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Safety of e-bikes compared to conventional bicycles: What role does cyclists' health condition play?

Paul Schepers, Dr. [a,b,*], Karin Klein Wolt, MSc [c], Marco Helbich, Dr. [b], Elliot Fishman, Dr. [d]

[a] *SWOV Institute for Road Safety Research, The Hague, the Netherlands*
[b] *Utrecht University, Faculty of Geosciences, Utrecht, the Netherlands*
[c] *Consumer and Safety Institute, Amsterdam, the Netherlands*
[d] *Institute for Sensible Transport, Melbourne, Australia*

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ABSTRACT

Introduction: The rising use of e-bikes (EBs) presents an opportunity to increase active transportation but may compromise road safety due to increased travel speed and weight compared to conventional bicycle (CBs). Evidence comparing the safety of EBs and CBs is limited while the influence of cyclists' health status has been neglected.

Methods: This cross-sectional case-control study compared EB and CB users in the Netherlands. Data were gathered 1) through a survey among crash casualties treated at emergency departments aged >16 ($N = 2383$) and 2) control group data were collected among cyclists without any known crash experience, randomly drawn from a panel of the Dutch population ($N = 1860$). Using logistic regressions, we assessed the likelihood of crashes and crash severity while adjusting for bicycle use and health status.

Results: EB users had poorer health than CB users, but they were not more likely to be involved in a crash or to sustain more severe injuries. However, older female cyclists did have an elevated risk on EBs and sustained more severe injuries. Health-related factors such as the presence of morbid conditions, medication use, and the body mass index were neither associated with crash likelihood nor associated with injury severity and accordingly did not explain the findings for older females. However, balance and coordination problems, and the use of anti-epileptic drugs were associated with crashes.

Conclusion: Our findings provide support that EB users have a poorer health status than CB users, while general health status is unrelated to the likelihood and severity of bicycle crashes. EBs enable more vulnerable groups to cycle or keep cycling but, after controlling for bicycle use, EB users are not more likely to be involved in a crash or to sustain severe injuries. As older females run a higher risk on an EB and are more likely to fall while (dis)mounting, we recommend to promote EBs enabling safer (dis)mounting such as by reduced saddle height.

1. Introduction

Purchase and use of e-bikes (EBs, bicycles offering pedal assistance up to 25 km/h and motor output up to 250 W) are on the rise in

* Corresponding author. SWOV Institute for Road Safety Research, The Hague, the Netherlands.
E-mail address: j.p.schepers@uu.nl (P. Schepers).

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many countries (Fishman and Cherry, 2016; Bovag-Rai, 2019). The Netherlands is no exception to this trend, as the share of EBs in total bicycle purchases rose from 14% to 41% in 2010–2018 (Bovag-Rai, 2019). This increase presents an opportunity to increase active transportation (Cairns et al., 2015; De Kruijf et al., 2018). Riding the same distance on an EB requires some 24% less energy than on a Conventional Bicycle (CB) (Langford et al., 2017), but net losses in physical activity in those switching from a CB to an EB are less due to increased trip distances (Castro et al., 2019). Replacing car trips by EB trips yields substantial increases in physical activity and related health benefits (Woodcock et al., 2011; Castro et al., 2019). However, the increased use of EBs raises questions of how road safety is affected (Haustein and Møller, 2016; Schepers et al., 2018). EBs are ridden at somewhat higher speeds which may elevate the risk, although the difference is only 1–3 km/h (Twisk et al., 2013; Van Boggelen et al., 2013; Langford et al., 2015; Vlakveld et al., 2015; Schleinitz et al., 2017). EBs higher weight may increase the risk of falling while mounting or dismounting (Twisk et al., 2017; Hertach et al., 2018).

The results of studies on EB safety are inconsistent. Few studies have compared crash risk on EBs with CBs while controlling for the amount of cycling. After controlling for age, gender, and cycling frequency, Schepers et al. (2014) found EB users were more likely to be involved in a crash that required treatment at an emergency department. In line with this conclusion, Haustein and Møller (2016) found 29% of EB users reported that they had been involved in crashes or safety critical incidents that they thought would not have arisen on a CB. In a study controlling for the amount of cycling, Fyhri et al. (2019) did not find EB users to have a higher risk in general, except for older women.

