International Transport Forum

The Safety of E-Bikes in The Netherlands
Discussion Paper

168 Roundtable

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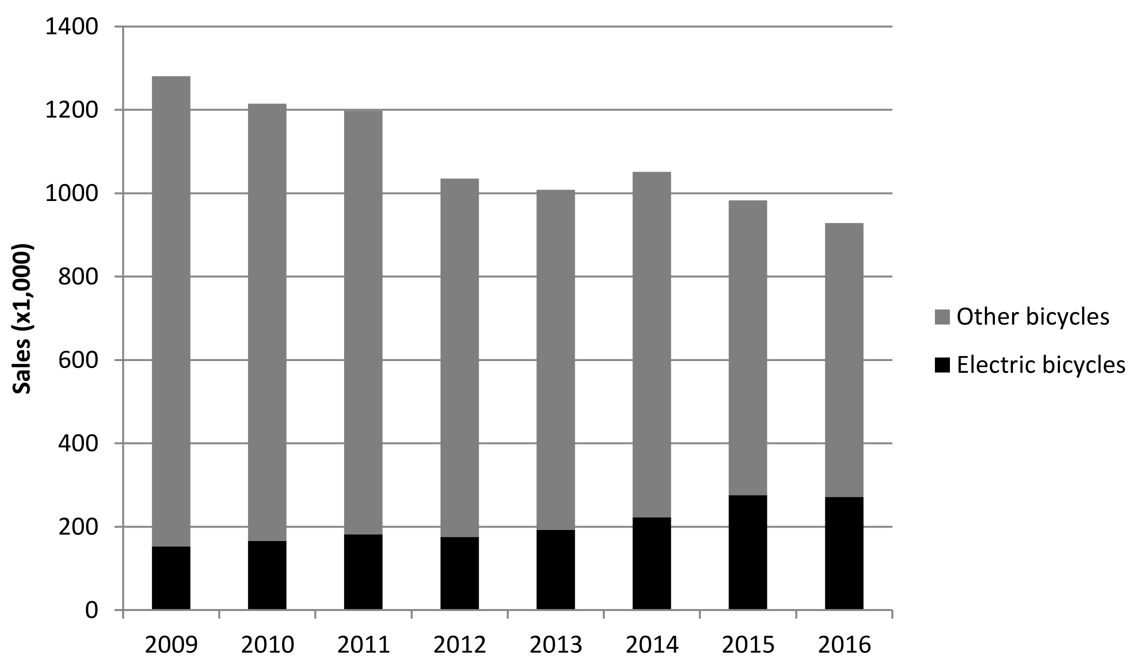
Introduction

E-bikes (EBs) enable longer distances to be cycled, especially in hillier areas (Haubold, 2016). EBs are therefore increasingly popular, as illustrated for the Netherlands in Figure 1. The increasing share of cyclists who become victims of road traffic crashes is a cause for concern (ITF, 2017), and also raises the question of how safe EBs are compared to other bicycles, here denoted as classic bicycles (CBs). This paper compares the crash likelihood and injury consequences of crashes with EBs and CBs among users 16 years and older in the Netherlands. Dutch EBs have to adhere to European legislation. An EB is a bicycle with pedal assistance of which the output is progressively reduced and finally cut off as the bicycle reaches a speed of 25 km/h (Kühn, 2012). The Dutch generally adhere to these rules, with the average cruising speed differing only 1 to 3 km/h between EBs and CBs (De Waard, 2013; Twisk et al., 2013; Van Boggelen et al., 2013). This differs from other countries. For instance, cruising speeds were found to be 40-50% higher in China (Fishman and Cherry, 2016).

Figure 1. **Bicycle sales in The Netherlands**



Source: BOVAG-RAI, 2017

A commonly researched aspect of EB safety is injury severity. Consistent with the speed differential in China, Hu et al. (2014) found EB crashes to be more severe than CB crashes. On the contrary, controlling for demographic factors such as age, no differences between EB and CB crash severity was found in the Netherlands, Germany and Switzerland (Schepers et al., 2014; Weber et al., 2014; Weiss et al., 2017).

