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Published in:
Journal of Transport and Health

Link to article, DOI:
10.1016/j.jth.2023.101748

Publication date:
2024

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Møller, M., Useche, S. A., Siebert, F. W., & Janstrup, K. H. (2024). What differentiates e-bike riders from conventional cyclists in Denmark? A user-based study. *Journal of Transport and Health*, *34*, Article 101748. https://doi.org/10.1016/j.jth.2023.101748

Journal of Transport & Health 34 (2024) 101748

Contents lists available at ScienceDirect

Journal of Transport & Health

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

What differentiates e-bike riders from conventional cyclists in Denmark? A user-based study

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ARTICLE INFO

Keywords:
Cycling
e-bikes
Riding behaviour
Differences
Cycling safety

ABSTRACT

Among the many technology-related advances in two-wheeled mobility, the growing share of e-bikes stands out. Indeed, despite their increased cost and user-related constraints, e-bikes have gained ground in European cities over the last two decades. However, not much is known about the psychosocial and behavioural characteristics of e-bike users compared with conventional bike (*c-bike*) users.

Aims: Therefore, the aims of this study were: first, to explore differences between e-bike and c-bike users regarding individual features, cycling habits, and riding behaviour; and second, to identify individual characteristics, cycling habits, and behaviours predicting using an e-bike as the main cycling mode.

Methods: The study used data from 557 Danish cyclists aged over 18, proportionally distributed according to population data (13% e-bike and 87% c-bike users). The cyclists responded to an electronic survey on cycling affairs, addressing trip patterns, risk perception, cycling anger, distractions, and riding behaviours.

Results: Overall, no differences were found regarding personality, distractions, riding errors, or cycling anger. However, e-bike users self-reported significantly lower rates of traffic violations and higher rates of positive behaviours, traffic rule knowledge and road risk perception. Furthermore, structural (SEM) analyses suggest that e-bike riding can be predicted through demographic factors, psychosocial characteristics, and cycling behaviours.

Conclusion: The results of this research provide insights into the characteristics and behaviours of e-bike and c-bike users in Denmark, indicating key differences between the two groups in relation to their demographic backgrounds and cycling habits. This underscores the importance of considering demographics, cycling habits, and psychosocial factors when studying and promoting the use of e-bikes.

1. Introduction

As a positive development in 21st-century mobility, the uptake of cycling as a means of transportation or leisure is increasing (Buehler and Pucher, 2022). The uptake is reinforced by increased e-bike use (Schepers et al., 2020), with e-bike users more than doubling their share of cycling as a means of transport in terms of both frequency and trip length (Fyhri and Fearnley, 2015; Fyhri and Sundfør, 2020). However, as a downside to this positive trend, the risk of being seriously injured or killed in a crash is higher for e-bike

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https://doi.org/10.1016/j.jth.2023.101748
Received 1 September 2023; Received in revised form 10 November 2023; Accepted 5 December 2023
Available online 15 December 2023
2214-1405/

users than users of conventional bikes (c-bike) (Janstrup and Møller, 2023). A potential reason for this higher crash risk for e-bike users could be differences in personal and behavioural characteristics compared with c-bike users. So far, the exact nature of this crash-risk imbalance between c- and e-bike users has not been investigated in detail. The contribution of this paper is, therefore, to reduce the knowledge gap on potential individual and behavioural differences between c-bike and e-bike users, using a broad self-report survey methodology.

1.1. Background

Active transport, such as cycling, benefits human health and well-being (Welsh et al., 2020). Recently, the use of bicycles has increased, partly driven by a rapid rise in the use of e-bikes. In addition, e-bike use has been shown to increase the total amount of cycling and to reduce car use (Andersson et al., 2021). When cycling replaces motorised travel, it also benefits the environment by reducing air and noise pollution (Mueller et al., 2015). Increasing cycling as the primary transport mode thus has the potential to benefit society as well as human well-being. To support this, various policies to increase cycling and other modes of active transportation have been implemented (Zukowska et al., 2022), and cycling is increasing in many countries (e.g. Buehler and Pucher, 2022; Lanzendorf and Busch-Geertsema, 2014).

As an obvious advantage, the e-bike allows for riding longer distances at higher speeds with less effort than the c-bike due to the support provided by the engine. This facilitates increased bicycle use among individuals with limited physical strength or capacity who might otherwise refrain from cycling. This, in turn, contributes to reduce inequality in access to cycling as a mode of transport (Andrews et al., 2018). However, cyclists with limited physical strength may face further challenges associated with e-bikes such as faster acceleration and higher weight (Haustein and Møller, 2016; Liang et al., 2021). Consequently, e-bike use may expose vulnerable cyclists to increased risk of crash involvement and injury (Schepers et al., 2020). Additionally, there could be relations between e-bike and c-bike use and cycling experience that could influence the links between bicycle types and cyclists' behaviour.