More studies have focused on the severity of crashes on EBs. Studies in European countries where EBs are allowed to offer pedal assistance up to 25 km/h showed that crashes on EBs are equally severe as those with CBs (Schepers et al., 2014; Weber et al., 2014; Weiss et al., 2018; Fyhri et al., 2019). Taken together, EB and CB crashes seem to be equally severe but more research is needed to draw conclusions on the risk (crashes per kilometre) of riding an EB compared to a CB.

To better understand risk differences such studies need to control for health status. The two aforementioned studies that found an elevated risk among (female) EB users (Schepers et al., 2014; Fyhri et al., 2019) did not control for health status. EB users are more likely to be obese and rate their health as poorer than CB users (Van Cauwenberg et al., 2019). Riding an EB enables people with chronic diseases to cycle or to keep cycling in old age (Johnson and Rose, 2015; Jones et al., 2016). EB riding has been suggested as a form of physical activity for people with diabetes to reduce their medication intake (Cooper et al., 2018; Searle et al., 2019). Health problems and reduced physical fitness may increase the likelihood of falls and other bicycle crashes (Sakurai et al., 2016; Engbers et al., 2018; Hertach et al., 2018). For comparison, the risk of falls has been found to be associated with health problems such as obesity (Mitchell et al., 2014), medication use (Kojima et al., 2012), and comorbidity (Lawlor et al., 2003). To our best knowledge, these factors have not yet been included in studies on the risk of falling while cycling. As health status differs between EB and CB users, neglecting this factor may confound the outcomes of a comparison of crash likelihood in EB and CB users.

To address this gap in knowledge, we compared the likelihood and severity of bicycle crashes between CBs and EBs in the Netherlands while controlling for bicycle use, age, gender, and health status.

2. Material and methods

2.1. Data

Data were collected through a survey in the year 2016 by the Dutch Consumer and Safety Institute among cyclists treated at an ED for severe injuries, after a crash, in 13 Dutch hospitals. In line with the Dutch definition, severe injuries are defined as those resulting in a Maximum Abbreviated Injury Score (MAIS) of 2 or higher and hospitalization (SWOV, 2019). Casualties' files were retrieved from the Dutch Injury Surveillance System, which records anonymous statistics of all people treated for an injury in one of the Dutch hospitals. Control group data of cyclists not involved in a crash were obtained from the market research company KANTAR-TNS (see Appendix 3 and 4 in Valkenberg et al., 2017 for the questionnaires). The Medical Ethics Review Committee of the Academic Medical Centre did not have any objections to the study (reference number W16_151 #16.175).

A total of 2383 caualties over 16 years of age responded, a 38% response rate (Valkenberg et al., 2017). To adjust for differences in the selection probabilities, the data were weighted for age and gender, based on the representation in the Injury Surveillance System. Out of 3364 KANTAR panel members, 1860 (55%) completed the questionnaire and 1811 were included after excluding those involved in a bicycle crash over the past year. The dataset contained a weighting factor, aimed to correct for the response rate differences, based on comparing the response to the KANTAR-TNS panel (containing 200,000 persons in total), to represent age, gender, and other demographic characteristics of the Dutch population.

Respondents were asked about background characteristics, health status, and bicycle use. Cycling frequency per week was rated in accordance to four categories and the number of kilometres cycled per year (preceding the crash among crash casualties) was obtained. Crash casualties were also asked about crash characteristics. People's health status was captured through the presence of morbid conditions, medication use, and weight and height. Body mass index (BMI) was calculated with the weight divided by the square of the body height. Respondents were asked about specific morbid conditions (problems regarding vision, hearing, balance, coordination, stamina, muscles or joints, fatigue and sleeping) and medications that may affect the visual, cognitive, and/or motor abilities needed for safe driving and therefore may also compromise cycling abilities. The latter were derived from medications listed by the Dutch Institute for responsible use of medicines (IVM, 2019): sleep medication, tranquilizers, anti-depressants, anti-epileptic drugs, attention deficit hyperactivity disorder (ADHD) medications, mental health medications, allergy and hay fever medication, painkillers and opiates, Parkinson's disease medications, and blood thinners. Self-reported involvement of health condition as a contributing factor (answer to the question 'Did your physical or mental condition play a role in the crash?') was added to the analysis on injury severity only because only crash casualties answered this question.