Research on crash likelihood is rare as it requires both crash data and exposure data. Schepers et al. (2014) used data from crash victims at emergency departments, as well as data from a survey of cyclists without any known crash experience. Use of electric bicycles was found to be associated with an increased likelihood to be treated at an emergency department due to a crash (after controlling for trip frequency). Several factors may explain risk differences between EBs and CBs. EBs battery weight and weight distribution may affect safety, especially while mounting and dismounting. Active steering is required to stabilize a bicycle at low speeds (Kooijman et al., 2011). Experimental research suggests that EBs are less stable in the initial mounting phase (transition from 'earth bound' to 'balance') but help (older cyclists) to accelerate faster and achieve speed at which a bicycle stabilises itself (Kovácsová et al., 2016; Twisk et al., 2017).

A similar positive effect of pedal support has also been shown while riding uphill (Boele-Vos et al., 2016). Another difference between CBs and EBs is how traction forces are transmitted. In CBs, traction needed to accelerate forward is provided by the rider through the rear wheel, whereas, the engine power of a substantial share of the EBs currently available is transmitted through the front wheel (Valkenberg et al., 2017). Front wheel traction reduces the normal forces in the front wheel contact area and increases the likelihood of front wheel skidding (Meijaard et al., 2007).

Whether the above described factors indeed make crashes more likely on EBs compared to CBs is still uncertain for a country such as the Netherlands where EBs and CBs ride at comparable speeds. Schepers et al. (2014) did control for age as EB users tend to be older and therefore more likely to crash and sustain severe injuries (Schepers and Heinen, 2013). They also controlled for how often cyclists used their EB or CB. However, the study did not control for distance travelled and health factors. This means that part of the risk difference found in this study may be confounded by these factors. Therefore, this study aims to replicate the 2014 study with additional control variables.

To increase our understanding of crash likelihood and injury severity in EB users, this paper sets out to examine two research questions. Firstly, does crash likelihood differ between those riding EBs and CBs? Secondly, are there differences in crash severity between EB and CB crash victims? The study is focused on the overall risk and severity of crashes.

Methodology

Two questionnaire studies, commissioned by the Dutch Ministry of Infrastructure and the Environment, were used in this study to gather data on crashes and exposure. The response and distribution between victims and controls and between EB and CB users is shown in Table 1. As the survey of cyclists was conducted among people over 16 years of age, we only included and reported on victims treated at emergency departments (EDs) over 16 years of age (the survey among victims included all ages).

Table 1. **Sample size among victims and controls (unweighted response)**

Bike type	Victims treated at Emergency Departments (Consumer and Safety Institute)	Cyclists/ Controls (KANTAR)
E-Bike	A. 795	C. 357
Classic Bike	B. 1 788	D. 1 451
Total	2 383	1 808

Note: group letters are included for reference in the Analysis section.

Survey of bicycle crash victims treated at Emergency Departments

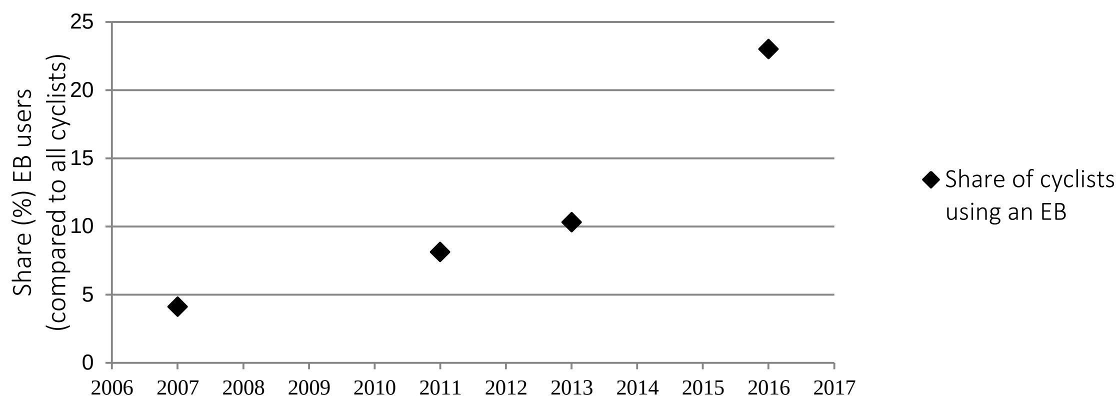
The Dutch Consumer and Safety Institute carried out a questionnaire study among bicycle crash victims treated at EDs in 2016 (for the questionnaire, see Appendix 3 in Valkenberg et al., 2017). Victims' files were retrieved from the Dutch Injury Surveillance System, which records anonymous statistics of all people treated for an injury by EDs in 13 Dutch hospitals. The EDs sent questionnaires to the victims two months after their crash, seeking information about crash characteristics and bicycle use preceding the crash. A total of 2 383 victims over 16 years of age responded corresponding to a response rate of 38% (Valkenberg et al., 2017). The data was weighted for age and gender, based on the representation in the Injury Surveillance System (to correct for differences in selection probabilities).

