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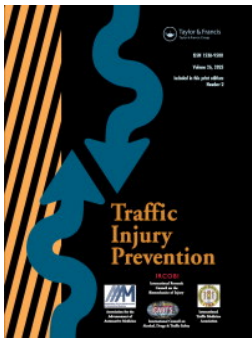
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ABSTRACT

Objectives: Understanding the risks associated with electric motorcycles (EMs) is essential for developing effective mobility and safety strategies in an era of increasing motorcycle use and the shift toward electric vehicles. In this research, we investigate the prevalence of crashes among EM and conventional motorcycle (CM) users, as well as factors contributing to the crashes.

Methods: This study uses primary survey data from 972 motorcyclists (481 EM and 491 CM riders) collected in December 2023 in Hanoi, Vietnam. It compares the frequency of risky riding behaviors and crash types between the 2 groups. Additionally, 2 binary logit regression models are applied to identify factors associated with crashes in the past 12 months for EM and CM riders.

Results: The results suggest that the prevalence of respondents who did not experience crashes (56.1%), minor crashes (68.8%), serious crashes with injury (80.9%), and hospitalization (91.1%) for EM riders was significantly higher than that for CM users. CM riders tend to engage in many risky riding behaviors more frequently than EM riders. Higher frequencies of speeding, smoking, and neglecting turn signals were related to greater crash risk in both groups. Red light running was a particular risk factor of crash prevalence for EMs only. Older EM users were more likely to experience a crash, and CM users traveling longer and living in urban districts were found to be linked to higher crash prevalence.

Conclusions: Transitioning from CMs to EMs in Vietnam may offer some safety benefits, such as cautious behavior by EM riders and lower speeds, but there are no major differences in crash prevalence between the groups. Risky behaviors like speeding, smoking, and neglecting turn signals increase crash risks for both; red light running is a particular concern for EM riders and longer travel distances and urban residency for CM users. Targeted interventions, proper training, and licensing are essential, with attention to older EM riders' vulnerabilities and the risks faced by CM users in urban areas and on long trips.

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Introduction

Motorcycles are a fundamental part of transportation systems around the world; as such, they are an important subject for research. While offering crucial benefits in personal mobility and freight logistics (Nguyen-Phuoc et al. 2023), and sometimes signifying the owner's social status (Zudhy Irawan et al. 2022), they also pose environmental challenges due to air and noise pollution (Kim Oanh et al. 2012). Governments are addressing these issues by considering the electrification of motorcycle fleets, which may alleviate environmental concerns (Murtiningrum et al. 2022; Nguyen-Phuoc et al. 2024). However, it is important to remember that even with electrification, motorcycles still represent a significant road safety risk because they offer little protection to riders in safety-critical situations such as crashes, indicating that

environmental improvements must be balanced with safety considerations.

In contrast to ample knowledge on safety matters for conventional motorcycles (CMs; C. Y. H. Wu and Loo 2016; Nguyen-Phuoc, De Gruyter, Nguyen et al. 2020; Tran et al. 2022), only limited research has been carried out on electric motorcycles' (EMs) safety, such as the study by Yang et al. (2020) conducted in China to identify risk factors contributing to fatal injuries. In addition, an emerging comparative literature of safety issues among different types of 2-wheelers has concentrated upon the crash severity and crash likelihood for CMs, e-bikes, and bicycles but not for EMs (Scheppers et al. 2014; Huang et al. 2020; Spörri et al. 2021; Qian and Shi 2023). Previous research has consistently suggested that the difference in crash profiles results primarily from the characteristics of vehicles