Potentially, the e-bike is a substitute for a car (Bourne et al., 2020), offering the advantages of riding longer distances at higher speeds and potentially inspiring road users to switch their main mode of transport from car to e-bike. This would introduce a new cyclist group who may have comparatively little cycling experience due to reliance on car travel in the past. Thus, with the increasing popularity of cycling, the number of crashes and associated personal injuries is likely to rise as well (Welsh et al., 2020).

In addition to physical injury, crash involvement may also impact mental health (Myhrmann et al., 2022), and have social, occupational, and economic consequences (Mayou and Bryant, 2003; Ohlin et al., 2017). Therefore, developing timely knowledge to ensure increased bicycling while minimizing detrimental safety effects is crucial for strengthening both bicycle-friendly urban planning and effective safety-related decision-making.

With increased e-bike use, the need for such knowledge becomes even more critical due to e-bike users' heightened risk of serious injury or fatality, a constraint in considerable rise over the last few years (Janstrup and Møller, 2023). As a relevant figure, in many major cities of countries like China, e-bikes are now the main mode for daily commute, and the number of e-bike crashes is 8.2 times higher than the number of crashes with a c-bike (Ma et al., 2019). Nevertheless, only a handful of studies have attempted to identify the reasons behind the elevated crash risk for e-bike users.

1.2. Differences in crash type and crash risk between e-bike users and c-bike users

In many countries, crash recording methods and protocols have only recently begun to distinguish between e-bike and c-bike crashes. In Denmark, this separate registration was initiated in the official crash database in early 2014. Consequently, the number of studies assessing differences in crash patterns and personal characteristics between e-bike users and c-bike users is more limited compared to studies on c-bike crashes. However, a few recent studies have identified relevant patterns when comparing e-bike and c-bike crashes.

For example, various studies endorse the idea that the proportion of single-bicycle crashes (where no other road user is involved) is larger in the case of e-bike crashes than in c-bike crashes (Møller et al., 2021; Panwinkler and Holz-rau, 2021). As a similar data point on specific crash type comparisons, the number of crashes where a straight-riding cyclist collides with a right-turning motor vehicle, which is significantly higher among e-bike crashes compared to c-bike crashes (Møller et al., 2021). In these regards, it is assumed that the higher riding speed of e-bikes largely explains both findings, as it increases the likelihood of losing control and other road users overlooking the cyclist or overestimating the time-gap to the approaching cyclist (Petzoldt et al., 2017; Twisk et al., 2021). Furthermore, compared to c-bikes, the risk of being involved in a crash at an intersection is twice as high for e-bikes (Petzoldt et al., 2017), and conflicts with c-bikes are the second most common type of traffic conflict for e-bikes (Liang et al., 2021).

Despite previous findings indicating that characteristics of the e-bike, such as fast acceleration and heavier weight, may contribute to difficulties in handling the vehicle and possibly be associated with crashes, the behaviour of road users has been identified as an additional key factor triggering these incidents. This is because all components in the road user-environment system need to be considered (Johansson, 2009; Li et al., 2022). Thus, to prevent e-bike as well as c-bike crashes, knowledge about the personal and behavioural characteristics of e-bike and c-bike users is crucial. As of today, such knowledge is limited. Existing studies mostly focus on sociodemographic characteristics relevant for choosing cycling as a mode of transportation (Ton et al., 2019), and not on whether the behaviour of an e-bike user differs from that of a c-bike user.

1.3. Differences between e-bike and c-bike user

The number of studies investigating differences between e-bike users and c-bike users is limited. A few studies show that, even though e-bikes increase the overall amount of cycling and have a broad impact on all age groups, females are more likely to adopt them than males (Fyhri and Fearnley, 2015; Bourne et al., 2020). Some of them indicate that e-bike users may have less cycling experience compared with c-bike users, and studies such as Kaplan et al. (2018) have found that having previous cycling experience reduced the likelihood of choosing an e-bike compared to a c-bike, and Bourne et al. (2020) found that e-bike trips mainly substitute car-travels but also some conventional cycling trips. Regarding behavioural differences, a literature review by Ma et al. (2019) found that e-bike users were more concerned with safety protection behaviours, such as helmet use, and less likely to ignore a red light when turning compared to c-bike users (Ma et al., 2019). However, as the review mainly referenced studies from China, it is unclear how these findings transfer to the European context. Other studies investigating cyclists' anger and anger expression found no difference between e-bike users and c-bike users (Zhang et al., 2022).

1.3.1. The current study

All in sum, with increased cycling, and e-bike use in particular, knowledge about differences in individual and behavioural characteristics between e-bike and c-bike users that may underlie or contribute to crash involvement is crucial. However, at present, such knowledge is limited, and this study aims to fill this knowledge gap.

Based on the above, the aims of this study were twofold: First, to explore differences between e-bike and c-bike users regarding individual features, cycling patterns, and self-reported riding behaviour. Second, to identify individual characteristics, cycling habits, and behaviours that predict adopting an e-bike as the main cycling modality.