Survey of cyclists (controls)

Between weeks 27 and 43 of 2016, KANTAR conducted a questionnaire study using their panel (for the questionnaire, see Appendix 4 in Valkenberg et al., 2017). KANTAR disseminated some 200 questionnaires per week. Background characteristics of the 200 000 persons of the panel such as age, gender, and previous response behaviour are known. Panel members were asked to participate in up to one survey per month and received a small reward in return. Members saved up points for a self-chosen gift voucher equalling to a payment of around EUR 10 per hour of participation. The dataset contained a weighting factor, based on comparing the response to the panel, to represent age, gender and other demographical characteristics in the Dutch population. This corrects for the response rate differences.

As shown in Figure 2, the share of cyclists using an EB is on the rise; 4.2% per year between 2013 and 2016 (corresponding to 0.08% per week). The KANTAR survey being disseminated in the second half of 2016 results in an overrepresentation of EB users. The weight factor for controls in the dataset was adjusted to represent the estimated 2016 average share of EB users. As week 35 was the middle of KANTAR's study period (10 weeks after the middle week of 2016), the average share of EB users in 2016 was estimated at 22.1% (22.96 – 10 x 0.081). Note that some of the EB users only ride their EB occasionally. Therefore we set an additional criterion to classify controls as EB users, i.e. they had to ride at least half of the distance cycled on an EB. This criterion is used to compare like with like, crash victims on EBs may occasionally ride a CB as well.

Figure 2. **Share of cyclists over 16 years of age using an E-Bike**



Source: Hendriksen et al. (2008); Duijm et al. (2012); TNS NIPO (2014); Valkenberg et al. (2017).

Analysis

Binary logistic regression was used in this case-control study to compare groups. This type of regression predicts a binary response from a set of variables, e.g. to compare cases to controls, crash types or levels of injury severity (Peduzzi et al., 1996; Vandenbulcke-Plasschaert, 2011). The following comparisons are made in this study:

1. Victims treated at an ED versus non-victims ('controls') in order to compare crash likelihood (groups A and B versus groups C and D in Table 1).
2. Victims who were admitted to hospital versus victims who were sent home after the ED treatment to compare injury severity.

The two logistic regression analyses yield Odds Ratio's (ORs) for the independent variables that are regressed on the dichotomous outcome variable and that can easily be related to the two research questions. Age, gender, health related variables (medication use, morbid conditions, and Body Mass Indix – BMI), and cycling frequency are added as control variables to all analyses as they are related to the likelihood and consequences of bicycle crashes (Schepers et al., 2014). Respondents were asked to estimate how many kilometres they cycle per year to achieve a control variable for distance travelled by bicycle. It was added in two separate analyses because of a higher number of missing values and to compare two ways to operationalise this variable. In the first additional analysis, it was included as kilometres cycled per year. In the second analysis we took the natural logarithm of kilometres cycled per year, i.e. ln(km). Exposure is commonly modelled with the logarithm of exposure in crash prediction models (FHWA, 2010). We report Nagelkerke R2 as a measure of model fit to determine which model fits the data best (Nagelkerke, 1991). In the regression analyses on crash severity in Section 4.2, speed is added as an additional control variable as it may contribute to injuries sustained in a crash. Instances of missing values for one of the variables are excluded from the analyses. Therefore, the numbers of included cases differ between analyses and are lower than those shown in Table 1.