2.2. Analyses

Due to our binary outcomes, we fitted logistic regression models to compare groups (1. EB vs. CB users, 2. Cases versus controls, 3. Seriously injured casualties vs. other casualties treated at an ED). Binary logistic regression models the probability of two alternatives, e.g. to compare cases to controls, crash types or levels of injury severity (Peduzzi et al., 1996; Vandenbulcke-Plasschaert, 2012). Logistic regression has been used in several studies to compare the likelihood of crashes on EBs with CBs and the severity of injuries of EB crashes with CB crashes (e.g., Schepers et al., 2014; Haustein and Møller, 2016; Fyhri et al., 2019). Three types of logistic regression were conducted in the current study. Firstly, we compared differences between EB and CB users among respondents without a crash (e.g. health status). Secondly, crash likelihood was examined by comparing casualties treated at an ED with non-casualties ('controls'). Thirdly, crash severity was studied by comparing hospitalized casualties with a MAIS of 2 or higher with other casualties treated at an ED.

We report odds ratios (ORs) and 95% confidence intervals (CIs). All three models were adjusted for cycling frequency and estimated kilometres cycled per year. A categorical variable was used in the first analysis on bicycle type to examine the interaction between age (16–60 years vs. 60+) and gender. Likewise, a categorical variable was used in the second and third analyses on crash likelihood and severity to examine the interaction between bicycle type (EB vs. CB), age, and gender. Due to combining these three variables, a distinction in more than two age categories would result in a small group size. A disadvantage of only two age categories is the possibility of age differences within groups. Therefore, in case the results for the categorical variable suggest a difference in crash likelihood (Section 3.2) or severity (Section 3.3) between EB and CB users within the same age and gender group, we ran an additional sensitivity analysis (Section 3.4). This analysis was restricted to this group with age as a continuous control variable and all other control variables including health factors (except gender as the group is restricted to either males or females in the group up to or above 60 years). Adding age to the main analyses would not be a suitable strategy as the relationship of age with crash likelihood and severity may differ between age and gender groups (see e.g. Ormel et al., 2008).

Health-related variables used in all three types of analyses are; the presence of morbid conditions, medication use, and BMI. Self-reported involvement of health condition as a factor contributing to the crash was only included in the third analysis as only crash casualties are able to answer a question about this factor. The second and third analyses on crash likelihood and injury severity are conducted without (Model 1 in Tables 2 and 3) and with (Model 2a in Tables 2 and 3) health-related variables to examine to what degree a potentially elevated risk among EB users may be explained by health status. An elevated risk among EB due to their health status would follow from an OR significantly greater than 1 in an analysis without health-related control variables that would decrease to around 1 in an analysis with health-related control variables. The following health variables were included in the regression on crash involvement: presence of morbid conditions, medication use, and BMI. These health variables were supplemented with self-reported involvement of health condition as a factor contributing to the crash in the regression on hospitalization for injuries with a MAIS of 2 or

Table 1
Logistic regression results on bicycle type among cyclists (Bicycle type: EB = 1, CB = 0).

	Bicycle type		
N[a]	CB	EB	OR (95% CI)
	1449	292	
Categorical variables:	Column %		
Age, gender			
60+, female (ref.)	10%	25%	1
60+, male	13%	28%	0.80 (0.55–1.18)
16–60, female	39%	33%	0.42 (0.29–0.60)***
16–60, male	38%	15%	0.19 (0.12–0.29)***
Cycling frequency per week			
less than 1 day (ref.)	26%	14%	1
1–2 days	20%	20%	1.78 (1.16–2.74)**
3–4 days	20%	25%	1.92 (1.26–2.92)**
5–7 days	34%	41%	1.63 (1.08–2.47)*
Medication use			
none (ref.)	62%	37%	1
one or more	38%	63%	1.62 (1.21–2.18) **
Morbid conditions			
none (ref)	64%	48%	1
one or more	36%	52%	1.10 (0.83–1.46)
Continuous variables:Mean (SD)			
BMI	25.4 (4.6)	27.7 (5.5)	1.09 (1.06–1.12)***
Distance cycled (km/year)	1007 (1649)	1502 (1364)	1.00 (1.00–1.00) ***

*p ≤ 0.05; **p ≤ 0.01; ***p ≤ 0.001.
OR = Odds Ratio; CI = confidence interval; ref. = reference category.
[a] Number of included cases, cases with missing or unknown values for one of the variables are excluded.

higher.