2. Methods

2.1. Data collection and participant recruitment

Data were collected through an online survey conducted in Denmark in the period June 2021–September 2021. Data were collected as part of the "Bike Barometer 2021–2022" survey macro-project which included 19 countries covering the following regions: Europe, Oceania, Latin America, Asia and Africa (Useche et al., 2022a,b). The aim of the Bike Barometer survey project was to collect information about cycling habits and experiences with cycling in traffic thereby allowing cross-cultural comparison. The Danish part of the survey was distributed through social media, by a newsletter from the Danish Cyclist Federation, at the Technical University of Denmark, and at Aalborg University. The study sample is described in Section 3. It took about 25 min for participants to complete the online survey.

2.2. Denmark – the country case study area

Denmark is a Nordic country with approximately 5,8 million citizens. On average Danes aged 6 years and older have 0.43 bicycle trips per day, covering a daily average distance of 3.32 km, equivalent to 1.4 km per person (Malmgren and Christiansen, 2022). Individuals aged 18–29 embark on the longest daily cycling trips, covering 2 km. Those aged 12–17 cycle 1.8 km per day, while individuals aged 30–59 cycle an average of 1.6 km per day. Workplace commute trips are the longest on average (4.5 km), followed by leisure trips (3.8 km).

As mentioned, data were collected from June to September 2021. During this period, most COVID-19 restrictions in Denmark were either removed or being phased out. The only remaining restriction potentially influencing cycling behaviour was the mandatory use of facemasks for standing passengers in public transport. However, results from the Danish National Travel Survey (TU) indicate that, at the time of data collection, cycling behaviour was at the same level as before Covid-19. In 2018, 2019, and 2021, bicycling accounted for approximately 3.5% of the total km travelled. In 2020, when Covid-19 restrictions were most prominent, bicycling accounted for approximately 4% of the total travelled km (Christiansen and Baescu, 2022).

Since 1975, data on the travel patterns of the Danish population has been collected via the Danish National Travel Survey (TU). TU is an interview survey conducted monthly among a representative sample of people aged 6 years or older, totalling approximately 10,000 interviews per year. Since 2014, TU has distinguished between e-bikes and c-bikes.

In Denmark, a bike is considered an e-bike if it is equipped with a motor providing support to the rider up to a maximum speed of 25 km/h, and this support is active only when the rider is pedalling. A person must be at least 6 years old to ride an e-bike. The same traffic rules apply to both e-bikes and c-bikes: helmet use is not mandatory, both bicycle types must ride on the cycle path if available, and on the road if not. Handheld phone use is not allowed. There is no alcohol limit, but the rider must be able to ride safely. The current legislation for e-bikes was introduced by July 1st, 2016 (TU-homepage).

2.3. Instruments

The questionnaire included the following measures:

Socio-demography: age, gender, education, primary occupation, and number of inhabitants in city of residence.

Cycling habits: Number of bike-hours during a normal week, trip purpose and duration of the most frequent bicycle trip.

Cycling Behaviour Questionnaire (CBQ) (Useche et al., 2018): Participants indicated on a 5-point scale (from "never/almost never" to "always/almost always") how often they performed 29 stated behaviours. A factor analysis with Varimax rotation confirmed a three-factor solution: *Violations*, *Errors*, and *Positive behaviour*. Cronbach's alpha was 0.80. All items had factor loadings above 0.37 and explained 39% of the variance.

Risk Perception and Regulation Scale (RPRS) (Useche et al., 2019a,b): Participants indicated on a 5-point scale ("totally disagree" - "totally agree") their degree of agreement with 4 statements about traffic rule knowledge and 7 statements about risk perception. A factor analysis with Varimax rotation confirmed a two-factor solution for the 11 items: *Traffic rule knowledge* and *Risk perception*. Cronbach's alpha was 0.72. All items had factor loadings above 0.38 and explained 41% of the variance.

Anger: on a 5-point scale ("absolutely none" to "really a lot") participants indicated how much anger they would feel in 14 different conflict situations involving other road users or the police. A factor analysis with Varimax rotation revealed a four-factor solution: *Police*, *Progress impeded*, *Narrow space*, *Pedestrians*. Cronbach's alpha was 0.85. All items had factor loadings above 0.50 and explained 71% of the variance.

Cyclist Anger Expression scale (CAX) (Møller and Haustein, 2017): Respondents assessed their anger expression on a 5-point scale ("never"- "always"). The factor analysis confirmed the original factor solution: *Physical, Constructive, Verbal, and Vehicle.* Cronbach's alpha was 0.78. All items had factor loadings above 0.49 and explained 61% of the variance.

Personality Traits (BFI) (Lang et al., 2011): Respondents assessed the degree to which they see themselves as a person with some specific characteristics (e.g. *worries a lot, gets nervous easily)* on a 7-point scale ("strongly disagree"–"strongly agree"). The factor analysis confirmed the original five factor solution: *Neuroticism, Extraversion, Openness, Agreeableness, and Conscientiousness*. Due to a problem with one question *Neuroticism* only includes two questions. The Cronbach's alpha was 0.68 and factor loading above 0.53 were found for all items. 68% of the variance were explained.

