experienced a crash and about every sixth participant had experienced a near crash. The survey also showed that 10% of the crashes and near crashes were attributed to e-bikes' greater speed and acceleration relative to conventional bicycles. An Australian survey (Johnson & Rose, 2015) found that more than half of the participants had experienced a safety critical incident on an e-bike. The most commonly reported factor that contributed to a critical situation was an interaction with a motor vehicle (46%), followed by rider error (13%; e.g. unintentional acceleration, loss of balance) and issues with the surface (12%). Sixteen percent of respondents reported that the e-bike (as compared to a conventional bike) had contributed to the unsafe event.

Qualitative interviews with e-bike users in the US (Popvich et al., 2014) suggested that users' safety concerns were related to the higher speed of e-bikes, recognising that with higher speed the kinds of crashes

typical for bicycles would have more severe consequences. Users also mentioned that the difficulty of distinguishing e-bikes from conventional bicycles visually was a problem as it could lead to underestimation of their speed by other road users; a similar point was made by Dozza et al. (2015). Still the majority of e-bikers seem to feel safer on an e-bike as compared to a conventional bike as a survey among e-bike owners in North America suggests (MacArthur et al., 2014).

While e-bike safety has been on the research agenda in Asia (esp. China) for quite some time (cf. Fishman & Cherry, 2015), there is now a growing body of research on e-bike safety also in western societies as the brief review above demonstrates. However, some of the results are conflicting, perhaps due to the limitations of the available data (particularly in the case of studies based on crash data), use of different methods but also different research contexts: Differences in cycling infrastructure, regulations, cycling norms and behaviour are most likely contributing to the different results regarding the risks related to e-bike use.

The present study was motivated by the desire to gain insight into e-bike safety in Denmark, which has the second highest cycling rate in Europe after the Netherlands (Nielsen et al., 2015) and relatively good cycling infrastructure (Pucher & Buehler, 2008). However, cycling paths can be very crowded during rush hours - 43% of commuting trips to and from Copenhagen are made by bicycle (TU, 2016) - which may pose specific challenges for e-bike users, perhaps increasing the risk of crashes relative to countries with lower cycling rates and affecting the nature of crash situations. E-bike uptake in Denmark is so far not that high: In 2015, two percent of bike trips were conducted on an e-bike (TU, 2016).

The aim of the study was twofold: first, to determine the individual-level factors (such as age, gender and attitude) relevant to perceived safety and involvement in safety critical incidents among e-bike users and second, to gain a more detailed understanding of the nature of the hazardous situations that are perceived as specifically related to e-bikes as compared to conventional bikes, including relationships between specific situations and types of e-bike or e-bike user. Based on this knowledge, relevant information for interventions to increase the safety of e-bikes users (and their counterparts) were expected.

2. Material and methods

2.1 Data collection

This study was based on an internet survey of people who had access to an e-bike for over one month and used it regularly. The data were collected by the market research company MEGAFON on behalf of the Danish Road Safety Council. To reach e-bike owners as well as persons sharing and persons testing an e-bike, different sampling methods were used: Participants were recruited through two internet panels and from the population of employees who had access to an e-bike through their employer, in some cases for a restricted period of time as part of a pilot project. The data were collected in October and November 2014.

2.2 Questionnaire

The questionnaire included questions in relation to e-bike access and use, attitude, e-bike characteristics, safety critical incidents, and background information.

E-bike access and use: Participants were asked how long they have had access to an e-bike (6-point scale from “up to 1 week” to “more than one year”) and in what way they had access to an e-bike (“e-bike owner”; “shared e-bike in the household”; “access through others (e.g. workplace, friends)”; “access for a limited period e.g. through participation in a trial”; “other”). Cycling frequency was assessed on a 7-point frequency scale reaching from “daily” to “never” and distances typically covered daily were assessed on an 8-point scale from “do/did not cycle” to “more than 20 km”. Cycling frequency and distances covered were assessed for the e-bike and for the use of a conventional bicycle both before and after access to an e-bike.

Attitude: The questionnaire assessed attitude to e-bike use, perceived safety on a conventional bike and an e-bike and contained items related to e-bike riding style (see Table 2). All responses were given on a five-point Likert scale (1 = “totally disagree” to 5 = “totally agree”).