As multiple morbid conditions and medications could be reported we conducted analyses in which the dichotomous variables for morbid conditions (i.e. did the respondent report one or more morbid conditions or not) and medication use (i.e. was medication use reported or not) were exchanged with variables for the individual morbid conditions and medications listed in the questionnaire. This allows an examination of whether there are specific diseases or conditions that may increase the likelihood of crashes or severe outcomes. Specific morbid conditions and medications found to be significantly related to crash likelihood and severity were combined in new categorical variables with a limited number of categories. In case the groups with morbid conditions and medication uses overlapped because of comorbidity and polypharmacy, we assigned respondents to a category for the condition and medication with the highest OR in the above-mentioned analyses. The results of logistic regression analyses with these new health-related variables are referred to as Model 2 b in Section 3.2 and 3.3.

3. Results

3.1. Relationship between health condition and EB use

Table 1 shows the descriptive statistics (i.e., column percentage for categorical variables and the mean and standard deviation for continuous variables left second and third column) and the regression results on EB use among cyclists without reported crash involvement (right column). EB users appear to differ from CB users in terms of age, gender, and health status. As shown by a low OR, younger cyclists are less likely to use EBs. Female cyclists over 60 years are more likely to use an EB than older male cyclists but this difference is not significant. Changing the reference category for this variable to female cyclists up to 60 years shows that male cyclists up to 60 years are significantly less likely to use an EB than female cyclist in the same age group (OR = 0.46, 95% CI = 0.31–0.66). EB

Table 2
Logistic regression results on crash involvement for which treatment at an ED is needed (Crash involvement: yes = 1, no = 0).

	Crash involvement (unadjusted)		Model 1 without health-related variables	Model 2a with health-related variables	Model 2 b with adjusted health-related variables
	No	Yes	OR (95% CI)	OR (95% CI)	OR (95% CI)
N[a]	1811	1890			
Categorical variables:	*Column %*				
Age, gender, bicycle type					
60+, female, CB (ref.)	8%	10%	1	1	1
60+, female, EB	5%	10%	1.62 (1.14–2.31)**	1.80 (1.25–2.58)**	1.74 (1.21–2.49)**
60+, male, CB	10%	11%	0.69 (0.50–0.96)*	0.71 (0.51–0.98)*	0.69 (0.50–0.96)*
60+, male, EB	5%	5%	0.70 (0.48–1.01)	0.79 (0.54–1.16)	0.70 (0.48–1.03)
16–60, female, CB	32%	23%	0.56 (0.43–0.73)***	0.52 (0.40–0.69)***	0.55 (0.42–0.73)***
16–60, female, EB	6%	5%	0.50 (0.35–0.73)***	0.54 (0.37–0.79)**	0.54 (0.37–0.80)**
16–60, male, CB	31%	33%	0.74 (0.57–0.96)*	0.69 (0.53–0.91)**	0.74 (0.56–0.96)*
16–60, male, EB	3%	2%	0.52 (0.31–0.87)*	0.58 (0.34–0.98)*	0.56 (0.33–0.96)*
Cycling frequency per *week*					
less than 1 day (ref.)	24%	5%	1	1	1
1–2 days	20%	15%	3.05 (2.29–4.07)***	2.97 (2.22–3.97)***	2.98 (2.22–3.98)***
3–4 days	21%	26%	4.14 (3.12–5.48)***	4.03 (3.03–5.35)***	4.11 (3.09–5.47)***
5–7 days	35%	54%	4.17 (3.17–5.47)***	3.96 (3.01–5.21)***	4.00 (3.03–5.26)***
Medication use					
none (ref)	57%	58%		1	
one or more	43%	42%		1.13 (0.95–1.34)	
Morbid conditions					
none (ref)	61%	70%		1	
one or more	39%	30%		0.67 (0.56–0.78)***	
Adjusted medication use					
none (ref)	91%	87%			1
anti-epileptic drugs	0.2%	2%			7.47 (2.48–22.52)***
blood thinners	9%	11%			1.23 (0.95–1.61)
Adjusted morbid conditions					
	98%	96%			1
coordination	0.4%	1%			2.95 (1.05–8.27)*
balance	2%	3%			2.46 (1.49–4.09)***
Continuous variables	*Mean (SD)*				
BMI	25.8 (4.8)	24.5 (4.2)		0.95 (0.93–0.97)***	0.94 (0.93–0.96)***
Distance cycled (km/year)	1098 (1611)	2720 (2936)	1.00 (1.00–1.00)***	1.00 (1.00–1.00)***	1.00 (1.00–1.00)***

*p ≤ 0.05; **p ≤ 0.01; ***p ≤ 0.001; OR = Odds Ratio; CI = confidence interval; ref. = reference category; SD = Standard Deviation.
[a] Number of included cases, cases with missing or unknown values for one of the variables are excluded.