Cycling distraction (Useche et al., 2018): Respondents were presented with eight different sources of potential distraction and asked to mark all that distracted them while cycling. A new variable was made grouping the number distraction sources marked by each participant: *low (0–1), medium (2–5), and high (6–8)*.

Psychological Distress (GHQ-12) (Goldberg et al., 1997): Respondents were presented 12 items where they assessed how often they experience a specific feeling on a 4-point scale ("never"-"very often"). The answers from the GHQ-12 were used to calculate an indicator for psychological distress measured from 0 to 36.

2.4. Data analysis

The analysis involved three steps. First, a test of representativeness regarding gender, age, and cycle type (e-bike and c-bike) based on information retrieved from the Danish National Travel Survey (TU). For further details about TU, see section 2.3. Second, a descriptive analysis aimed at identifying differences between participants using an e-bike as their main bike (e-bike users) and participants using a c-bike as their main bike (c-bike users). Third, modelling e-bike use as the main bike mode with a Structural Equation Model (SEM).

Only factors that were significantly different for e-bike and c-bike users (step two) were included in the model. However, we included all variables when testing how the variables related to the significant factors. We used χ^2-test to test to assess representativeness and differences between e-bike users and c-bike users regarding gender, number of inhabitants in the area of residence (<50,000; 50,000–200,000; >200,000), trip purpose, and trip duration. Aspin-Welch-Satterthwaite *T-test* was used to test for differences in mean score on the identified factors (*Violations*, *Errors*, and *Positive behaviour; Traffic rule knowledge* and *Risk perception;* anger towards the *Police, Progress impeded, Narrow space,* and *Pedestrians*; anger expression as *Physical, Verbal,* with the *Vehicle,* and *Constructive;* personality traits as *Neuroticism, Extraversion, Openness, Agreeableness, and Conscientiousness; Psychological Distress)*. The significance level was set to $p < 0.05$ in the χ^2-tests and t-tests.

In order to model the probability of adopting an e-bike as the main cycling modality and considering the literature insights described in the introduction (a confirmatory procedure), a Structural Equation Model (SEM) was built. Non-significant variables at the 0.10 level were subsequently removed. The model included three sets of equations: measurement equations linking the latent factors (CBQ, RPRS, Anger, CAX, and BFI) to the observed indicators (Eq. (1)), structural equations linking the latent factors to demographic characteristics, cycling habits, distraction, psychological distress, and crash involvement (Eq. (2)), and structural equations relating the latent factor constructs to e-bike use (Eq. (3)).

$$I_{rn} = Z^{*}_{ln}\alpha_r + \mu_{rn} \text{ and } \mu_n : N\left(0, \sum\nolimits_{\mu}\right) \text{ for } r = 1, \ldots, R \tag{1}$$

$$Z^{*}_{ln} = S_{ln}\beta_l + \omega_{ln} \text{ and } \omega_n : N\left(0, \sum\nolimits_{\omega}\right) \text{ for } l = 1, \ldots, L \tag{2}$$

$$Z^{*}_{in} = Z^{*}_{ln}\gamma_i + \rho_{in} \text{ and } \delta_n : N\left(0, \sum\nolimits_{\delta}\right) \text{ for } i = 1, \ldots, I \tag{3}$$

where Z_{ln} is the value of latent factor construct l for cyclist n, I_{rn} is the value of an indicator r of the latent factor construct Z_{ln} as perceived by cyclist n, S_{ln} is a vector of demographic characteristics, cycling habits, distraction, psychological distress, and crash involvement. Z_{in} is a vector of e-bike use. Error terms are expressed as elements μ_n, ω_n, and δ_n of the vectors following a normal distribution with respective covariance matrices. α_r, β_r, and γ_r are parameters to be estimated. Considering R indicators translates into writing R measurement equations and estimating a (R × 1) vector of parameters (i.e., one parameter is estimated for each equation), while considering L latent constructs translates into writing L structural equations and estimating a (M × L) matrix of β parameters (i.e., M parameters are estimated for each equation).

The model was estimated using the M-Plus program. The structural equations were simultaneously estimated using Maximum Likelihood with Huber-White covariance adjustment (Yuan and Bentler, 2000) and standard errors from the White's sandwich-based estimator, which produces robust statistics in the presence of non-normality of the indicators and the categorical variables (White, 1980). The goodness-of-fit for the model was evaluated with descriptive measure of chi-square test alongside the Comparative Fit Index (CFI), Root Mean Square of Approximation (RMSA) and the Standardized Root Mean Square Residual (SRMR) (Browne and Cudeck, 1992).