(e.g., weight, speed capacity, and braking system), riders (e.g., age, riding experience, and risky riding behaviors), and infrastructure (e.g., dedicated lanes; Schepers et al. 2014). As such, the prevalence and severity of crashes tend to decrease among users of motorcycles and e-bikes and cyclists (Schepers et al. 2014; Huang et al. 2020; Spörri et al. 2021). Given that EMs are promoted as an environmentally friendly alternative to CMs, especially in countries where motorcycles are prevalent, it is crucial to understand any differences in crash issues between CMs and EMs. This understanding will help guide the development of green and safe transportation solutions. However, determining whether EMs or CMs are definitively safer remains challenging (Eccarius and Lu 2020). Although EMs generally have lower maximum speeds, their lighter bodies resulting from the absence of internal combustion engines can reduce stability, which may increase the risk of crashes (Vlahogianni et al. 2012; Nayak et al. 2023). Moreover, the “nearly” quiet operation of EMs, particularly at low speed, with the low tire and wind noise, might pose an additional significant danger to riders and other road users (e.g., pedestrians, cyclists, and particularly for visually impaired persons) whose “flight response” relies on auditory signals (Garay-Vega et al. 2010; Barton et al. 2012; Poveda-Martínez et al. 2017; Pardo-Ferreira et al. 2020). For instance, the low noise emission of EMs has been linked to a 54% increase in pedestrian injuries from quiet motorized vehicles in the UK between 2012 and 2013 (Kennedy 2019). Additionally, in the United States, EMs were found to be twice as likely to be involved in pedestrian-related crashes compared to internal combustion vehicles under similar conditions (J. Wu et al. 2011). Therefore, we hypothesize that EMs may pose higher safety risks due to their lighter and quieter operation.

In this research, we investigate the prevalence of crashes among EM and CM users, as well as the factors contributing to crashes. Vietnam, a country heavily reliant on motorcycles, provides an ideal context for this study. By 2019 the country had 62 million registered motorcycles, equating to 640 units per 1,000 people (Eccarius and Lu 2020; VCCorp. vn 2021). Although the majority of these motorcycles are conventional, gasoline-powered models, the adoption of EMs is on the rise (M. H. Nguyen et al. 2024). Sales of EMs are nearing half a million units annually, especially in major cities like Hanoi and Ho Chi Minh City (VietNamNet News 2019). VinFast, a local electric vehicle manufacturer, aims to produce over 1 million EMs by 2025. However, the widespread use of motorcycles comes with a high risk of collisions, injuries, and fatalities. Between 2016 and 2020, motorcycles (without separate statistics on EMs and CMs) were involved in over 51,800 collisions (National Transportation Safety Committee of Vietnam. 2021. Report on road traffic injury in Vietnam during the period from 2016 to 2020. Hanoi (Vietnam): National Transportation Safety Committee of Vietnam 2021). On average, motorcycle users account for 58% of annual road deaths, with most head traumas linked to motorcycle crashes (Ngo et al. 2012). These statistics highlight the urgent need for research and policy interventions.

Methods

Conceptualization

To establish a theoretical foundation for this research, we reviewed studies investigating crash risks among motorcyclists (Wells 1986; Elliott et al. 2007; Blackman and Haworth 2013; Lam et al. 2019; Nguyen-Phuoc, Oviedo-Trespalacios et al. 2020; Rusli et al. 2020). This review identified 10 risky riding behaviors that can lead to crashes: (1) listening to music, (2) speeding, (3) smoking, (4) using the phone, (5) drunk riding, (6) traveling in the wrong lane/direction, (7) running red lights, (8) neglecting to use turn signals, (9) not wearing a helmet, and (10) carrying more than 1 person. Based on these findings, we developed the conceptual model shown in Figure 1.