E-bike characteristics: Questions related to price, type of e-bike (front-wheel drive, rear-wheel drive, mid drive), and place of purchase (bicycle dealer, supermarket, internet, other) were included.

Safety critical incidents: Participants were asked if they had ever been involved in a crash or a dangerous situation that they thought would not have happened on a conventional bike. If they responded positively to this question details on the situation were collected via an open question.

Background data: Age, gender, income, level of education, and the place of residence (municipality) were asked for.

2.3 Analysis

U-tests were used to test for differences in cycling frequency and covered distances between different e-bike users groups. Chi-squared tests and ANOVAs (according to scale of measurement) were used to investigate systematic differences in cycling attitude, riding style, perceived safety and incident involvement on an e-bike related to age, gender, and e-bike access. We further examined if perceived safety on an e-bike and conventional bike differed within the same sub-groups (by use of *t*-tests for depended samples).

We used linear regression to determine the variables contributing to perceived e-bike safety and logistic regression to determine the variables contributing to risk of being involved in a safety critical incident. The following factors were included as predictors: demographics (age; gender; income; education; municipality), e-bike attitude; riding style; use of e-bike and use of conventional bike (experience; frequency; distance covered).

The qualitative descriptions of incidents were categorised and we then used Chi-squared tests to examine relationships between incident categories and categories of e-bike user (age; gender; area of residence), e-bike type (front-wheel drive; rear-wheel drive; mid drive), e-bike price (below of above 10,000 DKK/1340 EUR) and place of purchase (bicycle dealer, supermarket, internet, other).

3. Results

3.1 Sample

The sample comprised 685 e-bike users, of whom 427 (62%) were recruited via internet panels and 191 (38%) through workplaces that provided access to an e-bike. The majority (57%) owned an e-bike, 28% had only access to one for a limited period (through participation in a trial) and 15% shared use of an e-bike e.g. with a household member or through the workplace. Participants were generally experienced e-bikers, with nearly half (49%) having had access to an e-bike for more than a year and the majority (63%) were women. The high proportion of women was mainly due to the fact that 74% of participants who only had access to an e-bike for a limited period were women; in the sub-sample recruited via internet panels the gender distribution was more even: 49% men and 51% women. Most participants (51%) were aged between 40 and 59 years; only 14% were between 18 and 39 years and 35% were 60 years old or over. The mean age of men was 57 ($SD=12.0$) and the mean age of women was 51 years ($SD=12.2$). In the data of the Danish National Travel Survey (cf. Christiansen & Skougaard, 2015), 67% of e-bike trips in the period from June 2014 until end of 2015 were conducted by women and 73% by persons aged 60 years or older, thus e-bikers in this sample are younger than e-bikers in the general population of Denmark (TU, 2016), most probably due to the recruitment via the workplace.

While 58% of e-bike owners got an introduction to the e-bike and the possibility to test the bike, this was only the case for 13% of those who only had access to an e-bike for a limited period. The latter, however, more often got a written instruction related to the e-bike and its use (44% vs. 29% of e-bike owners).

3.2 E-bike use

Table 1 shows how often the e-bike was used and what distances were covered. Because of the strong differences, the results are presented separately for people with access to an e-bike for a limited time period and those who either owned or shared an e-bike. People with limited access cycled more often ($U= 31551.50$, $p < 001$) and covered longer distances ($U= 18259.50$, $p < 001$), probably as they used it more regularly for their daily commuting to work. Almost half these participants cycled more than 20 km per day on an e-bike.

When comparing distances covered by normal bike and e-bike based on TU data (TU, 2016), we find that longer distances were covered by e-bike than by conventional bike. When comparing the daily distances covered by e-bike of this sample with e-bike distances reported in TU, we find that the shortest distances are underrepresented in this sample, which is probably due to the specific inclusion of people who had access to the e-bike through their workplace.