Table 3
Logistic regression results on the hospitalization for MAIS2+ injuries (Serious injuries: yes = 1, no = 0).

	Serious injuries (unadjusted)		Model 1 without health-related variables	Model 2a with health-related variables
	No	Yes	OR (95% CI)	OR (95% CI)
N[a]	1536	354		
Categorical variables:	*Column %*			
Age, gender, bicycle type				
60+, female, CB (ref.)	10%	10%	1	1
60+, female, EB	10%	14%	1.88 (1.13–3.13)*	1.96 (1.17–3.31)*
60+, male, CB	10%	16%	1.78 (1.08–2.95)*	1.79 (1.08–2.99)*
60+, male, EB	5%	7%	1.68 (0.93–3.05)	1.67 (0.91–3.06)
16–60, female, CB	25%	17%	0.82 (0.51–1.33)	0.79 (0.48–1.31)
16–60, female, EB	5%	4%	0.74 (0.36–1.54)	0.80 (0.39–1.67)
16–60, male, CB	33%	31%	1.03 (0.65–1.61)	1.08 (0.68–1.72)
16–60, male, EB	2%	2%	0.65 (0.24–1.79)	0.73 (0.26–2.02)
Cycling frequency per *week*				
less than 1 day (ref.)	5%	4%	1	1
1–2 days	15%	13%	1.02 (0.53–1.96)	1.14 (0.59–2.21)
3–4 days	26%	28%	1.05 (0.56–1.96)	1.11 (0.59–2.09)
5–7 days	54%	54%	1.06 (0.57–1.94)	1.11 (0.60–2.06)
Medication use				
none (ref.)	59%	51%		1
one or more	41%	49%		1.26 (0.96–1.66)
Morbid conditions				
none (ref.)	72%	65%		1
one or more	29%	35%		1.14 (0.87–1.49)
Role of health condition in crash				
none (ref)	87%	83%		1
physical/mental condition played a role	13%	17%		1.47 (1.05–2.06)*
Continuous variables:	*Mean (SD)*			
BMI	24.6 (4.3)	24.1 (3.4)		0.95 (0.92–0.98)**
Distance cycled (km/year)	2634 (2816)	3092 (3381)	1.00 (1.00–1.00)*	1.00 (1.00–1.00)*

*p ≤ 0.05; **p ≤ 0.01; OR = Odds Ratio; CI = confidence interval; ref. = reference category; SD = Standard Deviation.
[a] Number of included cases, cases with missing or unknown values for one of the variables are excluded.

users travel significantly more kilometres per year regardless of their health condition and are less likely to cycle less than 1 day per week.

Health status also differs between EB users and CB users. The share of EB users reporting morbid conditions is greater than the share of CB users (52% vs. 36%). In the multivariate regression analysis however, even though the OR exceeds 1, this difference is not significant and may be explained by other factors such as EB users' higher age that are included in the analysis as control variables. Medication use is significantly more common among EB users and their BMI is significantly higher than CB users' BMI. These outcomes indicate that the availability of an EBs may enable those with poorer health to cycle or to keep cycling. This outcome also shows that health status may be an important control variable in the analyses on crash likelihood and crash severity reported in Section 3.2 and 3.3.

3.2. Crash likelihood

Table 2 shows the results of regression analysis on involvement in crashes resulting in injuries for which treatment at an ED is needed. A lower or higher OR suggests a lower or higher risk (crashes per distance cycled) because all results are adjusted for distance cycled per year. The results of the analysis without health-related control variables (Model 1) suggest that the odds of being treated at an ED after a bicycle crash is significantly greater among older women on an EB compared to those on a CB. Such differences for bicycle type were not found for male cyclists and younger female cyclists. Cycling more frequently and travelling more kilometres per years is associated with crash involvement.