Our model considers risky riding behaviors along with sociodemographic and travel characteristics typically examined in transportation studies. Gender has been widely studied as a potential predictor of crash prevalence, though its effect is not always significant (Rusli et al. 2020). Lin and Kraus (2009) found that being male and having a low socioeconomic status are risk factors for motorcyclists, and Elliott et al. (2007) observed that the likelihood of crash involvement decreases with age. Commercial motorcyclists who are students and/or have a lower educational level show a higher prevalence of traffic collisions (Nguyen-Phuoc et al. 2019). A higher crash risk is associated with motorcyclists in more urbanized areas due to greater congestion (Keall and Newstead 2012). Increased travel is linked to a higher crash risk (Elliott et al. 2007), whereas there is an inverse relationship between crash risk and the duration of holding a motorcycle license (i.e., riding experience; Wong et al. 1990; Truong and Nguyen 2019). We excluded some potentially relevant natural and built environmental variables, such as weather and road conditions, due to a lack of data, relying

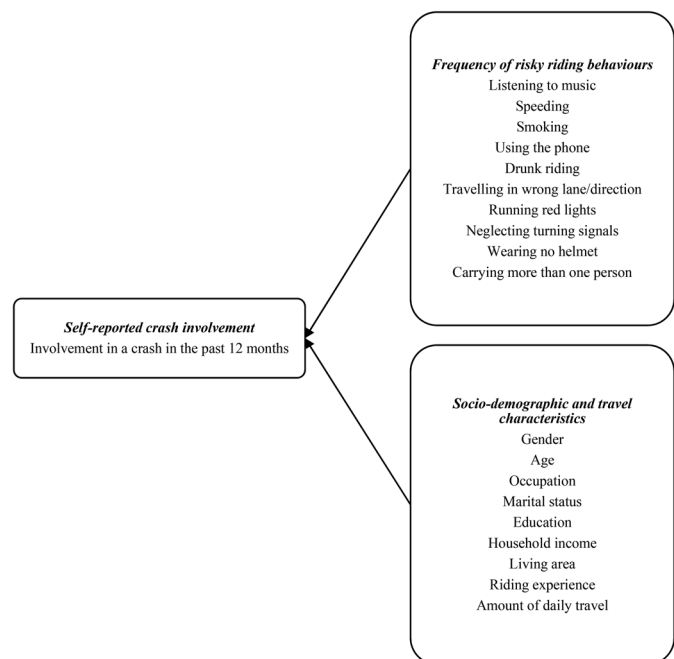


Figure 1. Conceptual model, applicable to both CM and EM users.

instead on self-reported crash data rather than official police records.

Questionnaire and data collection

Based on the conceptual model, we designed a structured questionnaire for primary data collection (Table 1A, see online supplement). The questionnaire is divided into several parts: The first part outlines the scope and objectives of the current study and includes a request for each participant to provide their signed consent, ensuring informed participation. It also includes a question regarding the type of motorcycle currently used by the respondent. A conventional motorcycle is defined as a 2-wheeled vehicle that has an internal combustion engine capacity ranging from 50 to 125 cc (i.e., small-displacement motorcycles that account for over 90% of the national fleet). These motorcycles may either have a step-through chassis and footrest platform or not (D. V. M. Nguyen et al. 2021). An electric motorcycle, on the other hand, is defined as a 2-wheeled vehicle powered by an electric engine that resembles the design of a motorcycle, notably lacking pedals. Eligibility criteria for participation require individuals to be at least 18 years old, currently living in Hanoi, and using their current motorcycle (either electric or conventional) not for commercial purposes and for at least 12 months, enabling us to consider their safety record over the past year. The second section gathers sociodemographic information (e.g., gender, age, occupation, education, household income, and living area) and travel data (riding experience and amount of daily travel). The third part asks participants to rate the frequency of 10 risky riding behaviors in the past 12 months on a 3-point scale: (1) *never* (nearly 0% of trips), (2) *sometimes* (<30% of trips), and (3) *usually* ($\geq 30\%$ of trips). The behaviors assessed include listening to music, speeding (driving faster than the speed limit), smoking, using the phone, drunk riding, traveling in the wrong lane/direction, running red lights, neglecting turn signals, not wearing a helmet, and carrying more than 1 person. Participants were also asked to report any risky behaviors engaged in at the time of a crash. The last part inquires about participants' experiences with 5 types of crashes during the last 12 months, defined as follows: a minor crash (no damage to property or injuries), a crash with property damage only, a crash with injuries (not requiring hospital treatment), a crash requiring hospitalization, and a crash with fatalities.