Table 1: Cycling frequency and distances covered by e-bike for people with and without limited access to an e-bike.

e-bike cycling frequency							
	< monthly	monthly	2-3 times a month	weekly	2-5 times a week	daily	total
unlimited access (n=445)	2.0%	3.4%	7.6%	11.2%	46.3%	29.4%	100.0%
access for limited period (n=171)	0.0%	0.6%	1.8%	5.8%	55.6%	36.3%	100.0%
total (n=616)	1.5%	2.6%	6.0%	9.7%	48.9%	31.3%	100.0%
covered distances (daily)							
	do/did not cycle	<3 km	3–5 km	5–10 km	10-20 km	> 20 km	total
Survey							
unlimited access (n=437)	0.9%	8.0%	18.8%	25.4%	28.8%	18.1%	100.0%
access for limited period (n=171)	0.0%	0.6%	2.3%	12.3%	35.1%	49.7%	100.0%
total (n=608)	0.7%	6.0%	14.1%	21.7%	30.6%	27.0%	100.0%
TU data (e-bike)^a	-	21.4%	7.6%	19.0%	25.8%	26.2%	100.0%
TU data (normal bike)^a	-	21.8%	21.1%	27.9%	21.0%	8.1%	100.0%

^aincluding data of all bike/e-bike trips in TU (2016) from June 2014 until end of 2015; data is weighted.

3.3 Participants' attitudes, riding style, and perceived safety

As Table 2 shows, most participants agreed that they rode faster on an e-bike than on a conventional bike; that it was fun to ride on an e-bike; that the higher riding speed was exciting and that the speed surprised other road users. These four variables were combined to give a new variable “e-bike excitement” (Cronbach’s alpha = 0.69) as confirmed by factor analysis (see Haustein & Møller, 2016). With regard to perceived safety, most participants felt safe on an e-bike as well as on a conventional bike. All means of the

items presented in Table 2 differ significantly from the neutral midpoint of the Likert scale (“3”) (one-sample t-tests, all $p < .001$).

Table 2: Average level of agreement to items related to e-bike attitude, riding style and perceived safety on a five-point Likert scale (1=totally disagree; 5 = totally agree)

Item/Scale	<i>N</i>	<i>M</i>	<i>SD</i>
E-bike excitement (mean scale)	685	4.11	.77
I ride faster on an e-bike than on a conventional bike.	682	4.61	.83
It is fun to ride on an e-bike.	607	4.03	1.11
I find the higher speed and acceleration on an e-bike exciting.	676	3.91	1.16
I experience that my higher speed surprises other road users.	656	3.86	1.07
I ride in the same way no matter what type of bike I am riding.	673	3.81	1.18
I feel safe riding on an e-bike.	682	4.24	.85
I feel safe riding on my normal bike.	633	4.17	.98

Table 3 presents the results separated for men and women in different age groups (apart from age group 18-29 years, which was too small to divide by gender). Men aged 30-59 years reported lower e-bike excitement than all other categories (ANOVA; Bonferroni-corrected for multiple comparisons, $p < .01$). There were some differences in perceptions of the relative safety of e-bikes and conventional bikes. The mean scores suggested that young people felt safer on a conventional bike than on an e-bike, but the difference was not statistically significant ($p > .10$). Men aged 60 years or more felt safer on an e-bike (paired samples t -test, $p < .05$). Amongst the other groups there were no remarkable differences between perceived safety on an e-bike and a conventional bike. Table 3 also includes results divided by participants’ access to an e-bike. Persons with access for a limited period reported a higher level of e-bike excitement than bike owners and people sharing a bike (ANOVA; Bonferroni-corrected for multiple comparisons, $p < .001$) and were more likely to disagree that they rode the same way on an e-bike as on a conventional bike (compared with e-bike owners: $p < .001$; compared with shared e-bike users: $p < .05$). E-bike owners felt less safe on a conventional bike than both people with limited e-bike access ($p < .001$) and those with shared access to an e-bike ($p < .05$). The more interesting results relate to the groups’ relative perceptions of their safety on e-bikes and conventional bikes. E-bike owners felt safer on an e-bike than on a conventional bicycle (paired samples t -

test, $p < .001$) whereas those with limited access felt safer on a conventional bike ($p < .001$) and people who shared an e-bike felt similarly safe on both types of bike ($p > .10$).

In interpreting the results of Table 3 it is important to remember that gender and e-bike access were not independent variables as most of the people with limited e-bike access were women.

