Accident Analysis and Prevention 132 (2019) 105248

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Gender differences in accident risk with e-bikes—Survey data from Norway

A. Fyhri*, O. Johansson, T. Bjørnskau

Institute of Transport Economics, Norway

ARTICLE INFO

Keywords:
E-bikes
Self-reported accidents
Gender

ABSTRACT

E-bikes are becoming increasingly popular, and are given an important role in the green mobility of the future. However, some have raised concerns that the increased speed and the increased weight of the e-bike can lead to more accidents among cyclists riding an e-bike, as compared to conventional bicycles. Furthermore, it has been suggested that e-bikes may appeal to new groups of cyclists with little cycling experience, which may further impede cyclist safety. Previous research has not provided a clear picture. We investigate these questions with data from three surveys carried out in Norway (N = 7752). A logistic regression analysis comparing conventional and electric bicycles, controlling for age gender and exposure, shows an overall risk increase (all accidents) for e-bike users. The results suggest that this increased risk derives from females having a higher accident risk on e-bikes. For men there is no risk difference between e-bikes and conventional bikes. Some, but not all, of this elevated risk can be attributed to being unfamiliar with the bicycle. E-bikes are not more likely to cause serious accidents than conventional bicycles. In-depth analysis of accident causation showed that there was no difference in the factors leading to accidents, except that there was a somewhat higher prevalence of accidents resulting from balance problems with e-bikes.

1. Introduction

In recent years, e-bike sales have increased significantly in Norway (Tronstad, 2017). It is expected to increase further in the coming years, as the authorities want to increase cycling shares. Increasing the usage of e-bikes may be considered an environmental policy, as e-bike propulsion produce negligible carbon emissions. Another advantage is the effect of e-bikes on the health of the population (Sundfør and Fyhri, 2017). The electric motor assists acceleration or up hills, but still requires pedalling. E-bikes have proven to be an effective means to attract new cyclists (Fyhri et al., 2016) and can make it easier for people with physical disabilities to travel greater distances by their own.

E-bikes following the regulations made by the EU are formally known as EPACs (electric pedal assisted cycle), but are also known as Pedelecs. The EU regulations apply in Norway, which means that the motor assistant is limited to 250 W, and that the motor stops assisting beyond 25 km/h. Other countries, such as China, have more liberal regulations, with fewer restrictions on max speeds or need for applying the pedals to move forward, so that e-bikes typically can reach above 60 km/h using only the motor assistance. Studies looking at the accident risk related to e-bikes need to take into account the laws and regulations under which they are introduced (Fishman and Cherry, 2015).

Some have raised concerns that an increased use of e-bikes may lead to more traffic accidents (Papoutsi et al., 2014; Schepers et al., 2014; Weber et al., 2014). There are several factors that need to be taken into account to when investigating whether the increased share of e-bikes will increase the number of bicycle accidents. In discussing this claim, we will distinguish between a mere *exposure effect*, an *increased risk* and differences in *injury severity*.

Regarding the exposure effect, people tend to ride longer when they switch from a conventional bike to an e-bike (Fyhri et al., 2016). An Israeli study based on data from the National Trauma Registry, concludes that electric-powered 2-wheeled vehicles (herein e-bikes) increase accident numbers and “questions the social and economic advantages” of them (Siman-Tov et al., 2017, p. 318). However, the study did not account for possible changes in number of e-bikes in traffic nor for differences in usage between conventional and electric bikes. Another limitation is that trauma data only cover a small share of all accidents. Several studies have found substantive underreporting of bicycle accidents, both to the police and to hospitals (Shinar et al., 2018). Recent studies from Oslo, Norway, reveal that only 10% of bicycle traffic accidents resulting in personal injury are reported to the police. (Bjørnskau, 2005; Bjørnskau and Ingebrigtsen, 2015). This implies limited ability to draw conclusions about all cyclist accidents, especially if there are systematic differences in what kinds of accidents get

* Corresponding author.
E-mail address: af@toi.no (A. Fyhri).

https://doi.org/10.1016/j.aap.2019.07.024
Received 22 March 2019; Received in revised form 28 June 2019; Accepted 22 July 2019
Available online 13 August 2019
0001-4575/

reported; e-bikes are more expensive, which may increase willingness to report accidents for insurance claims.

A Dutch study that accounted for exposure found a small, but significant increase in accident risk for e-bikes (Schepers et al., 2014). This is a methodologically sound study, albeit it has some short-comings. The measure of exposure used, is only a crude sum of number of days cycled. Furthermore, since it is a case-control study, it is imperative that the groups are sufficiently matched on important background variables that may impact the difference between the two groups. As previously noted, e-bikes may be particularly attractive for specific segments of the population, which may also be segments that are more prone to have accidents.

In a replication of this study, a total of 2383 victims from emergency wards responded to a survey about accident characteristics, and type of bicycle used (Schepers et al., 2018). As in the former study exposure data was collected from an external web-panel. In the follow-up study no increased risk of accidents, nor any increased accident severity associated with e-bikes was found. The authors argue that the difference in results may be attributed to improved control for exposure and over secondary influences from poor health. However, other factors, such as improved quality of e-bikes (mid- and back-wheel mounted motors as opposed to front wheel motors) might also have contributed.

Some studies argue that e-bikes may cause more serious accidents and injuries because of higher speeds and greater weight than conventional bicycles (Lawinger and Bastian, 2013; Poos et al., 2017). However, several other studies found no difference in severe accidents between e-bikes and conventional bikes (Otte et al., 2014; Weber et al., 2014), and Papoutsi et al (2014) concluded that their data was insufficient to draw any conclusion about relative risk.