Results

Table 2 provides an overview of two important characteristics of crashes with EBs and CBs. Crashes with EBs are more often single-bicycle crashes while (dis)mounting and less often collisions with other road users. The road situations at which crashes occur do not differ between EBs and CBs.

Table 2. **Characteristics of crashes with Classic Bikes and E-Bikes**

	Bicycle type		Bicycle type*	
	CB	EB	CB	EB
Crash types				
multiple vehicle crash	588	132	33%	23%
single-bicycle, (dis)mounting	135	89	8%	15%
other single-bicycle crashes	1 070	363	60%	62%
Total	1 793	584	100%	100%
Chi-square test for comparison of crash types	$\chi2(2, N=2{,}377) = 43.3; p<0.001$			
Road situation				
straight road	872	270	57%	56%
curve	379	134	25%	28%
intersection or roundabout	277	79	18%	16%
different situation	230	79		
Total	1 758	562	100%	100%
Chi-square test for comparison of crash types	$\chi2(2, N=2{,}011) = 1.98; p=0.37$			

* Column percentages excluding different road situation

In the next sections the results of the logistic regression analyses are described. Descriptive statistics are included in the tables by cross tabulation of the independent and dependent variables, e.g. percentages of column counts for victims and non-victims for categorical variables and the mean and standard deviations for victims and non-victims for continuous variables.

Involvement in crashes requiring Emergency Department treatment against bicycle type

Table 3 presents the outcomes for the comparison between victims treated at EDs and controls. The odds of being treated at an ED after a bicycle crash is significantly greater among EB riders than among CB riders. As expected, higher age and frequent cycling (i.e. higher exposure) are correlated with the likelihood that a cyclist is involved in a bicycle crash. Interestingly, the impact of most health related control variables is different from what we expected, e.g. a higher BMI is associated with a reduced likelihood to be treated at an ED. EB riders generally have poorer health (e.g. the average BMI of all EB riders included in this study was 26.8 versus 24.7 for CB riders), but given the unexpected direction of the relationship, health factors do not explain EB riders increased crash likelihood.

Table 3. **Association between bicycle type and involvement in crashes for which treatment at an Emergency Department is needed**

	Treated at an emergency department		
	no	yes	Odds Ratio (95%CI)
N*	1,806	2,082	
Categorical variables	*share*		
type of bicycle			
CB	82%	77%	1
EB	18%	23%	**1.24 (1.03 - 1.48)**
gender			
male	49%	51%	1
female	51%	49%	**0.86 (0.75 - 0.98)**
age			
16 - 24 years	13%	17%	1
24 - 49 years	41%	29%	0.84 (0.68 - 1.03)
50 - 69 years	33%	35%	1.21 (0.97 - 1.51)
>70 years	13%	19%	**1.60 (1.22 - 2.09)**
bicycle use per week			
less than 1 day	24%	5%	1
1 – 2 days	20%	15%	**3.53 (2.69 - 4.63)**
3 – 4 days	21%	27%	**5.86 (4.52 - 7.59)**
4 – 7 days	36%	54%	**6.95 (5.45 - 8.87)**
medication use			
none	57%	58%	1
one or more	43%	42%	1.10 (0.94 - 1.29)
morbid conditions			
one or more	39%	30%	**0.65 (0.55 - 0.75)**
none	61%	70%	1
Continue var.	*gem (SD)*		
Body Mass Index	25.8 (4.8)	24.5 (4.1)	**0.94 (0.93 - 0.96)**
Nagelkerke R^2	16.8		

* Number of included cases, cases with missing values for one of the variables are excluded; numbers are therefore lower than in table 1

The most important control variable in an analysis on crash likelihood is exposure. Table 3 controlled for cycling frequency but not for trip distances. Table 4 shows the results of two similar logistic regression analyses including the same control variables along with an additional control variable for distance travelled per year by bicycle. The number of cases included in the analysis is somewhat reduced as more respondents did not answer this question. Nagelkerke R2 suggests model fit is substantially improved by adding distance travelled by bicycle to the model, especially by modelling exposure by the natural logarithm of distanced cycled. In the latter model (the right model in Table 4), the difference in crash likelihood between EBs and CBs completely disappears. This suggests that the difference between EBs and CBs in Table 3 is confounded by distance travelled.