Table 3: E-bike excitement, riding style and perceived safety according by age/gender groups and e-bike access

	e-bike excitement ^a	same riding style on e-bike	perceived safety e-bike	perceived safety conventional bike
age/gender groups				
18-29	4.09	4.03	4.47	4.70
women 30-59	4.23	3.69	4.26	4.24
men 30-59	3.75	3.82	4.37	4.28
women 60+	4.14	3.71	4.04	3.97
men 60+	4.13	4.04	4.17	3.91
ANOVA results	$F(4, 657) = 8.75,$ $p < 0.001$	$F(4, 668) = 2.37,$ $p = 0.51$	$F(4, 666) = 3.00,$ $p = 0.02$	$F(4, 618) = 6.21,$ $p < 0.001$
e-bike access				
access for limited period	4.32	3.43	4.10	4.36
shared e-bike	3.88	3.81	4.16	4.26
e-bike owner	4.05	3.95	4.28	3.98
ANOVA results	$F(2, 615) =$ $12.71, p < 0.001$	$F(2, 603) =$ $11.45, p < 0.001$	$F(2, 613) = 2.86,$ $p = 0.06$	$F(2, 572) = 9.01,$ $p < 0.001$

Note. Means express the level of agreement (1 = “totally disagree” to 5 = “totally agree”). ^aMean scale of 4 items.

3.4 Involvement in safety critical incidents

Overall 29% of e-bike users reported that they had been involved in crashes or safety critical incidents that they thought would not have arisen on a conventional bike. Analysis indicated that there were systematic differences in incident involvement according to age-gender categories, $\chi^2(8, 654) = 31.18, p < .001$, with young people (aged 18-29 years) and older men (aged 60 years and over) reporting the lowest incident rates (26.6%; 17.6%) – both groups were highly underrepresented in people with access to an e-bike for a limited time period. Chi-squared tests indicated systematic differences in incident involvement related to e-bike

access, $\chi^2(4, 600) = 26.69, p < .001$. While 20.2% of e-bike owners and 22.8% of people sharing an e-bike reported that they had been involved in a safety critical incident, this percentage was about twice as high (41.3%) in the group of trial participants with e-bike access for a limited period.

There was no relationship between incident involvement and type of e-bike motor ($\chi^2(2, 517) = 2.57, p > .10$), price ($\chi^2(1, 542) = 3.62, p > .10$) or place of purchase ($\chi^2(3, 424) = 3.92, p > .10$) of the e-bike people used most often.

3.5 Factors related to perceived safety and incidents

We used linear regression and logistic regression to investigate which factors were related to perceived safety and incident involvement respectively (see Table 4). In both analyses demographic factors, e-bike excitement, e-bike riding style, e-bike use (distance/frequency), use of a conventional bike before e-bike access, e-bike access and overall e-bike experience were treated as potential predictors. Given that a causal relationship between perceived safety and incident involvement could go in either direction we calculated two models for both outcomes, one not including the other “outcome” variable as a predictor (Model 1) and the other including it (Model 2). Analyses with perceived safety as the outcome indicated that male gender increased perceived safety (Model 1) although this effect was reduced when incident involvement was included as a predictor (Model 2), indicating that part of the relationship between perceived safety and gender was due to men’s lower involvement in dangerous situations. Being above the age of 60 years was associated with lower perceived safety, whereas high e-bike excitement and a riding style that was independent of the type of bike were associated with higher perceived safety. Although e-bike experience was generally associated with greater perceived safety, covering longer daily distances on an e-bike had a negative impact. There was a trend towards a negative relationship between perceived safety and having had access to an e-bike for a limited period ($p < .10$), which disappeared when incident involvement was included as a predictor variable; this can be explained by the fact that people who only had access to an e-bike for a trial period were more likely to have reported involvement in an incident. When predicting incidents, e-bike excitement and riding style again played a relevant role. While e-bike excitement was

related to higher perceived safety it at the same time increased the reported involvement in incidents – especially when perceived safety was controlled for. In contrast, having the same riding style on an e-bike and a conventional bike was positively associated with both subjective and “objective” safety. Cycling more frequently was associated with incident involvement, which may simply reflect the difference in exposure to dangerous situations. In line with the results reported above, there was a trend towards a negative relationship between incident involvement and having limited access to an e-bike, which disappeared when perceived safety was included in the analysis as a predictor variable, indicating that the higher incident rate accounted for the lower perceived safety reported by users with limited e-bike access. Surprisingly, having regular use of a conventional bike before gaining access to an e-bike was not related to perceived safety or incident involvement. Living in Copenhagen, which we regarded as an informal proxy for exposure to higher levels of cycling congestion, was also unrelated to subjective and “objective” safety.