A Swedish study found that e-bicyclists brake harder, more suddenly, and have a higher mean speed than conventional bikes (Huertas-Leyva et al., 2018). Similarly, a Norwegian study also found e-bikes to have significantly higher mean speeds in Norway than conventional bikes, (20.8 vs 21.8 km/h for male cyclists and 17.4 vs 20.4 km/h for female cyclists), but small differences in maximum speeds (Flügel et al., 2017; Johansson and Fyhri, 2018). A Dutch study, comparing the same cyclists on the same route, with electric and conventional bicycles, found that middle aged participants rode on average 2.6 km/h faster on an e-bike than a conventional bike (Vlakveld et al., 2015). A study using self-report data found that cyclists who reported to cycle fast, where more likely to be involved in accidents, controlling for a range of other known risk factors (Fyhri et al., 2010).

The added weight of the e-bike may also contribute to difficulty handling the bike. This will also vary between bikes and by where the engine and battery are placed. Some evidence suggests that e-bike riders more often experience accidents while turning or while mounting and dismounting the bike, and older people may have greater trouble handling the extra weight (Haustein and Møller, 2016; Schepers et al., 2014). One study suggested that e-bikes are more unstable in phase one (mounting the bicycle) but more stable in phase two (acceleration) of riding (Twisk et al., 2017). The study found that there were age and gender differences in the strategies used in phase one. However, in none of the phases were there any interaction between age, gender and bicycle type. So, males and younger participants accelerated faster, and women and elderly had somewhat poorer stability, but using e-bikes did no influence this pattern. A different study found that elderly do have better stability while riding e-bikes compared to conventional bikes (Kovácsová et al., 2016). Crash-tests suggests no extra risk associated with e-bikes (Niska and Wenäll, 2017). In the latter study it was argued that the motor and battery may lower the centre of gravity, thus actually *reducing* the risk of tipping over while braking.

This literature review shows that to bring knowledge further there is need for studies with large enough sample sizes to be able to compare accident risk between electric and conventional bicycles. This also implies having sufficient control with exposure (i.e. distance travelled on the bicycle). Further, user groups differ, which might again have implications for accident risk or injury severity; older women have been suggested as a group with particular high risk while riding e-bikes (Fietsberaad, 2013). Hence, having detailed information about important background characteristics of the cyclist is imperative.

1.1. Objectives

While a number of studies have investigated the accident risk of e-bikes, evidence is still quite mixed. In this article, we aim to investigate some of the questions regarding e-bikes and accident risk. The main aim is to investigate if e-bikes have a higher risk for being involved in accidents than conventional bicycles. Further we aim to investigate if women, and in particular older women have a higher risk on e-bikes than male cyclists. We also investigate if a potential accident risk from e-bikes can be attributed to their novelty for the users. Finally, we will explore if the causes and consequences of e-bike accidents differ from ordinary bicycle accidents; more specifically if they are more serious, and if they more often happen because of higher speeds or manoeuvring problems.

2. Methods

We used three data sets to carry out the analysis. Data set one (DS1) was a two-stage survey carried out in nine Norwegian urban areas in 2017, where participants were first recruited in a large scale study about general cycling behaviour and accident involvement and then given a more detailed questionnaire about the accident they had been involved in. Data set two (DS2) was a study about general cycling behaviour carried out in Norway's four largest cities 2018, using the same questionnaire items as in DS1. Data set three (DS3) was a study carried out in 2018 among a random population sample covering all of Norway, functioning as a baseline study of a coming campaign for improved road safety (focussing on distractions in traffic).

There were some variations in questionnaire items (as will be explained), but a common feature of all questionnaires is that accident involvement during the previous and current year was recorded.

2.1. Data set one (DS1)

2.1.1. Sampling

Participants were recruited in two steps. First, 40,000 participants were randomly selected from the National Register of Bicycle Owners (a voluntary register for reducing 'own risk' in insurance cases). Members were invited via email to participate in a web survey during the summer of 2017. Second, those who reported an accident while cycling during the last three years, received an additional web survey a few weeks later.

In the first data collection, a total of 6337 (16%) participants responded. Invitations to participate in the follow-up survey was sent to 555 persons who reported an accident, and 390 of these responded (70.2%). Of these 390 respondents 66 (16.9%) had been using an e-bike when the accident occurred.

2.1.2. Survey items

The first survey was quite extensive. In the following, we describe the items used for the current analysis in the order in which they were presented to the respondents in the survey.

We measured *bicycle use* with three questionnaire items. The first was about how often they used a bicycle for transport purposes (More than four days/week; two to four days/week; one day/week; one to three days per month; less often; never). The second was about how often they used a bicycle for recreation purposes (More than four days/ week; two to four days/week; one day/week; one to three days per month; less often; never).

The third question was: "Approximately, how far (in kilometers) did you ride your bike in the past week, i.e. in the past seven days?"

Respondents were asked to distinguish between cycling for transport purposes and cycling for recreation.

Respondents registered what kind of bike they used the most (Mountain bike; Classical (retro) bike; “Hybrid bike” (commuter bike); Racer bike; Shared bike; E-bike; Other).

Accident involvement was recorded with the question “Have you had an accident with a bicycle in the last few years? With accident we mean crashing, running of the road or falling over, and resulting in damage either to yourself or to the bicycle” (Yes, in 2017; Yes, in 2016; Yes, in 2015; No).

In the follow-up questionnaire a range of questions regarding the accident was asked. Survey items included in the current paper were:

- Did you visit a doctor? (yes; no)
- What type of bicycle did you use? (Mountain bike; Classical (retro) bike; “Hybrid bike” (commuter bike); Racer bike; Shared bike; E-bike; Other)

The respondents were asked if the accident was a collision or a single accident. Respondents who had been in a single accident were asked to select one of 13 pre-defined categories of accident causes[1] . For the current study these were grouped into the following: Braked too hard; Went off road/Hit object; Fell over (Hit tram-line, sidewalk, hole); Object into wheel; Problem with the pedal; Lost balance.