The Models 2a and 2 b in Table 2 describe the outcomes of the regression analyses including health-related control variables. Adding these variables in a second step allows to examine their effect on the OR for bicycle type and thereby the degree to which health status may confound the relationship between crash likelihood and bicycle type. Medication use and BMI are particularly important because, as reported in Section 3.1, EB users have a higher BMI and are more likely to use medication than EB users. In Model 2a (Table 2) with general health-related variables, medication use was not found to be associated with crash involvement. Counterintuitively, the results suggest a negative association between BMI and crash involvement meaning that those with a higher BMI are somewhat *less* likely to be involved in a bicycle crash. Those reporting one or more morbid conditions are also *less* likely to be involved in a crash (but EB users and CB users did not significantly differ in terms of morbid conditions, see Section 3.1). Accordingly, the elevated risk among older female EB users is not explained by health condition and the OR for this group in the analysis with health-related control variables hardly differs from the OR in the analysis without these variables. The outcomes regarding the risk among EB users do not appear to be mediated by health status.

The dichotomous variables for morbid conditions and medications included in Model 2a in Table 2 combine a list of morbid conditions and medications. Additional analyses including individual morbid conditions and medications were conducted to identify those that might be related to crash likelihood. Coordination and balance problems, and anti-epileptic drugs and blood thinners were significantly related to crash likelihood and combined in new categorical variables for the analysis in the right column. The groups reporting coordination and balance problems are relatively small and partly overlapping. As the association with coordination problems was greater than with balance problems, we assigned respondents reporting both to the group with balance problems, resulting in minimal changes in the shares of both groups (share among crash casualties for separate groups: 1.2% coordination and 3% balance problems; share after accounting for overlap 0.6% coordination and 3% balance problems). As crash likelihood was more strongly related to anti-epileptic drugs than to blood thinners, the respondents reporting use of both medications were assigned to the group of anti-epileptic drug users. The group reporting use of blood thinners was substantial (11.3% of all crash casualties; 11.1% after accounting for overlap). The outcomes of the logistic regressions with these new categorical variables (Model 2 b, Table 2) show that crash likelihood is related to coordination and balance problems and to use of anti-epileptic drugs. The use of blood-thinners was not significant, but possibly worthy of further investigation given its p-value of 0.12. Again, the outcomes of the analyses regarding the risk among EB users do not appear to be mediated by health status in this analysis with adjusted health-related variables.

3.3. Injury consequences

The results on crash severity among crash casualties (i.e. hospitalization for MAIS2+ injuries) follow the same pattern as was found for crash likelihood in Table 3. Among casualties treated at an ED due to a bicycle crash, the odds of sustaining severe injuries is highest among older female cyclists on an EB, significantly higher than among older females on CBs. Such differences between EB and CB users were not observed within other groups. Comparing the results for Model 1 without health-related control variables to the results of Model 2 with health-related control variables shows that the outcomes regarding crash severity and bicycle type did not appear to be mediated by health condition.

The results regarding health-related variables (Model 2, Table 3) show that medication use and morbid conditions are not significantly related to injury severity. The results suggest a negative association between BMI and crash severity meaning that obese casualties are less likely to sustain severe injuries if they are involved in a crash. The analysis on crash severity being restricted to casualties allowed us to include an additional health related variable. Crash casualties sustaining severe injuries more often reported physical or mental condition to play a role in crashes. Note that among crash casualties, the share of those reporting health conditions to play a role in the crash was not higher among EB crash casualties (12%) than among CB crash casualties (14%).

We exchanged the dichotomous variables for the presence of morbid conditions and medication use by the specific health conditions and medications listed in the questionnaire. The outcomes did not yield any conditions or types of drugs significantly related to crash severity which is why Model 2 b is excluded from Table 3. The use of blood was related to injury severity but its OR was not significant (OR = 1.36, CI = 090–2.04, $P = 0.14$). We also looked at the adjusted medications use and morbid conditions, but did not find any significant relation to crash severity. Therefore, we excluded the analysis with adjusted health-related variables from Table 3.

Table 4
Logistic regression results on crash involvement (for which treatment at an ED is needed) and crash severity (hospitalization for MAIS2+ injuries).