Table 4. **Association between bicycle type and involvement in crashes for which treatment at an ED is needed with kilometres travelled by bicycle as additional control variable***

	Treated at an Emergency Department			Treated at an Emergency Department		
	no	**yes**	**Odds Ratio (95%CI)**	**no**	**yes**	**Odds Ratio (95%CI)**
N*	1,806	1,882		1,806	1,882	
Categorical variables	*share*			*share*		
type of bicycle						
CB	82%	77%	1	82%	77%	1
EB	18%	23%	1.18 (0.97 - 1.43)	18%	23%	1.01 (0.83 - 1.22)
Continue var.	*gem (SD)*			*gem (SD)*		
annual km by bicycle	1098 (1611)	2725 (2931)	**0.94 (0.93 - 0.96)**			
ln(annual km by bicycle)				6.0 (1.6)	7.3 (1.2)	**1.0003 (1.0003 – 1.0004)**
Nagelkerke R^2	24.5			26.3		

* Other control variables included in the analysis but not shown in the table are: gender, age, bicycle use per week, medication use, morbid conditions, and BMI

Injury consequences against bicycle type

Out of all 2 063 crash victims treated at an ED, 451 (22%) were admitted to hospital. Table 5 presents the outcomes for the comparison between victims who were admitted to hospital and victims who were sent home after the ED treatment. The non-significant Odds Ratio (OR) of 1.17 for EB users compared to CB users shows that victims using EBs are about equally often hospitalised as victims using CBs.

Table 5. **Association between bicycle type and injury severity (hospitalisation required after an emergency department treatment)**

	Admitted to hospital		
	no	yes	Odds Ratio (95%CI)
*N**	1,622	460	
Categorical variables	*share*		
type of bicycle			
CB	78%	73%	1
EB	22%	27%	1.17 (0.89 - 1.55)
gender			
male	49%	57%	1
female	51%	43%	**0.63 (0.50 - 0.80)**
age			
16 - 24 years	19%	11%	1
24 - 49 years	30%	25%	**1.67 (1.15 - 2.44)**
50 - 69 years	35%	36%	**2.03 (1.39 - 2.96)**
>70 years	17%	28%	**3.11 (2.01 - 4.80)**
bicycle use per week			
less than 1 day	5%	4%	1
1 – 2 days	15%	13%	1.02 (0.57 - 1.83)
3 – 4 days	26%	29%	1.21 (0.70 - 2.09)
4 – 7 days	54%	54%	1.28 (0.75 - 2.17)
medication use			
none	59%	52%	1
one or more	41%	48%	1.12 (0.87 - 1.43)
morbid conditions			
one or more	28%	35%	1.22 (0.96 - 1.56)
none	72%	65%	1
speed			
up to 5 km/h	6%	9%	1
15 - 25 km/h	22%	22%	0.77 (0.50 - 1.21)
up to 5 km/h	37%	33%	0.75 (0.49 - 1.16)
5 - 15 km/h	23%	27%	0.95 (0.60 - 1.51)
> 25 km/h	12%	11%	0.73 (0.43 - 1.25)
Continue var.	*gem (SD)*		
Body Mass Index	24.6 (4.4)	24.2 (3.4)	**0.94 (0.91 - 0.97)**
Nagelkerke R^2	5.6		

* Number of included cases. Cases with missing values for one of the variables are excluded; numbers are therefore lower than in table 1

Crash type: mounting and dismounting

Recent literature suggests an increased risk while mounting or dismounting amongst EB users (Twisk et al., 2017). Our current study also showed that crashes with EBs are more often crashes while (dis)mounting (see Table 2). In table 6 results are shown for the comparison between victims whose crash type did or did not involve (dis)mounting. In total 172 victims treated at an ED had an accident while (dis)mounting their bicycle. Again, the non-significant OR of 0.92 suggests that EB users are not more often involved in accidents when mounting or dismounting their bicycle.