Further all participants were asked to indicate on a 7-point Likert scale ranging from 1 (totally disagree) to 7 (totally agree) for each of the items:

- I was well used to the bike
- The accident happened because I did not know the bike
- The accident could have been avoided if I had a bike I was more familiar with
- The accident happened because I did not brake fast enough
- The accident happened because I cycled too fast
- The accident happened because I accelerated too fast

2.2. Data set two (DS2)

2.2.1. Sampling

The survey was part of a large scale study aiming to recruit participants to a number of interventions for increased cycling and walking in everyday life.

In late August 2018, 40,000 members of the Norwegian Automobile Federation (NAF), whose membership base covers 10% of the Norwegian population, were contacted by email and invited to take part in a web survey. The sample was a random selection of members living in the cities of Oslo, Bergen, Trondheim and Stavanger (Fyhri et al., 2017).

In addition, participants were recruited from an advertisement on Facebook, and from other registers of willing participants available.

In total 7355 participants responded to the survey. The response rate cannot be directly calculated since the total sample is not known, but for the NAF sample it was 11% (4421 participants).

As a follow up to the baseline survey, respondents who had agreed to be contacted again received an invitation to respond to a second survey in October 2018, some six weeks after the baseline survey. Of the 3514 participants who were invited, 1642 responded.

2.2.2. Survey items

We measured *bicycle use* in three ways. The first was about how often they used a bicycle for transport purposes (More than four days/week; two to four days/week; one day/week; one to three days per month; less often; never).

The second was about how often they used a bicycle for recreation purposes (More than four days/week; two to four days/week; one day/week; one to three days per month; less often; never).

The third question was part of a questionnaire section about weekly cycling activity. First respondents were asked to report which of the days of last week they cycled a trip of more than 10 min duration. They were then presented with a list of the days they had reported, and asked: “How many minutes and how many kilometers did you bicycle in total on these days?”. Respondents could choose to answer both or just one of these questions. Only the data about kilometres cycled were used in the analyses presented in the following.

Respondents registered what kind of bike they used the most (Mountain bike; Classical (retro) bike; “Hybrid bike” (city bike); Racer bike; Shared bike; E-bike; Electric cargo bike; Other).

In the baseline survey accident involvement was recorded with the question “Have you had an accident with a bicycle in 2017[2] ? With accident we mean crashing, running of the road or falling over, and resulting in damage either to yourself or to the bicycle”.

In the follow up survey accident involvement was recorded with the question “Have you had an accident with a bicycle in 2018. With accident we mean crashing, running of the road or falling over, and resulting in damage either to yourself or to the bicycle”. In addition, respondents were asked if they had seen a doctor due the accident. All participants who had a bicycle were asked for how long they had used it.

2.3. Data set three (DS3)

2.3.1. Sampling

Data set three was a study carried out in 2018 among a random population sample covering all of Norway, functioning as a baseline study of a coming campaign for improved road safety (focussing on distractions when walking and cycling in traffic).

In June 2018 23,700 holders of drivers licenses, were contacted by postal mail and invited to take part in a web survey. Participants were randomly selected from the national registry of drivers licences in Norway.

In total 4170 participants responded to the survey, giving a response rate of 17.6%

2.3.2. Survey items

Bicycle use was measured with the question: “Approximately, how far (in kilometers) did you ride your bike in the past week, i.e. in the past seven days?” Respondents were to distinguish between cycling in traffic and off-road cycling.

Accident involvement was recorded with the question “Have you had one or more accidents with a bicycle in the last five years? With accident we mean crashing, running of the road or falling over, and resulting in damage either to yourself or to the bicycle” (Yes, No). They were then asked “In which year did the last accident happen? (2014–2016; 2017; 2018).

Bicycle type, accident severity (injury) and experience with the bicycle was measured in the same way as in DS2. The participants who had been involved in an accident were asked if they had changed their amount of cycling because of the accident (Yes, permanently; Yes, temporarily; No).

2.4. Data preparation & analysis

In DS1, respondents in the follow-up were matched with the first data collection using a unique ID. For those respondents who had

[1] Those who had been in a collision (N = 110) were asked a range of questions about the other part and the cause of the crash, but these data are not analysed here.

[2] This was a typographical error in the survey, it should have been «2018».

responded to the follow-up questionnaire (N = 390), we recoded the variable “bicycle type” according to what bicycle they reported to have used in the accident.

The variables cycling frequency (transport/recreation) was recoded so that higher numbers indicated higher cycling frequency.

For analyses of factors related to e-bike accidents, we use the data from the 390 participants reporting an accident in DS1. These data, and the data regarding injury involvement where analysed using simple chi-square statistics, since the N was too low to run logistic regression models.

For the logistic regression analyses, we hold data from 4230 participants from DS1, 1945 participants from DS2, and 1577 participants from DS3. To study the interaction between bicycle type, age and gender we first included the interaction term between gender and bicycle type in the model for both genders. We then ran separate models for males and for females where the interaction term between age and bicycle type was included. We only analysed accidents having occurred in the current year, i.e. the period from January to the time of interview. Further details about these analyses are presented in Section 3.2.

We initially tested logistic regression models with dummy variables for each data set, and these analyses indicated that the accident risk differed in each of the surveys. However, the overall patterns remained the same. For reasons of clarity, and because the number of accidents in each study is quite low we have not included dummy variables for each data sets as explanatory variables in the models.

The data were analyzed using SPSS Statistics 24.

3. Results

3.1. Demographics and accident counts

The main categorical variables included in the study, are presented in Table 1.