3. Results

The study sample consisted of complete responses from 557 Danish cyclists. 13% (N = 74) of the respondents used an e-bike as their main bike mode which is in line with the proportion of e-bike use (12%) in TU. When comparing our sample with TU for the e-bike users, no significant gender difference was found. However, our sample includes a smaller proportion (19% vs 35%) of people aged 61 or older, a larger proportion of students (10% vs 5%), and a smaller proportion of retired or unemployed people (18% vs 30%). For the c-bike users, no significant gender difference was found, but our sample included a significantly smaller proportion (18% vs 32%) of younger people (18–30 years old) and people who are retired or unemployed (9% vs 20%) compared to TU.

3.1. Differences between e-bike and c-bike users

Table 1 provides an overview of the comparison between the cyclists that mainly used an e-bike and those who mainly used a c-bike. Overall, and compared to c-bike users, e-bike users are characterized by a larger share of females, people living in smaller cities (<50,000 inhabitants), people being retired, and a trip duration of 31–59 min for the most frequent trip, whereas c-bike users are characterized by a larger share of males, students or unemployed, people living in larger cities (>200,000 inhabitants), and people

Table 1
Comparison of the distribution of socio-demographic characteristics, cycling habits, and self-reported crash involvement between e-bike and c-bike users.

Variable	Value	e-bike (n = 74)		c-bike (n = 483)		χ^2-test,
		Number	Pct.	Number	Pct.	p-value
Gender	Male	22	30%	219	45%	
	Female	52	70%	264	55%	**0.01**
Age (years)	18–30	10	14%	89	18%	
	31–60	49	66%	303	66%	
	≥61	15	20%	91	19%	0.59
Area of residence	<50,000 inhabitants	27	36%	102	21%	
	50,000–200,000 inhabitants	20	28%	163	34%	
	>200,000 inhabitants	27	36%	218	45%	**0.01**
Education	Short (<2 post primary school)	38	51%	218	45%	
	Long (≥2 post primary school)	36	49%	265	55%	0.32
Occupation	Working	53	71%	356	74%	
	Retired	13	18%	43	9%	
	Unemployed, student and other	8	11%	84	17%	**0.04**
Trip purpose*	Commuting to work/school	57	77%	384	80%	0.63
	Short trips to specific places	70	95%	449	93%	0.61
	Leisure	63	85%	384	80%	0.26
	Exercise/training	23	31%	217	45%	**0.03**
	Job tool	23	31%	146	30%	0.88
Weekly cycling	0–2 h	16	22%	96	20%	
	3–5 h	28	38%	178	37%	
	6–9 h	20	26%	128	27%	
	≥10 h	10	14%	81	17%	0.92
Most frequent trip	<20 min	11	15%	119	25%	
	20–30 min	30	41%	200	41%	
	31–59 min	25	34%	102	21%	
	≥1 h	8	11%	62	13%	0.06
Crash involvement**	As cyclist	25	34%	161	33%	0.93

Notes: * Differences regarding trip purpose were tested individually because the participants could indicate more than one purpose. ** Crash involvement during the last five years.

using the bike for training or exercise.

No differences regarding the number of self-reported sources of distraction while cycling between e-bike and c-bike users were identified (Table 2). The largest proportion in both groups reported being distracted while cycling by two to five of the potential sources of distraction listed in the questionnaire (Table 2). Both e-bike and c-bike users reported being least distracted by text messages, chats, or social networks while cycling, with the behaviour of other road users being the most distracting for both groups.

The mean scores on the *positive behaviour*, *traffic rule knowledge*, and *risk perception* factors were significantly higher for e-bike users than c-bike users (see Table 3). For both e-bike users and c-bike users, the highest anger levels were experienced in situations of *Progress impeded*, with the second highest in conflicts with *Pedestrians*. For anger expression, the highest score was on Constructive anger expression, and the second highest was on verbal anger expression. E-bike users experienced significantly lower levels of anger towards the police compared to c-bike users. No other differences in anger levels, anger expression, or personality traits were identified. The mean value for psychological distress is slightly higher for c-bike users compared to e-bike users, but there is no significant difference.

3.2. Predicting e-bike as the main cycling mode

The results of the SEM reveal a significant relation between CBQ and RPRS and the use of an e-bike (Fig. 1). In addition to its theoretical plausibility, the model fit is reasonable for the relative measures with CFI equal to 0.867 (Browne and Cudeck, 1992), and good for the absolute measures with RMSEA equal to 0.047, and SRMR is 0.064 (Browne and Cudeck, 1992; Hu and Bentler, 1995).

The specific model estimates and the p-value estimates from the structural equations linking the e-bike use to the latent factors are presented in Table 4, and the structural equations linking the latent factors to cyclists' habits, distraction, psychological distress, and socio-demography are shown in detail in Table 5.