Table 4: Factors related to perceived safety and incident involvement on an e-bike based on linear and logistic regression analyses

	Level of perceived safety				Incident involvement (dummy)			
	Linear regression				Logistic regression			
	Model 1		Model 2		Model 1		Model 2	
	β	<i>P</i>	β	<i>P</i>	O. R.	<i>P</i>	O. R.	<i>p</i>
Gender (male)	.084	.032	.071	.066	.849	.471	1.021	.930
Aged 18-29	.043	.257	.039	.296	.791	.772	.816	.804
Aged > 60	-.152	.000	-.167	.000	.800	.357	.629	.070
Copenhagen	-.021	.584	-.026	.482	.878	.645	.869	.631
Only basic education	-.021	.577	-.021	.575	.899	.827	.887	.806
Access to e-bike for a limited time period (dummy)	-.091	.054	-.076	.102	1.693	.058	1.548	.128
Used conventional bike less than monthly (dummy)	.050	.192	.044	.242	.922	.732	1.023	.926
E-bike excitement	.207	.000	.226	.000	1.466	.015	1.909	.000
Same riding style on e-bike	.268	.000	.230	.000	.648	.000	.723	.000
Cycling frequency on e-bike	.052	.221	.056	.177	.809	.096	.764	.041
Cycling distance on e-bike	-.086	.044	-.098	.020	1.086	.261	1.108	.179
Experience on e-bike	.178	.000	.187	.000	.999	.997	.863	.318
Incident involvement			-.202	.000				
Perceived safety							.473	.000
	R^2 (adjusted R^2)		.208 (.192)		.245 (.228)			
	Nagelkerkes R^2				.180		.244	

3.6 Incident involvement and specification

One hundred and ninety-one people (29%) reported that they had been involved in at least one safety-critical incident that would probably not have happened on a conventional bike, of whom 156 provided a description of the situation; 26 did not remember or did not want to provide further details and 9 provided descriptions that could not be used as they did not relate directly to the incident situation, being instead related to e-bike experience more generally. In total 186 situations were described; 30 e-bike users described more than one incident. The answers were first coded in detail and then merged to give meaningful main categories (e.g. gliding/problems/crashes when it rains/snows/when it is slippery/under specific road surface was merged into the category “road grip/surface”; other cyclists/pedestrians/car users/road users underestimated the speed

was merged into the category “other road users underestimated e-bike speed”). In this way, the participants’ descriptions of dangerous situations were assigned to eight categories as shown in Table 5.

Table 5: Categories and frequency of reported incidents

Incident category	N	% of responses	% of respondents^a
Other road users underestimate the speed of e-bike	74	39.8	47.4
Regulation of speed	34	18.3	21.8
Road grip/surface	22	11.8	14.1
E-bike weight (balance problems)	19	10.2	12.2
E-bike user rode too fast	12	6.5	7.7
Lack of rider familiarity with e-bike	10	5.4	6.4
Brake problems	8	4.3	5.1
Higher speed of e-bike	7	3.8	4.5
Total	186	100	

^a Percentages do not add up to 100% as thirty respondents described more than one incident

Most incidents were attributed to other road users underestimating the speed of the e-bike, most frequently in the context of a car turning right in front of an oncoming e-bike (Denmark drives on the right). Several participants concluded that this underestimation resulted from the difficulty of differentiating an e-bike from a conventional bicycle:

“You ride faster on an e-bike and often car drivers are not aware of that. Especially, when drivers intend to turn right they think they can manage before one comes past on a bike. I experienced that twice, where I had to break heavily.”