Table 6. **Association between bicycle type and involvement in crashes regarding (dis)mounting the bicycle**

	Crash type mounting/dismounting		
	no	yes	Odds Ratio (95%CI)
*N**	1,890	172	
Categorical variables	*share*		
type of bicycle			
CB	79%	61%	1
EB	21%	39%	0.92 (0.59 - 1.43)
gender			
male	53%	29%	1
female	47%	71%	1.40 (0.91 - 2.17)
age			
16 - 24 years	18%	6%	1
24 - 49 years	31%	10%	1.03 (0.39 - 2.69)
50 - 69 years	35%	34%	1.94 (0.81 - 4.64)
>70 years	16%	50%	**3.09 (1.26 - 7.55)**
bicycle use per week			
less than 1 day	4%	11%	1
1 – 2 days	15%	17%	0.68 (0.31 - 1.49)
3 – 4 days	26%	35%	0.66 (0.33 - 1.34)
4 – 7 days	56%	37%	**0.38 (0.19 - 0.75)**
medication use			
none	60%	29%	1
one or more	40%	71%	1.34 (0.85 - 2.13)
morbid conditions			
one or more	33%	68%	1.39 (0.93 - 2.01)
none	67%	32%	1
speed			
up to 5 km/h	3%	48%	1
15 - 25 km/h	19%	44%	**0.16 (0.10 - 0.24)**
up to 5 km/h	39%	7%	**0.02 (0.01 - 0.03)**
5 - 15 km/h	26%	2%	**0.01 (0.00 - 0.03)**
> 25 km/h	13%	0%	0
Continue var.	*gem (SD)*		
Body Mass Index	24.4 (4.1)	26.0 (4.9)	1.02 (0.98 - 1.06)
Nagelkerke R^2	47.6		

* Number of included cases. Cases with missing values for one of the variables are excluded; numbers are therefore lower than in table 1

Discussion

This study was one of the first to compare crash likelihood of EBs to CBs and can be seen as a replication of the Schepers et al. (2014) study. Both studies focused on bicycle crash victims treated at an ED and compared those to a control group without known crash experience. Schepers et al. (2014) found that, after controlling for age, gender and cycling frequency, EB users were more likely to be involved in an injury crash. Although with a smaller Odds Ratio (OR), this study also found a higher likelihood of being involved in an injury crash for EB riders. However, it appeared that the difference disappeared completely after adding the natural logarithm of annual distance cycled as a control variable. Similar to Schepers et al. (2014), this study found EB users are equally likely to be admitted to hospital as CB users in case they needed treatment at an ED after a bicycle crash. The outcome for injury severity matches the results of studies in Germany and Switzerland (Weber et al., 2014; Weiss et al., 2017).

Improved control for exposure and health related factors has improved the validity of this study compared to the Schepers et al. (2014) study. However, given that the OR for injury crashes with EBs compared to CBs was also higher in that study, it may be that other factors have changed as well. As shown in Figure 2, the share of cyclists who occasionally or frequently use an EB was over two times as high in 2016 (our study period) as in 2013 (the study period of Schepers et al., 2014). The quality of EBs may have changed in this period of time. For instance, the industry trend is for ‘mid-mounted’ motors. This may keep the weight of the motor closer to the centre of gravity of the rider/bike. Moreover, in their paper it was suggested that engine power being transmitted to the front wheel in a large share of EB types may have contributed to skidding while cornering. Schepers et al. (2014) found crashes with EBs to be more frequent in curves. Table 2 suggests the share of crashes in curves now hardly differs between EBs and CBs, possibly indicative of improved vehicle quality.