	Crash likelihood	Crash severity
Categorical variables:	OR (95% CI)	OR (95% CI)
Bicycle type		
CB	1	1
EB	1.63 (1.12–2.36)**	2.13 (1.23–3.71)**
Cycling frequency per *week*		
less than 1 day (ref.)	1	1
1–2 days	1.01 (0.51–2.01)	1.19 (0.33–4.26)
3–4 days	2.18 (1.15–4.14)*	1.18 (0.37–3.76)
5–7 days	1.26 (0.67–2.35)	1.83 (0.58–5.80)
Medication use		
none (ref.)	1	1
one or more	0.98 (0.66–1.45)	1.28 (0.69–2.36)
Morbid conditions		
none (ref)	1	1
one or more	0.56 (0.36–0.88)*	1.00 (0.58–1.75)
Role of health condition in crash		
none (ref.)		1
physical/mental condition played a role		0.84 (0.35–2.02)
Continuous variables:		
BMI	0.98 (0.94–1.02)	0.93 (0.87–0.99)*
Distance cycled (km/year)	1.00 (1.00–1.00)**	1.00 (1.00–1.00)
Age (years)	1.04 (1.01–1.07)**	1.03 (0.99–1.07)

*p ≤ 0.05; **p ≤ 0.01; OR = Odds Ratio; CI = confidence interval; ref. = reference category; SD = Standard Deviation.

3.4. Sensitivity of the analyses, controlling for age among females over 60 years

Additional logistic regression analyses were conducted on crash likelihood and crash severity for females over 60 years. Compared to the Models in tbl2Tables 2 and 3tbl3, the categorical variable combining age, gender, and bicycle type was replaced by a categorical variable for bicycle type. Age was added as a continuous control variable to adjust for possible age differences between EB and CB users within the group of older females. Other control variables resemble Models 2a in Tables 2 and 3 The analyses among females over 60 years (see Table 4) yield ORs for EBs of 1.63 for crash likelihood and 2.13 for crash severity. This is comparable to the related ORs for crash likelihood and crash severity found with Models 2a (Tables 2 and 3), i.e. 1.80 for crash likelihood and 1.96 for crash severity among females over 60 years on EBs compared to females over 60 years on CBs. This suggests the outcomes for older females are hardly sensitive for additional control for age within this group.

4. Discussion

The results of this study suggest that, on average, EB users are not more likely than CB users to be involved in a crash for which treatment at an ED is needed or to sustain more severe injuries if they are involved in a crash. However, older female cyclists are more likely to be involved in such crashes and sustain more severe injuries if involved in a crash. More severe crashes suggest that their increased likelihood of needing treatment at an ED may be due to vulnerability because treatment at an ED already implies more than minor crash consequences. Hertach et al. (2018) found female EB users to sustain more moderate to serious injuries while they were not more likely to be involved in minor crashes. In contrast the earlier studies (e.g., Schepers et al., 2018; Fyhri et al., 2019) we did control for health-related variables but there may be additional factors not included in this study that increase the likelihood of severe injuries in older female EB users. We recommend further research to explain the findings for older women to develop preventive policies.

We also examined the role of health-related factors which are important as, compared with CB users and controlling for age and gender, EB users are more likely to need medications and have a higher BMI. However, the outcomes of this study do not suggest that poor health contributes to crash likelihood. Accordingly, adding health conditions to the analyses did not appear to explain the elevated risk among older female EB users. The same goes for the outcomes regarding crash severity. An exception to these general conclusions regarding health condition is that cyclists reporting balance or coordination problems and using anti-epileptic drugs were more likely to be involved in a bicycle crash for which treatment at an ED is needed. Balance and coordination problems and epilepsy are likely to contribute to single-bicycle crashes (the majority of severe injuries among cyclists are due to single crashes, see e.g. Schepers et al., 2015).

The finding that crashes with EBs are equally severe as crashes with CBs matches the results of other European studies (Schepers et al., 2014; Weber et al., 2014; Weiss et al., 2018). The finding that, on average, the risk of crashes on EBs is similar to CBs is in line with the results of Fyhri et al. (2019) in Norway and is more favourable than the results found by Schepers et al. (2014) for the Netherlands. A similar level of risk and crash severity may be explained by the fact that riding speeds on EBs exceed speeds on CBs by only by 1–3 km/h (De Waard, 2013; Twisk et al., 2013; Van Boggelen et al., 2013; Schleinitz et al., 2017; Fyhri et al., 2019). The findings of the current study being more favourable than those reported by Schepers et al. (2014) cannot be explained by the additional health-related control variables in the current study. Part of the difference may be due to more extensive model adjustments. The present study included yearly distance cycled which appears to be some 50% higher among EB users than among CB users, which is consistent with results from Norway by Fyhri et al. (2019). Also, EBs and those who ride them may have changed as the share of EB users among cyclists increased from 10% to 22% between the two studies (TNS NIPO 2014; Valkenberg et al., 2017). Importantly, the share of women over 60 years among EB users decreased from 34% in 2014 to 25% in 2016. A technical improvement reducing their weight from 25 to 32 kg in 2013 to between 22 and 28 kg in 2018 may prevent falls while mounting or dismounting (Haustein and Møller, 2016; Twisk et al., 2017; Elektrische Fietser, 2020). Moreover, most EBs had front wheel (hub) motors around 2013 and only few mid-drive motors while the majority of new EBs had the latter type of motor around 2016 (Van Schaik, 2014; Gfk, 2018) which may lower the centre of gravity and contribute to good balance, and it may also reduce the risk of front wheel spin, loosing traction of loose gravel and contribute to a fall.