The main part of our respondents are between 35 and 54 years old. The participants who mainly use e-bikes are on average two years older than those who use other bikes. There is also a clear gender difference, where more women use e-bikes. The descriptive analysis also indicates that a larger share of those who mainly use e-bikes experience accidents, at least in the current and previous year.

In DS3 the mean cycling distance is half that which is observed in the other data sets, and the share of e-bikes is also lower. It should be noted that this DS3 is from a national sample, including rural areas, as compared to the DS1 and DS2 that are from urban areas. Also, the categories of cycling contexts, for measuring distance, differed somewhat from the other two samples.

3.2. Logistic regression, all accidents

To test if e-bikes have an elevated risk for accidents above that of conventional bicycles, we conducted a stepwise binary logistic regression analysis with *been involved in an accident* (in the current year) as dependent variable.

We used data from all data sets. At step one, independent variables included in the model were *age, gender, bicycle type (e-bike* vs *conventional bike)* and *total number of kilometres cycled per week*[3] . At step two the *interaction term* between gender and using an e-bike was included. The results of this logit model is shown in Table 2.

Age (young people have higher risk), gender (females have lower risk) and amount of cycling (kilometres per week) all predict accident involvement. At step one having an e-bike significantly increases the likelihood of an accident. When the interaction term between e-bike and gender is introduced at step two, there is no effect of e-bike use alone, but the interaction term is statistically significant, indicating that female e-bike riders have a higher risk than females on conventional bicycles, and higher risk than men.

To investigate deeper into the interaction effect by bicycle type, age and gender on accident risk, we ran separate analyses for males and females. We conducted binary logistic regressions with *been involved in an accident* (in the current year) as dependent variable.

We used data from all data sets. The results of these two logit models are shown in Table 7. For the interaction term between age and using an e-bike we recoded age into a binary variable (over/under 50 years).

To test if the observed increased risk for females on e-bikes could be explained by the fact that the bicycle was new and unfamiliar, we included the variable *length of use*. Note that not all participants were asked this question, hence the total N for this analysis is lower than in Table 2.

In the model for males, age and amount of cycling (kilometres per week) predict if cyclists are involved in accidents. E-bike and the interaction term between e-bike and age is not significant. Among men young age increases the likelihood of accidents.

For females e-bike and distance are both significant. Age and the interaction term between e-bike and age is not significant. The model can be interpreted such that females who cycle longer distances and who use an e-bike are more likely to be involved in accidents.

For both male and female cyclists, distance cycled and length of use show significant relationships with accident involvement. Longer cycling distances increase the likelihood of an accident, and the newer the bicycle is, the more likely it is to be involved in an accident.

3.3. Injuries

To investigate if e-bikes are involved in more serious accidents than conventional bicycles, we compare the ratio of injury accidents to non-injury accidents for different groups.

We used data from all three data sets. Of the 296 participants who had been involved in an accident during the last year, there were 46 participants who reported they had consulted a doctor as a result of the accident. These were coded as being *injured from an accident*. The number of cases is too low to run a logistic regression, so we resolved to analyse the relationship using Chi-square statistics.

Table 4 summarises the results from the crosstabs, and shows the share of accident-involved participants who were injured in the different groups.

In general, there is a higher proportion of men who are injured as a result of the accident. There is no total difference between e-bikes and conventional bicycles (both have an injury to accident ratio of 16%). However, there is an interaction between bicycle type and gender, so that a higher share of men are injured on a conventional bike than an e-bike, and a higher share of women are injured on an e-bike than a conventional bike. Chi square tests show that none of these differences are statistically significant. The gender difference for e-bikes is not

Table 1
Descriptive statistics for variables in the three data sets and in the total sample.

	DataSet			Bike type		Total
	1	2	3	Conventional	E-bike	
E-bike (%)	21	22	9			19
Age (mean)	47.6	46.9	50.8	47.7	49.7	48.0
Female (%)	45	36	45	40	54	43
Distance cycled/week (km)	55.4	54.5	24.2[a]	48.0	52.4	48.8
Accident. this year (%)	4	7[b]	2	5	6	5
Accident. previous year (%)	9	11	3	7	9	8
N	4230	1945	1577	6301	1451	7752

[a] Limited to cycling in traffic.
[b] Reported in the follow up survey in October. N = 1642.

[3] For DS3 this was measured as total distance cycled in *traffic*

Table 2
Logistic regression model with been involved in accident as dependent variable (n = 6661). Number of accidents = 267. Odds ratios (Exp (B)).

	Step 1	Step 2
Gender (male = 0; female = 1)	0.77*	0.64**
Age (in years)	0.99*	0.99*
Distance cycled/week (km)	1.01***	1.01***
Bicycle type (conventional = 0; e-bike = 1)	1.40*	0.45
Gender*E-bike		2.14*
Nagelkerke R2	0.026	0.029

* $p < .05$.
** $p < .01$.
*** $p < .001$.

statistically significant, whereas for conventional bicycles it is, *X2(1, N = 229) = 3.41, p < .05.*

Some of the participants in our study (N = 109) were asked if the accident resulted in them cycling less than they used to before the accident. Five percent said that they permanently had reduced their amount of cycling, 23 percent said that they temporarily had reduced their cycling, and the remaining 72 percent had not changed their amount of cycling. There was a slight tendency for women to reduce their cycling to a larger degree, but this tendency was not statistically significant.

3.4. Manoeuvrability

To closer investigate the causes of accidents, we use data from the follow up survey in DS1. Table 5 summarizes answers to questions about the cause of accident, distributed by bike type.

The only notable differences in accident causes between bicycle types, are in braking hard (higher among conventional bicycles) and losing balance (higher among e-bikes). The difference between bike types in accidents relating to losing balance is not statistically significant, using chi square statistics.