Regarding the CBQ, results reveal a direct and positive relation between e-bike use and *Errors* (0.35), *Positive behaviour* (0.44), *Risk perception* (0.35) and *Traffic rule knowledge* (0.40). *Positive behaviour* has the highest impact, hence e-bike users score higher on *Positive behaviours* than c-bike users do. A direct and negative relation is found between *Violations* (−0.56) and e-bike use, but the relation is only significant at the 0.10 level. Results also reveal a positive and direct relation between *Violations* (0.28) and *Errors*, hence a higher score on *Errors* is associated with a higher score on *Violation*. *Positive behaviour* (−0.17) is negatively related to *Errors*, hence a higher score on *Errors* is related to a lower score on *Positive behaviour*. Finally, a negative relationship between *Errors* (−0.40) and *Traffic rule knowledge* was found, suggesting that the score on Errors increases with an increasing score on Traffic rule knowledge.

The results indicate a positive relationship between *Violations* and *being male*, and a negative relationship with having a short education, being ≥61 years old, and psychological distress. This suggests that if a rider has a high score (indicating high stress) on the GHQ-12 scale, the probability of making *Traffic violations* in traffic decreases. For *Errors*, a negative relationship was found with a short education, but a positive relationship with cycling more than 3 h per week, high distraction, cycling crash involvement, and psychological distress. High distraction (0.47) had the highest impact. *Positive behaviour* is negatively related to *being male* and positively related to *working* as the main occupation and cycling 3–5 h per week, with *working* as the main occupation (0.17) as the one having the highest impact.

Regarding RPRS, *Traffic rule knowledge* is positively related to being male and the most frequent cycling trip being 30–59 min. Further, *Traffic rule knowledge* is negatively associated to *Distraction* high which also has the highest impact on the factor (−0.40) and psychological distress. *Risk perception* is positively related to a lower educational attainment, and negatively related to *Distraction* high, living in an area with ≥200,000 inhabitants and psychological distress.

4. Discussion

The overall purpose of this study was to explore differences in users' personal characteristics, cycling habits, and behaviour between e-bike and c-bike users, as well as to identify predictors for adopting e-bike use as the main cycling mode.

Table 2
Comparison of distraction from different sources between e-bike and c-bike users.

Sources of distraction	e-bike		c-bike		χ^2-test,
	Number	Pct.	Number	Pct.	p-value
Text messages, chats, or social networks	1	1%	28	6%	–
Phone calls	6	8%	51	11%	0.52
Billboards	11	15%	69	12%	0.52
People that I find attractive	13	18%	89	18%	0.86
Own thoughts or concerns	29	39%	180	37%	0.75
Weather conditions	38	51%	248	51%	0.99
The behaviour of other road users	52	70%	385	80%	0.07
Obstacles in the way	45	61%	290	60%	0.90
Distraction level					
Low (0–1)	20	27%	98	20%	0.19
Medium (2–5)	51	69%	364	75%	0.24
High (6–8)	3	4%	21	4%	–

Table 3
Comparison of mean value of the identified factors for e-bike and c-bike users.

Measures and identified factors		e-bike		c-bike		*t*-test,
		Mean	SD	Mean	SD	p-value
CBQ[a]	Violations	1.56	0.39	1.65	0.41	0.07
	Errors	1.31	0.29	1.31	0.30	0.92
	Positive behaviour	4.30	0.60	4.11	0.68	**0.02**
RPRS[b]	Traffic rule knowledge	4.49	0.41	4.31	0.50	**< 0.01**
	Risk perception	4.41	0.41	4.29	0.44	**0.04**
Anger[c]	Police	2.04	0.72	2.24	0.94	**0.04**
	Progress impeded	4.05	0.80	4.09	0.72	0.63
	Narrow space	3.06	0.85	3.21	0.90	0.18
	Pedestrians	3.46	0.87	3.42	0.84	0.72
CAX[a]	Verbal	1.92	0.77	1.99	0.74	0.46
	Physical	1.06	0.16	1.08	0.22	0.28
	Vehicle	1.41	0.50	1.49	0.52	0.16
	Constructive	2.33	0.81	2.38	0.78	0.61
BFI[d]	Neuroticism	3.07	1.37	3.15	1.63	0.66
	Extraversion	4.32	1.22	4.13	1.39	0.27
	Openness	4.71	1.01	4.75	1.19	0.77
	Agreeableness	5.13	0.93	5.28	0.96	0.23
	Conscientiousness	5.08	1.01	5.18	0.87	0.34
GHQ-12[e]	Psychological Distress	8.39	4.74	9.23	5.35	0.20

Notes: A 5-point scale from "never/almost never" to "always/almost always", b 5-point scale from "totally disagree" to "totally agree", c 5-point scale from "Absolutely none" to "really a lot", d 7-point scale from "strongly disagree" to "totally agree", and e score rating from 0 "not stressed at all" to 36 "very stressed".