“Several times I have had cars make a right turn just ahead of me, because the driver had misjudged how fast I was going. I think that when you’re on a racing bike, car drivers expect you to be going fast. The e-bike I loaned looked like a conventional ladies bike and the driver expected me to be riding slowly.”

Other categories of road user also underestimated the speed of e-bikes:

“Dangerous situations often occur because other cyclists (...) cannot estimate how fast we ride, e.g. at roundabouts or when you want to overtake other cyclists on a cycle path.”

The second most common situation related to regulation of e-bike speed. Cyclists described, for example, situations in which the motor started unexpectedly or continued although the cyclist was not using the pedals, leading to him or her running a red light or crashing into other cyclists or pedestrians. Some respondents reported that this was a particular problem in dense traffic, when it is necessary to brake frequently. It was not always clear from descriptions whether the problem was caused by handling error or failure of the e-bike.

“When I just wanted to get a little bit further at a traffic light, the motor started and I drove straight onto the pavement.”

“I wanted to stop at a red light but it [the e-bike] carried on when I got off.”

Several cyclists reported dangerous situations caused by a slippery surface, e.g. because the e-bike seemed to behave differently from a conventional bike when there was gravel, snow or ice on the road:

“When it is slippery or there is gravel, the rear wheel can skid out.”

Another category of incident was related to the greater weight of e-bikes. Several participants reported that they had been involved in situations in which weight of the bike had caused balancing problems:

“I dismounted from the bike and forgot how heavy it was, so I fell down and scraped my leg.”

“E-bikes are heavy and it can be difficult to lift them into an s-train or over the kerb, which made me fall over the bike.”

Some participants reported that a dangerous situation had arisen simply because they were driving too fast. There may be some overlap between these incidents and those assigned to the first category (underestimation of e-bike speed by other road users) but as this could not be determined from the descriptions a separate category was used for these cases. Another group of responses related to the need to get used to the e-bike or stated that the problem had arisen because the respondent was not yet used to the e-bike, without providing more specific information about the situation. Other cyclists described braking problems and in these cases it was not always clear if there had been a technical failure or if the e-bike rider had not adjusted to the

difference between braking on an e-bike and braking on their conventional bike. Finally, some participants' descriptions simply stated that the incident had been caused by "high [*or* higher] speed" without providing more details, e.g. if they had been going too fast or whether the consequences had been more serious because of the higher speed. Again, some of these answers might have been relevant to the first and fifth category.

3.7 Relationships between incident category and e-bike user characteristics

We investigated whether safety critical incidents that were mentioned by at least 10% of respondents (underestimation of speed; regulation of speed; road grip/surface; weight) were related to certain e-bike user characteristics, namely gender, age, education, income, area of residence and e-bike access.

We uncovered relationships between age and two categories of incidents. Just over half (51%) of participants aged 36-65 years reported that they had been involved in incidents because other road users had underestimated their speed, whereas less than 30% of participants under 36 years old or over 65 years made the same claim, $\chi^2(2,155) = 6.17, p < .05$. Problems related to the weight of the e-bike and to balance were more often reported by older people; in fact no-one under 40 year old reported problems of this type, whereas 7% of 41-59 year-olds and 31% of people aged 60 years or more reported problems due to the high weight of the e-bike, $\chi^2(2, 155) = 19.55, p < .001$.

We also found that people who only had access to an e-bike for a limited time period were more likely to report problems related to regulation of speed, $\chi^2(1,113) = 0.23, p < .05$.

3.8 Correlation between incident type and bicycle type

There are some dangerous situations which one would expect to be related to the type of e-bike (e.g. front-wheel drive, rear-wheel drive, mid drive) or quality as indicated by price. Most participants used a front-wheel driven e-bike (53%), 23% a rear-wheel driven one and only 6% used an e-bike with a mid drive; 22% did not know the motor specification. About half of participants (51%) used an e-bike with a price above 10,000 DKK (ca. 1500 EUR), 31% one with a lower price, and 19% could not or did not wish to provide information about the price (especially participants in e-bike trials). Similar as for overall incident

involvement (see Section 3.4), we were unable to detect any relationship between the most frequent incident category and either e-bike type or price, which suggests that road user factors are more relevant to incident involvement than e-bike factors. It should be noted, however, that the small number of people with an e-bike with a mid drive, and the relatively higher proportion of e-bike users who did not provide information about the type of e-bike they used, places severe constraints on the power of these analyses.