It has also been suggested that the higher mass of EBs compared to CBs may interfere with (dis)mounting (Kovácsová et al., 2016; Twisk et al., 2017). Table 2 confirms that EB users are more often involved in crashes while mounting or dismounting; 15% of EB crash victims fell while mounting or dismounting. However, this study shows that after controlling for age, gender, bicycle use, and health factors, EB and CB users are equally likely to fall while mounting or dismounting. Apparently, EB users’ high frequency of falls while (dis)mounting is due to factors such age. EB users are older and older cyclists are more like to fall while (dis)mounting (Dubbeldam et al., 2017). Nevertheless, given the high frequency of this crash type we recommend to apply measures such as those advised by Dubbeldam et al. (2017), e.g. designing a bicycle such that the cyclist is able to sit on the saddle with feet on the ground.

To develop measures to maximise the health benefits and minimise the risk of EB use, more research is needed. Research could also be experimental, for instance related to mounting and dismounting, see e.g. Twisk et al. (2017). New buyers of EBs may also benefit from training. More generally, it is likely that EB users benefit from a variety of measures that have also been proven effective for CB users such as safer infrastructure.

Transferability and limitations

To what degree are the results of this study transferable to other countries? Cycling safety in the Netherlands is at a much higher level than other European countries (see e.g. Pucher and Buehler, 2008), and this applies to both EBs and CBs. Where differences in operation speeds between EBs and CBs are as small as in the Netherlands, the outcomes may be in the same range. Similar to our study, crashes with EBs and CBs were found to be equally severe in Germany and Switzerland (Weber et al., 2014; Weiss et al., 2017). Electric bicycle speed is dependent on legislation which differs between countries (for an overview, see Rose, 2012). Similarly, this studies' outcomes cannot be transferred to the new type of e-bike now being introduced in Europe, the so-called 'high speed e-bike' with an engine power cut off at 45 km/h (see e.g. Kühn, 2012). Similarly, our results may not be transferable to countries where speed differences between EBs and CBs are greater than in the Netherlands. For instance, even though the same vehicle legislation applies to EBs in Israel as in the Netherlands, EBs frequently ride at higher speeds in Israel (Gitelman, 2017).

Less severe crashes for which no treatment was needed or for which treatment by a general practitioner was sufficient were not included in this study. We are therefore unable to draw conclusions about the likelihood of crashes in general. However, the advantage of our focus on more severe crashes is that it aligns well with the national targets that are mostly focused on severe crashes.

This study may suffer from problems of self-reporting such as inaccurate recall of crash circumstances and responding in socially desirable ways (Heiman, 1999). This may especially apply to the comparison of crash types and characteristics, but probably less to the analysis on crash risk that includes only bicycle type and demographic characteristics that are specific and less prone to recall bias. Nevertheless, future research using other approaches than questionnaire research may improve the validity of the findings, for instance experimental research.

Conclusions

Crash risk and injury consequences were compared between users of EBs and CBs. From the results we conclude that use of electric bicycles is not associated with an increased risk of being treated at an emergency department (ED) due to a crash. Among victims treated at an ED, EB users are about equally likely to be admitted to hospital as CB users.

The present study only looked at the risks for individual users. The overall impact of EBs on road safety are complex and requires more research. There is some evidence that EBs may lead to a modal shift from driving but also new (recreational) kilometres by older cyclists (Fishman and Cherry, 2016; Hendriksen et al., 2008). Even though cyclists are not more at risk on EBs than on CBs, the EB enables relatively vulnerable elderly to cycle more often and longer. Due to the elevated risk of older cyclists this increases the number of serious road injuries (an exposure effect). These injuries need to be weighed against the health benefits of more cycling within this group.

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International Transport Forum

The Safety of E-Bikes in The Netherlands

This case-control study compares the likelihood and injury severity of crashes between users of e-bikes and classic bikes in The Netherlands. Use of e-bikes with a maximum speed of 25 km/h is rapidly increasing in European countries. Cyclists being hospitalised are compared to those being sent home after the treatment at the emergency department in order to compare the injury consequences between e-bike and classic bike victims.

Whilst results suggest that e-bike and classic bike users are equally likely to be involved in a crash and the severity of crashes are also about equal, the overall impact of e-bikes on road safety is complex and requires more research. As with all forms of physical activity, injuries need to be weighed against the health benefits of more cycling.

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