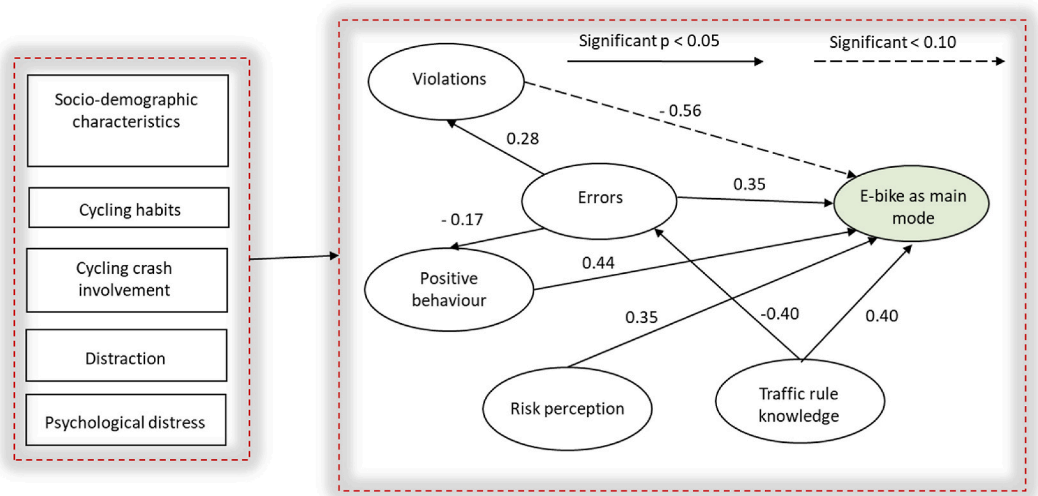

Fig. 1. SEM for variables and latent factors and their relation to e-bike as the main cycling mode. Notes: Standardized values; Path significance levels vary in accordance with the arrow continuity.

Regarding the first (i.e., cycling habits and trip characteristics), our results reveal very few differences between e-bike and c-bike users. In both groups, most trips were short trips with a specific purpose and the duration of the most frequent trip was 20–30 min. However, the proportion of people using the bike for exercise was higher among c-bike users compared to e-bike users. Additionally, for e-bike users, the proportion of trips with a duration of 31–59 min was longer compared to c-bike users. These findings align with previous studies conducted in North European countries, indicating that e-bike use facilitates more biking (Fyhri and Fearnley, 2015; Fyhri and Sundfør, 2020).

At the self-reported behavioural level there are, however, interesting differences. Specifically, e-bike users scored higher on positive behaviours, risk perception, and self-reported traffic rule knowledge, and lower on anger towards the police. This suggests that the behaviour of e-bike users is more safety-oriented, supported by the results of the Structural Equation Modelling (SEM) procedure, where a lower score on traffic violations predicts using an e-bike as the main bike mode. Furthermore, the SEM shows that violations

Table 4
Estimates of the structural equations explaining latent factors of e-bike as main cycling mode.

Variables	Est.	P[a]
E-bike as main mode		
Violations	−0.56	**
Errors	0.35	*
Positive behaviour	0.44	*
Traffic rule knowledge	0.35	*
Risk perception	0.40	*
Violations		
Errors	0.28	*
Positive behaviour		
Errors	−0.17	*
Errors		
Risk perception	−0.40	*

Notes: [a] P-value where * means significant at 0.05, ** means significant at 0.10, and *** means significant at 0.15.

Table 5
Estimates of the structural equations explaining the relation of latent factors to cyclists' habits, distraction, psychological distress, and socio-demography.

CBQ	Est.	P[a]	CBQ	Est.	P[a]
Violations			*Positive behaviour*		
Male	0.27	*	Male	−0.16	*
Education short	−0.05	**	Occupation: working	0.17	*
31–60 years old	0.01	***	Occupation: retired	0.07	***
≥61 years	−0.06	**	3–5 cycling hours per week	0.08	**
Psychological distress	−0.01	*	**RPRS**		
Errors			*Traffic rule knowledge*		
High distraction	0.47	*	Male	0.24	*
Education short	−0.16	*	High distraction	−0.40	*
3–5 cycling hours per week	0.24	*	Most frequent trip: 30–59 min	0.17	*
6–9 cycling hours per week	0.34	*	Psychological distress	−0.04	*
10+ cycling hours per week	0.40	*	*Risk perception*		
Cycling crash involvement	0.13	**	Distraction high	−0.31	*
Psychological distress	0.03	*	Education short	0.15	*
			>200,000 inhabitants	−0.18	*
			Psychological distress	−0.02	*

Note: [a] P-value where * means significant at 0.05, ** means significant at 0.10, and *** means significant at 0.15.

are positively and significantly associated with errors. This outcome aligns with previous studies, endorsing the assumption that, although violations constitute deliberate risky cycling behaviours, they are commonly linked with unintentional ones (i.e., errors), often a result of low degrees of risk perception, road training, and/or norm knowledge, supporting the interpretation of a safety-oriented approach (Useche et al., 2019, 2022). However, in the case of e-bike users, found to be more safety-oriented, it is more likely that the link between violations and errors is related to challenges handling the e-bike, as identified in previous studies (e.g., Haustein and Møller, 2016).