4. Discussion

This study had two main purposes: first, to identify the individual characteristics related to perceived safety on an e-bike and incident involvement; and second, to improve the understanding of the nature of safety critical incidents involving e-bikes.

We identified several individual factors related to perceived e-bike safety and incident involvement, the most important ones were riding style and e-bike excitement. The data do not permit causal inferences, but the most plausible interpretation of the association involving riding style, attitude, perceived and “objective” safety is that people who are excited about the higher speed and acceleration of the e-bike are more likely to engage in a riding style that has a detrimental effect on safety, resulting in a higher incident rate, which in turn reduces perceived safety. It is, however, important to note that our measure of riding style was based on a single item and thus has limited reliability and validity: we do not know how people interpreted the statement “I ride in the same way no matter what type of bike I am riding”; it could be related to speed, or to conformance with traffic rules, communication with other road users, keeping distance etc. The inclusion of different aspects related to riding style and road user behaviour, such as a standardised measurement of violations, errors and lapses (cf. Martinussen et al., 2013) would give more insight into this and is suggested for future studies.

Both age and gender were factors in perceived safety; higher age (> 60 years) and female gender decreased perceived safety. The gender difference is not surprising as women generally report feeling less safe and secure in traffic (e.g. Garrard et al., 2012; Haustein & Kemming, 2008; Møller & Hels, 2008). The age difference might be related to the weight of the e-bike since older people were especially likely to report this

as the cause of an incident. E-bikes are best balanced when the motor is located centrally, with the battery on the seat tube as this reduces the risk of the front wheel losing traction and the risk of overbalancing in corners (Jellinek et al., 2013) – both these situations were coded as balance problems and were reported more frequently by older e-bike users. It is thus important to ensure that older people are aware of the weight of the e-bike when purchasing and of the weight distribution when cycling with a loaded e-bike.

Given that nine out of eleven people who died in e-bike crashes in Denmark in 2014 and 2015 were over seventy years of age (Vejdirektoratet, 2016), it may appear surprising that we found no significant relationship between age and reported incident involvement. This suggests that the higher mortality among older people may be due to higher rates of e-bike use in the older population as shown based on TU data (TU, 2016); it may, however, also reflect “fragility bias” i.e. that older people are more likely to be injured or killed in a given incident because they are physically more fragile and thus more often appear in crash records (see e.g., Keall & Frith, 2004; Meuleners et al., 2006). A comparison of self-reported and archival crash data (Arthur et al., 2001) revealed that archival data is not necessarily more accurate or reliable than self-reports and a later study concluded that self-report data should be preferred for analyses of “lower threshold” crashes (Arthur et al., 2005) as in our study. Nevertheless, self-report data can be biased by factors such as social desirability (Lajunen & Summala, 2003), non-response, memory and/or hindsight bias (Roese & Vohs, 2012). In case of our study what people perceive as a safety critical situation may vary in accordance with personal characteristics, such as gender and personality traits. It is thus relevant to confirm and specify our results by studies including other measures of data collection. Naturalistic cycling studies are, as first results indicate (Dozza et al., 2015; Langford et al., 2015; Schleinitz et al., 2014, 2015), an excellent method of collecting useful data on dangerous situations and we expect that a combination with psychometric data such as reliable measures of cycling attitude and riding style, will further improve our understanding of how situational and individual factors contribute to hazardous situations involving e-bikes.

Although this study was not designed to answer questions about the prevalence of e-bike incidents, we found some indication that the prevalence in Denmark was higher as compared to countries, where cycling is less common: The percentage of persons that were involved in at least one incident in our survey (29%) was