Table 6 summarises the results of gender*e-bike crosstabs for losing balance.

Overall, there is no difference between men and women in the share of accidents that are caused by losing balance. Men are more likely to have balance related accidents on conventional bicycles and women are more likely to have balance related accidents on e-bikes. This indicates an interaction effect between bicycle type and gender. However, none of these differences are statistically significant, using chi square statistics, which is quite explainable given that there are only 18 balance related accidents in total.

3.5. Speed as a cause of accidents

As e-bikes are equipped with an electric motor to help with acceleration, it could be assumed that some differences in accidents are related to speed. Thus, the motor assistant may also cause a greater need for timely braking. Answers to questions regarding these issues are presented in Table 7.

There are no clear trends in the answers to these questions. If anything, more users of conventional bicycles attribute the accident to high speed, but the difference is not statistically significant. We also tested if there was an interaction between gender and bicycle type on this question, but found no effect– female e-bike users did not report more speed related accidents than females on conventional bicycles.

4. Discussion

The results from the different analyses are not uniform, but they show some common outcomes. We find an overall increased risk of accidents associated with e-bikes in the analyses of all accidents. Just like in previous studies we find that males have a higher accident risk on bicycles than females (Bjørnskau and Ingebrigtsen, 2015; Fyhri et al., 2010). However, we do find that females, when riding an e-bike, have a higher risk for accidents than when riding a conventional bike (Tables 2 and 3). Some, but not all, of this elevated risk can be attributed to being unfamiliar with the bicycle (Table 3). E-bikes are not more likely to cause serious accidents than conventional bicycles (Table 4).

Table 3
Logistic regression models with being involved in accident as dependent variable. Separate models for males (n = 1599) and females (N = 1179). Odds ratios (Exp(B)).

	Male	Female
Age (in years)	0.98**	1.01
Distance cycled/week (km)	1.01***	1.01***
Bicycle type (conventional = 0; e-bike = 1)	0.67	2.36*
Age 50+ * E-bike	1.45	0.51
Length of use	0.86**	0.80***
Nagelkerke R2	0.075	0.105

* $p < .05$.
** $p < .01$.
*** $p < .001$.

The finding that e-bikes do have a general higher risk than conventional bicycles (Table 2) is somewhat at odds with previous results (see e.g. Schepers et al., 2018), but it should be noted that the risk increase we find is not very strong, and disappears when controlling for gender*bicycle type interaction (Tables 2 and 3).

As has been shown previously, e-bikes run at a higher average speed than conventional bicycles, particularly among women (Flügel et al., 2017; Johansson and Fyhri, 2018). Moreover, women are more at risk on e-bikes than on conventional bicycles. Hence, the increased speed may be an important risk factor behind the higher risk of women on e-bikes. An increased speed should imply an increased risk. For motor vehicles the relationship between speed and accident risk is well documented (Elvik, 2013). For bicycles this relationship between speed and risk has also been assumed, even though there exists surprisingly little empirical evidence using objective data to back it up (Schleinitz et al., 2017).

E-bikes have the ability to accelerate faster than conventional bikes, which could be a factor contributing to explain the elevated risk for females we have found. The study by Twisk et al. (2017) looking at age and gender differences in phase two (acceleration) of riding a bike found a non-significant tendency that elder women benefitted more in terms of improved balance from the e-bike than other groups. Our data are not particularly suitable for examining this. However, we did ask the respondents to specify the most probable causes of the accident and there was no general difference between the answers between riders on e-bikes and conventional bikes about acceleration being an accident cause (Table 7). We did not find any gender difference in the response to the question about acceleration as cause of accidents.

Apart from higher speeds among women on e-bikes, are there other risk factors that may contribute to their elevated risk? One candidate could be difficulties in handling and manoeuvring e-bikes due to their

Table 4
Summary of crosstab results. Share of accidents that resulted in injury for male and female cyclists, with conventional bicycle and e-bike. N = 296.

	Male		Female	
	E-bike	Conventional bike	E-bike	Conventional bike
Injury	12.0	19.2	14.4	9.6
No injury	88.0	80.8	85.7	90.4
Total	100	100	100	100
N	25	156	42	73

Table 5
Participants reported cause of accidents, distributed by bike type. Percent. N = 237.

	Other bike (N = 178)	E-bike (N = 59)
Braked too hard	18.0	15.3
Went off road/Hit object	10.7	10.2
Fell over (Hit tram-line, sidewalk, hole)	61.8	61.1
Object into wheel	1.7	1.7
Problem with the pedal	1.1	1.7
Lost balance	6.8	10.2

Table 6
Summary of crosstab results. Share of accidents that was caused from losing balance for male and female cyclists, with conventional bicycle and e-bike. Percent, N = 237.

	Male E-bike	Conventional bike	Female E-bike	Conventional bike
Balance related	5.00	8.00	12.80	4.50
Other cause	95.00	92.00	87.20	95.50
Total	100	100	100	100
N	20	112	39	66

greater weight.

Our data, and previous results (Haustein and Møller, 2016; Kovácsová et al., 2016; Niska and Wenäll, 2017; Schepers et al., 2014; Twisk et al., 2017), are not conclusive in terms of handling difficulty (Table 5). It could be argued that the accident risk for females could stem from the heavy weight of the e-bike and that women on average are weaker than men. We found a non-significant tendency for women having to have more handling problems with e-bikes than males (Table 6). This corresponds with the non-significant tendency for an interaction with bicycle type, gender and age in the mounting phase (elder women having more mounting problems with e-bikes than other groups) that was found by Twisk et al. (2017). But such accidents are quite rare, and happen at low speeds, so it is not very likely that this is a major cause for gender differences in risk.