As yet, we cannot explain why older female cyclists are more likely to be involved in EB crashes. However, we do not have to wait for the outcomes of new research on this issue to be able to enhance the safety for these cyclists. Older females are more likely to fall while mounting or dismounting their bicycle. Dubbeldam et al. (2017) developed a protype bicycle with an automatic adjustable saddle height (lowered at low speeds), optimised frame and wheel geometry and drive-off assistance. Drive-off assistance solves the problem found in some EBs by Twisk et al. (2017) that accelerating from standstill takes longer on an EB. Van Raam (2020) developed a bicycle with cranks moved slightly forward of the rider instead of underneath to reduce the saddle height sufficiently to allow the rider to put both feet firmly on the ground at all times. Accelerating the development and uptake of such safer bicycles by older cyclists is a challenge as cyclists appear to be largely unaware of the risk of single-bicycle crashes such as falling while (dis)mounting (Schepers et al., 2020). Educational measures may be suitable to raise the awareness of the risk of single-bicycle crashes. General measures such as safer infrastructure are recommendable to improve road safety for all cyclists (Reynolds et al., 2009; Schepers, 2013).

This study has a number of limitations. This study did not include minor crashes and therefore we cannot conclude whether the elevated 'risk' among older female EB users (in the current study defined as crashes for which ED treatment is needed) is purely due to an elevated crash risk or due to more severe consequences such as injuries for which treatment at an ED is needed. However, the advantage of our focus on more severe crashes is that it aligns well with road safety targets that are mostly focused on severe crashes. Our results regarding gender may not be generalizable to other countries, because cycling participation among females in the

Netherlands is far more common than in other countries. Dutch women cycle somewhat more often than men and cover a slightly lower distance per year (Statistics Netherlands, 2020). This study may suffer from problems of self-reporting such as inaccurate recall of crash circumstances and responding in socially desirable ways (Heiman, 1999), for instance regarding health condition. We recommend more experimental research such as the studies by Vlakveld et al. (2015) and Twisk et al. (2017) to increase insight into potential factors that may explain problems of older female EB users such as speed, the weight in relation to mounting, and their health condition.

5. Conclusions

The main aim of this study was to investigate the role of bicycle type (EBs versus CBs) and health condition in bicycle crashes and injury severity. The following conclusions can be drawn from our results:

- Most groups of EB users were not more likely than CB users to be involved in a crash for which treatment at an ED is needed or to sustain more severe injuries if they are involved in a crash.
- Older female EB users were more likely than older female CB users to be involved in crashes for which treatment at an ED is needed and to sustain more severe injuries if involved in such a crash.
- After controlling for age and gender we found EB users were more likely to need medications and have a higher BMI.
- General health-related factors such as taking medications, presence of morbid conditions, and BMI were not associated with an elevated crash likelihood or injury severity and accordingly did not explain the elevated crash risk and injury severity among older female EB users. However, balance and coordination problems, and use of anti-epileptic drugs were associated with an increased likelihood of crashes for which treatment at an ED is needed.

Authorship statement

J.P. Schepers, Conception and design of study, Drafting the manuscript, Revising the manuscript critically for important intellectual content, K. Klein Wolt, Acquisition of data, Conception and design of study, Drafting the manuscript, Revising the manuscript critically for important intellectual content, M. Helbich, Conception and design of study, Drafting the manuscript, Revising the manuscript critically for important intellectual content, E. Fishman, Conception and design of study, Drafting the manuscript, Revising the manuscript critically for important intellectual content.

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