almost twice the rate as in a similar Austrian survey (Jellinek et al., 2013) although our survey only considered incidents that were specific to the use of e-bikes. One would therefore predict that the total number of dangerous situations is even higher. While the percentage of people who reported a safety critical incident in an Australian survey was even higher (55%), the e-bike was thought to have contributed to these events only in 16% of the cases, which indicates that a higher percentage of riders in Denmark experienced critical situations that they would not have experienced on a conventional bike. While doubts about the validity and reliability of the question on incident involvement are justified as the persons' ability to assess if the e-bike was a main contributing factor or not may be limited and because no specific date was included, we still believe that the number of reported safety critical situations appears comparably high. The relatively high level of cycling congestion in Denmark compared with Austria and Australia (and most other Western countries) may account for this difference, as city traffic and congestion were often mentioned in the context of problems related to regulation of the speed of the e-bike. The result that living in Copenhagen was not related to incident involvement, however, contradicts this interpretation. Another possibility is that because Denmark has a large number of conventional cyclists, Danish drivers may have quite specific expectations about the speed of cyclists which, however, have not yet been adjusted to include e-bike users. This interpretation is supported by "underestimation of e-bike speed by other road users" as the most frequently reported problem, and difficulties in distinguishing e-bikers from conventional bikers as the provided explanation, particularly when the e-bike and/or the user was associated with a lower cycling speed (e.g. the e-bike is a transport/ladies cycle, the bike rider is an older person). This might explain why younger cyclists reported this kind of problem less frequently. That people over 65 years reported that situation less frequently may be related to the fact that this age group actually rides slower on an e-bike as compared to other age groups (Schleinitz et al., 2015). From a prevention perspective, there are two strategies which could be used to address this problem: e-bikes could be made easier to distinguish from conventional bikes (cf. Dozza et al., 2015) or one could use campaigns to increase road users' awareness of the existence and relatively high speed of e-bikes. Without legislation the first strategy is only likely to work if there is a market for distinctively looking e-bikes. International studies suggest that the opinion that e-bikes are only for certain groups of people with special difficulties (e.g. older people, people with a physical impairment) is

in decline (Preissner et al., 2013), so stigmatisation of e-bike users may not be a problem. The promise of increased safety could also be used to incentivise adoption of more distinctive e-bike designs.

The second most frequently reported type of safety critical situation was those involving problems regulating e-bike speed (e.g. the motor starting unexpectedly or continuing to run when the rider tries to halt), a category that strongly overlaps with what Johnson and Rose (2015) subsumes under “rider error”. To what extent these problems can be attributed to technical failures of the e-bike, lack of rider familiarity with the e-bike, handling errors and errors in e-bike instructions cannot be determined from our data and thus requires additional research. That this problem was reported more frequently by people trialling an e-bike than by e-bike owners indicates a need for e-bike users to familiarise themselves with the e-bike and the differences from a conventional bike before using it in demanding traffic situations.

In line with previous findings, we found poor surface quality (e.g. gravel) to be a factor leading to safety critical situations (cf. Johnson & Rose, 2015). The need for good surface quality and snow removal seems to be increased for e-bikes as compared to conventional bikes, possibly because the e-bike behaves differently from what expected based on experiences on a conventional bike or actual problems of particular types of bikes, e.g. with a motor on the back. However, no association between type of e-bike and incident involvement was detected, possibly due to data limitations. Future research based on sufficient data on all types of e-bikes is needed to address this issue.

Crashes with vehicles not complying with the regulations is a well-known problem in case of mopeds (e.g. Møller & Haustein, 2016) and could possibly also be an issue in relation to e-bike safety, particularly with regard to incidents involving high speed. To the best of our knowledge, e-bikes not complying with the regulations are currently not a main issue in Denmark. Yet, future studies addressing the development of this issue are highly relevant.

5. Conclusions

Our study indicates that the excitement about speed and a riding style that deviates from the riding style on a conventional bike contributes to the involvement in dangerous situations on an e-bike. While older people do

not experience more safety-critical incidents, the higher number of older e-bike users and their higher fragility make preventive measures targeted to this group particular relevant. Such measures include information about the characteristics of specific types of e-bikes, in particular in relation to weight and weight distribution, as well as possibilities to gain e-bike experience under safe conditions before using it in demanding traffic situations. Both will help to exploit the full potential of health benefits that e-bike access offers through higher levels of physical activity. In terms of other road users, increased awareness is required to avoid an underestimation of the speed of e-bikes, which was most frequently regarded as the cause of a safety critical incident. Future research is needed to validate and specify our results, including other data sources in addition to surveys.

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