Being inexperienced in traffic is a well-known risk factor for car drivers and PTW riders (Bjørnskau et al., 2012; Bjørnskau and Sagberg, 2005). It seems that e-bikes attract more novel users to cycling (Fyhri et al., 2017), and that these novel users to a larger extent are females. E-bike users more often attribute the accident to themselves being inexperienced cyclists (Johansson and Fyhri, 2018). Our study supports such a "novel-user effect", since familiarity with the bicycle is a strong predictor of accidents, both for conventional and e-bikes (Table 3). This being said, the gender effect is only reduced, not entirely removed, when this variable is included in the regression model. It should be noted that we could only include the variable "familiarity with the bicycle" (due to lacking data) in our regression model, and not the more general question about experience as a cyclist. These two questions capture slightly different aspects of novelty, and should ideally both be included in a regression model. Future studies should aim to ask about general cycling experience among cyclists, and to compare accident-involved cyclists with all cyclists on this matter.

Table 7
Responses to the questions about cause of the accident, on a scale from 1 (strongly disagree) to 5 (strongly agree). Means, N = 389.

	Conventional bicycle	E-bike
Did not brake fast enough	1.73	1.66
Cycled to fast	2.05	1.62
Accelerated too fast	1.24	1.24
N	301	88

The gender risk-effect may be illuminated by looking at three of the studies carried out in the Netherlands from a time series perspective. In the first large scale Dutch study about this (Fietsberaad, 2013), the same risk difference between men and women was found. In the second study from the Netherlands, there was a risk difference between e-bikes and conventional bicycles (Schepers et al., 2014). In the third study, no risk difference was found (Schepers et al., 2018). One likely explanation for this difference in results is that it derives from methodological differences. Another more substantial explanation is that e-bikes do in fact change their risk profile over time.

It could be that when e-bikes are new to the market the novel users are typically females. After a while, this gender difference in appeal becomes less pronounced, and the "novel-user effect" is equally distributed among males and females. It could also be that e-bike users just become more experienced, and that the novel-user effect is dissipated.

This study, as previous studies, clearly show the gender appeal of e-bikes. On conventional bicycles, the males in our sample covers more than twice as many kilometres as the females. On e-bikes females covers slightly more kilometres than the men.

As opposed to in the first Dutch study (Fietsberaad, 2013), we found no interaction effect with age and e-bikes for women. If anything, our data points to the opposite, that the elevated risks for females was (not significantly) more associated with young females. It is hard to tell why this difference occurs, but it might be related to the difference in the (early) e-bike market in the Netherlands and in Norway, where Dutch e-bike users to a larger extent were reported to be of an older age (Fietsberaad, 2013) than what we see in Norway (Fyhri and Sundfør, 2014).

The study gives an important contribution to a further understanding of whether e-bikes are a public health hazard or not. It is the largest study until now that attempts at measuring accident risk for e-bike users and comparing it with the accident risk of users of conventional bicycles. Most previous studies on this topic have looked at injury risk (the ratio of injuries to accidents), or have not had any valid measure of exposure, thus not being able to say anything about risk, but only about accident frequencies.

A strength of our study is that we have a relatively large sample of participants, and quite specific data about exposure to risk (cycling kilometres last week) for these. We also have included data about potential confounding factors for the users, such as gender, age and experience with the bicycle. To our knowledge, this is the first large scale study that shows that experience with the bicycle can explain accident risk. This has been made possible by combining data from different surveys. The slight differences in survey methods in these surveys (sampling and framing of questions) is a potential challenge, but our initial tests indicated that the trends in our data was the same in all data sets.

One important limitation of the data is that we use self-reported accident data, as opposed to official hospital data. Hence, the interpretation of what is an "accident" is to a certain extent up to the individual respondents. We tried to limit this effect by providing a definition ("With accident we mean crashing, running of the road or falling over, and resulting in damage either to yourself or to the bicycle"). Still we cannot rule out this as a source for bias. If respondents systematically differ in how serious an incident should be before they report it, this would pose a threat to the validity of our results. If, for instance females are more likely to report a situation as an accident than men, this would result in a higher risk for females. By also looking at accidents where the respondent has had to see a doctor, some of this potential bias is accounted for. Even if injury accidents were too few to provide reliable estimates, the pattern that was found for all accidents was confirmed (Table 4).

The sampling strategy was different for all three data sets. DS1 used a registry of bicycle owners, DS2 used members of a car-owner's association alongside a Facebook recruitment, and DS3 a general population sample. The study is not intended to be representative of the whole population, since the aim is to look for *relative* differences in accident risk. The bike owner's registry used in DS1 has a quite low membership fee (30 Euros for 3 years) and it covers a wide range of bicycle types, from the cheapest to the most expensive. With approximately 250.000 members it covers approximately 5% of all households in Norway. The database has existed since 1993 (long before the advent of e-bikes in Norway), and hence most of the members are not e-bike owners. The car owner's association used in DS2 contains predominantly car owners. Still, this is not a requirement for being a member, since household membership is quite common. A previous study recruiting from NAF, found that 12 percent cycled on the day of interview, compared to the official figure of 9 percent obtained from the national travel survey (Fyhri et al., 2017). As can be seen (Table 1), the samples in DS1 and DS2 have quite similar background characteristics. DS3 which was a general population sample had the lowest accident involvement and the lowest average cycling. It is important to note that this DS3 also consisted of rural areas, whereas DS1 and DS2 where only from urban areas, which might explain some of this difference.

The response rate is not known for the Facebook sample. For the other samples it was fairly low, in the region of 10 to 20%. As already mentioned some of the differences between the data sets, most likely stems from differences in the original samples. Even if there were differences in response rates, this should not pose any substantial threat to the results above that of the differences from the original samples. The *generalizability* of results is open for discussion. It is quite likely that the share of cycling, and the share of participants having had an accident, in our study is higher than what would have been found in the general population. It is not likely that having a more representative sample would have affected the results, other than that it would have required a very large sample to obtain enough accidents to reach sufficient statistical power.