From a crash-focused point of view, previous studies have established that engagement in traffic violations is associated with an increased risk of crash involvement, both associatively and predictively (Hamann and Peek-Asa, 2017; O'Hern et al., 2021). Accordingly, our results thus indicate, that in cases where e-bike crashes are associated with such violations, these tend to be not intentional but possibly the result of errors. These errors could stem from the previously identified difficulties in handling e-bikes, such as fast acceleration, higher weight, and higher speed. This suggests a need for strengthening access to information and training on these specific features for e-bike users, a point highlighted in both single-user (e-scooter rider) and comparative studies conducted in different countries (Cherry and MacArthur, 2019; Hoj et al., 2018; Sundfør and Fyhri, 2017).

Furthermore, the interpretation of the outcome suggesting higher awareness or concern about crash risk among e-bike users is bolstered by previous findings indicating that e-bike users are more likely to wear safety equipment, such as helmets (Cherry and MacArthur, 2019; Jing et al., 2023). All in all, this indicates that the higher risk of serious injury cannot be solely explained by increased deliberate risk-taking behaviour among e-bike users, but through passive safety and positive behavioural-related issues. Therefore, the focus on preventing crashes should therefore be on preventing errors and encouraging safe riding habits as a part of promoting e-bike use.

4.1. Limitations of the study

Although this study used a considerably extensive set of participants, variables and instruments, there are some key limitations from various spheres that must be acknowledged, to help readers to correctly interpret the study outcomes, as well as their actual scope.

First, and related to the representativeness of our sample should be mentioned. For both e-bike and c-bike users our sample was representative regarding gender. However, for both e-bike and c-bike users unemployed and retired persons were underrepresented in our sample, and the generalizability of our results to these groups may therefore be limited. Regarding age, older riders (>61 years old) were underrepresented among e-bike users whereas younger riders (18–30 years old) were underrepresented among c-bike users. The reasons for the underrepresentation of these groups are unknown. Both data collections include online surveys, but the TU data collection includes reminders, which our data collection did not. As reminders are known to increase the response rate (Sammut et al., 2021), it is a possible contributing factor in case these groups were less motivated to participate.

Additional studies ensuring more participants from these groups are needed to assess the possible impact on our results. However, based on previous studies showing that both younger e-bike users (Møller et al., 2019) and c-bike users (Malmgren and Christiansen, 2022) ride longer trips than older riders do, our results may be less applicable to e-bike riders who ride shorter trips and c-bike riders who ride longer trips than average. In addition, specifically regarding e-bike users, a previous study found increasing age (>60) to be associated with feeling less safe (Haustein and Møller, 2016). Thus, our result that e-bike users are more concerned with safety compared to c-bike users might have been even more pronounced if older e-bike users had not been underrepresented in our study sample.

5. Conclusion

This study had two core aims: first, to explore some key differences between e-bike and c-bike users and, second, to identify individual factors predicting the fact of adopting an e-bike as the main cycling modality. Accordingly, the conclusions were structured to summarize the findings in these two regards, as follows:

In regard to the first, the key demographic differences between e-bike and c-bike users include e-bike users more likely being female, living in smaller cities and riding longer trips, whereas c-bike users are more likely to be male, live in larger cities and to use the bike as a means of exercise. The profile of these two groups is thus quite different which highlights the importance of considering demographic factors and cycling habits when studying and promoting increased and safe use of e-bikes.

As for the second, the main predictors of using an e-bike as the main cycling modality include fewer violations, but more errors, positive behaviours, higher level of traffic rule knowledge and awareness of risks associated with cycling. Although the results do not allow conclusions regarding crash causation, the identified predictors indicate that the increased risk of crash involvement and serious injury associated with e-bike use cannot be explained by increased risk-taking behaviour among the e-bike users.

All in all, these results contribute to reduce the knowledge gap about difference between e-bike and c-bike users and are relevant for development of targeted strategies to increase safe e-bike use, even though to a limited extent, i.e., limited to the particular set of variables covered by the study questionnaire.

In further research terms, these outcomes help to underscore the need for additional applied studies looking into the crash mechanisms are relevant to verify this and improve the understanding of a possible impact of the higher risk-awareness among e-bike users and crash involvement. This is especially relevant as our results targeted a positive association between riders' errors and violations. Although the specific types of errors that e-bike users are involved in were not addressed in this study, it could be errors leading to violations increasing the risk of serious injury.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author contributions

Mette Møller: Conceptualization; Investigation; Writing - original draft; Writing - review & editing, **Sergio, A. Useche:** Investigation; Writing - review & editing, **Felix W. Siebert:** Investigation; Writing - review & editing, **Kira H. Janstrup:** Conceptualization; Formal analysis; Investigation; Writing - review & editing.

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.

Data availability

The data that has been used is confidential.

Acknowledgements

The authors of this study would like to thank **XXXX (Anonymized for Review)** (licensed translator) for the professional proofreading of the revised version of the manuscript.

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