We have only used accidents occurring in the current year as outcome variables. We have information about accidents occurring in preceding years as well, and have tested regression models with these. However, such models are difficult to substantially interpret, since we do not know for certain that the data about cycling kilometres and type of bicycle used is correctly accounted for (people are prone more to forget or misrepresent what happened one year ago). Especially in this case, where we are studying a phenomenon that is growing every year, e-bike use, this might lead to strong biases in the results. There were some variations in how the accident time frame was displayed. In DS1 and DS2 participants were asked to consider if they had been in an accident in the current year, or in a previous year, straight away. In DS3 participants were first asked if they had been in an accident in the last five years, and then in the follow-up question to specify which year. This slight variation should not have any practical implication for the results, since we in all instances were able to select out accidents having occurred during the current year.

Still, a limitation of our analysis is that we cannot fully control for the causal relationship between exposure and outcome (crash). The possibility that people who have been involved in an accident might reduce their cycling, and hence have a lower reported number of kilometres post-accident than they had pre-accident might lead to an elevated risk estimate. If this tendency is equally distributed among different groups, this is not a challenge to our results, since we are looking at relative differences. If it is not, it might bias the risk estimates. In other words, if women are more prone to be scared away from cycling by an accident than males, this will have the result that female accident victims will systematically report a lower exposure than their male counterparts, which again will artificially inflate females' relative risk. The same would hold for e-bike users vs. conventional bike users. As we showed, there was a slight tendency for women to reduce their cycling more than men following from an accident, but this was not significant. Future studies should include information about pre-accident exposure to better deal with this potential bias.

The generalizability of the results is not known. The main reason for this is that the study is performed in Norway where cycling modal share is relatively low, and where the e-bike market has increased rapidly in the last few years. Importantly, Norway follows the EU EPAC regulations (capping the top speed at 25 km/h). The share of illegal e-bikes, not adhering to this regulation is not known, but is assumed to be of minor importance to the total picture. Speed-PEDELCS (with top speeds of 45 km/h, and specific regulations) are legal, but are still a very minor part of the e-bike market. Similar results can be expected in countries with similar characteristics, most notably with the same formal regulation (and enforcement of such regulations) about e-bikes.

5. Conclusion

The main aim of this study was to investigate if e-bikes have a higher risk than conventional bicycles. The following conclusions can be drawn from our data:

- The overall accident risk for e-bikes is somewhat higher than that of conventional bicycles, but only for female cyclists
- Males have a higher accident risk on bicycles than females
- E-bike users are just as likely to see a doctor after an accident as conventional bicycle users
- Being unfamiliar with your bicycle increases accident risk
- E-bike accident victims are more likely to be unfamiliar with their bicycle, which might explain some of the elevated risk for females since females seems to be a large part of the novel user group
- E-bikes are more often involved in balance-related accidents which might explain some of the elevated risk for females (even if these are rare, and the difference is not significant)

E-bikes have been around for many years. Some countries have already experienced their dramatic influx, and have become used to their presence. Some countries are in the middle of this change, and some have yet to experience it. E-bikes tend to bring cycling to new groups wherever they are introduced, and have strong impacts on travel behaviour. The study gives important new contributions to the on-going debate about policies to meet these changes. Some cities (such as New York City) have at present banned them.

Our results indicate that E-bikes (following the EU EPAC regulative or any other regulative that caps their max speed at normal cycling speeds) are not dangerous in themselves. True enough, we find an elevated risk for female e-bike users. This result is hard to explain with any known theory about risk factors in traffic, except that of the influence of inexperience on accident involvement. In other words, the risk involved is most likely associated with their strong appeal to new user groups. Promoting e-bikes is therefore not more dangerous than any other policy aimed to attract new people to cycling, such as campaigns and fiscal incentives, with the only difference that e-bikes actually are effective at achieving these goals.

Declaration of Competing Interest

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

Acknowledgements

This research was funded partly from The Norwegian Public Road Authorities' research program BEST and partly from Norwegian Research Council's Transport 2025 research program.

References

Bjørnskau, T., 2005. Sykkelulykker. Ulykkestyper, skadekonsekvenser og risikofaktorer. (Vol 793/2005). Transportøkonomisk Institutt., Oslo.

Bjørnskau, T., Ingebrigtsen, R., 2015. Alternative forståelser av risiko og eksponering. Retrieved from Oslo. .

Bjørnskau, T., Nævestad, T.-O., Akhtar, J., 2012. Traffic safety among motorcyclists in Norway: a study of subgroups and risk factors. Accid. Anal. Prevent. 49 (0), 50–57. https://doi.org/10.1016/j.aap.2011.09.051.

Bjørnskau, T., Sagberg, F., 2005. What do novice drivers learn during the first months of driving? Improved handling skills or improved road user interaction? In: Underwood, G. (Ed.), Traffic & Transport Psychology. Theory and Application. Elsevier, pp. 129–140.

Elvik, R., 2013. A re-parameterisation of the power model of the relationship between the speed of traffic and the number of accidents and accident victims. Accid. Anal. Prevent. 50, 854–860. https://doi.org/10.1016/j.aap.2012.07.012.

Fietsberaad, 2013. Feiten over de elektrische fiets. Fietsberaadpublicatie, Utrecht.

Fishman, E., Cherry, C., 2015. E-bikes in the mainstream: reviewing a decade of research. Transp. Rev.

Flügel, S., Hulleberg, N., Fyhri, A., Weber, C., Ævarsson, G., Skartland, E.-G., 2017. Fartsmodell for sykkel og elsykkel. (1557). Transportøkonomisk Institutt., Oslo, Norway.

Fyhri, A., Sundfør, H.B., 2014. Ebikes -Who Wants to Buy Them, and What Effect Do They Have? (1325/2014). Retrieved from Oslo. .

Fyhri, A., Bjørnskau, T., Backer-Grøndahl, A., 2010. Bicycle helmets - a case of risk compensation? Submitted Transp. Res. - Part F September.

Fyhri, A., Sundfør, H.B., Weber, C., 2016. Effekt av tilskuddsordning for elsykkel i Oslo på sykkelbruk, transportmiddelfordeling og CO2 utslipp. Transportøkonomisk institutt, Oslo.

Fyhri, A., Heinen, E., Fearnley, N., Sundfør, H.B., 2017. A push to cycling—exploring the e-bike's role in overcoming barriers to bicycle use with a survey and an intervention study. Int. J. Sustain. Transp. 11 (9), 681–695.

Haustein, S., Møller, M., 2016. E-bike safety: individual-level factors and incident characteristics. J. Transp. Health 3 (3), 386–394. https://doi.org/10.1016/j.jth.2016.07.001.

Huertas-Leyva, P., Dozza, M., Baldanzini, N., 2018. Investigating cycling kinematics and braking maneuvers in the real world: e-bikes make cyclists move faster, brake harder, and experience new conflicts. Transp. Res. Part F: Traffic Psychol. Behav. 54, 211–222. https://doi.org/10.1016/j.trf.2018.02.008.

Johansson, O.J., Fyhri, A., 2018. Miniscenario: Increased Use of E-Bikes. (1625/2018). Transportøknomisk institutt, Oslo.

Kovácsová, N., de Winter, J.C.F., Schwab, A.L., Christoph, M., Twisk, D.A.M., Hagenzieker, M.P., 2016. Riding performance on a conventional bicycle and a pedelec in low speed exercises: objective and subjective evaluation of middle-aged and older persons. Transp. Res. Part F: Traffic Psychol. Behav. 42, 28–43. https://doi.org/10.1016/j.trf.2016.06.018.

Lawinger, T., Bastian, T., 2013. Neue Formen der Zweiradmobilität. Eine empirische Tiefenanalyse von Pedelec-Unfällen in Baden-Württemberg. Zeitschrift für Verkehrssicherheit 59 (2).

Niska, A., Wenäll, J., 2017. Cykelfaktorer som påverkar huvudskador: Simulerade omkullkörningar med cykel i VTIs krocksäkerhetslaboratorium (Vol. 931/2017). Statens väg och transportforskningsinstitut (VTI), Linköping.

Otte, D., Facius, T., Mueller, C., 2014. Pedelecs im Unfallgeschehen und Vergleich zu konventionellen nicht motorisierten Zweiraedern. VKU Verkehrsunfall und Fahrzeugtechnik 52 (2).

Papoutsi, S., Martinolli, L., Braun, C.T., Exadaktylos, A.K., 2014. E-bike injuries: experience from an urban emergency department—a retrospective study from Switzerland. Emergency Med. Int.

Poos, H., Lefarth, T., Harbers, J., Wendt, K., El, M.M., Reininga, I., 2017. E-bikers are more often seriously injured in bicycle accidents: results from the Groningen bicycle accident database. Ned. Tijdschr. Geneeskd. 161 (0).

Schepers, J., Fishman, E., Den Hertog, P., Wolt, K.K., Schwab, A., 2014. The safety of electrically assisted bicycles compared to classic bicycles. Accid. Anal. Prev. 73, 174–180.

Schepers, J.P., Wolt, K.K., Fishman, E., 2018. The Safety of E-Bikes in The Netherlands. Retrieved from. .

Schleinitz, K., Petzoldt, T., Franke-Bartholdt, L., Krems, J., Gehlert, T., 2017. The German naturalistic cycling study – comparing cycling speed of riders of different e-bikes and conventional bicycles. Saf. Sci. https://doi.org/10.1016/j.ssci.2015.07.027.

Shinar, D., Valero-Mora, P., van Strijp-Houtenbos, M., Haworth, N., Schramm, A., De Bruyne, G., Tzamalouka, G., 2018. Under-reporting bicycle accidents to police in the COST TU1101 international survey: Cross-country comparisons and associated factors. Accid. Anal. Prev. 110, 177–186. https://doi.org/10.1016/j.aap.2017.09.018.

Siman-Tov, M., Radomislensky, I., Group, I.T., Peleg, K., 2017. The casualties from electric bike and motorized scooter road accidents. Traffic Inj. Prev. 18 (3), 318–323.

Sundfør, H.B., Fyhri, A., 2017. A push for public health: the effect of e-bikes on physical activity levels. Bmc Public Health 17 (1), 809. https://doi.org/10.1186/s12889-017-4817-3.

Tronstad, H., 2017. Første norske elsykkelstatistikk. Retrieved from. https://elbil.no/forste-norske-elsykkelstatisikk/.

Twisk, D., Platteel, S., Lovegrove, G., 2017. An experiment on rider stability while mounting: comparing middle-aged and elderly cyclists on pedelecs and conventional bicycles. Accid. Anal. Prev. 105, 109–116.

Vlakveld, W.P., Twisk, D., Christoph, M., Boele, M., Sikkema, R., Remy, R., Schwab, A.L., 2015. Speed choice and mental workload of elderly cyclists on e-bikes in simple and complex traffic situations: a field experiment. Accid. Anal. Prev. 74, 97–106. https://doi.org/10.1016/j.aap.2014.10.018.

Weber, T., Scaramuzza, G., Schmitt, K.-U., 2014. Evaluation of e-bike accidents in Switzerland. Accid. Anal. Prev. 73, 47–52.