Before widespread deployment, the questionnaire underwent a pretest with 10 motorcycle users in Hanoi and was revised in collaboration with 5 transport safety experts. Modifications included clarifying the definition of EMs and specifying the speeding behavior for EMs, particularly highlighting the speed limit of 50 km/h for EMs according to Vietnamese road regulations. Modifications also involved adding definitions of a crash and the 5 types of crashes, providing a clearer understanding of the parameters for analysis. The pilot survey averaged about 9 min in length.

In Vietnam, research ethics approval is not required for surveys not involving special subjects (e.g., children). Data

were collected in Hanoi in December 2023. Hanoi, located in the south of the country with approximately 8.3 million inhabitants, heavily relies on motorcycles, accounting for over 80% of the modal split. The public transport system, which includes 131 public bus routes, 1 bus rapid transit corridor, and 1 metro line, accounts for less than 10% of trips. Cycling is mainly for recreation and school travel. In 2023 the number of EMs exceeded 184,000 units (baodautu.vn 2023).

We aimed to gather 2 comparable samples of conventional and electric motorcyclists. Ten local university students were recruited and trained to conduct face-to-face surveys across all 12 urban districts and 12 out of 18 non-urban districts. Only adults (18+) were surveyed, with a \$1 incentive offered for participation. We excluded professional motorcyclists, such as moto-taxi and food delivery riders, due to their distinct work conditions. Professional riders seldom use EMs. Given the ubiquity of CMs and the relative rarity of EMs in Hanoi, surveyors spent 3.5 h daily in locations likely to encounter EMs, such as shopping mall entrances, certain residential areas, electric motorcycle stores, e-bike service points, and university campuses. Initially, EM riders were approached for the first 2 h, followed by a 30-min verification of demographic data and, finally, 1 h surveying CM users to ensure similar demographic distributions between the 2 groups. The survey yielded 502 CM users and 495 EM users, with final sample sizes of 481 for EM users and 491 for CM users after excluding incomplete and unreliable responses.

The CM sample was collected in accordance with the EM sample; therefore, we expected that the size of the latter was reasonable. With a confidence interval of 95%, margin of error of 5%, and EM user population of 184,471 (baodautu.vn 2023), the minimum sample size should be at least 384.¹ As such, the EM sample's size was sufficient. Moreover, previous studies exploring crashes and risk factors for motorcyclists also relied on samples with a similar size to ours (M. H. Nguyen et al. 2023).

Data analysis

The analysis was followed the 3 steps delineated by M. H. Nguyen et al. (2023) and Nguyen-Phuoc, De Gruyter, Nguyen et al. (2020) in other road safety-related studies:

Step 1: We explored the connection between self-reported crashes and independent variables (sociodemographic characteristics and risky riding behaviors).

Step 2: We looked at whether and which risky riding behaviors had been performed when crashes occurred to understand the relationship between two.

Step 3: We investigated the statistically significant risk factors that led to crashes by estimating binary logit regressions for EM riders and CM riders separately. To fit parsimonious models, which explain a great deal of variation with as few predictors as possible, we followed Sam et al's

¹<https://www.qualtrics.com/blog/calculating-sample-size/>

Table 1. Sample description.

Sociodemographic and travel characteristics	EM sample (N=481)		CM sample (N=491)	
	Frequency	%	Frequency	%
Gender				
Male	236	49.06	239	48.68
Female	245	50.94	252	51.32
Other/non-binary	0	0	0	0
Age				
Continuous	31.831 (mean)	14.07 (SD)	28.684 (mean)	11.463 (SD)
	18 (min)	77 (max)	18 (min)	75 (max)
Occupation				
Student	197	40.96	206	41.96
Employed	244	50.73	260	52.95
Unemployed	40	8.32	25	5.09
Education				
Secondary degree	202	42.00	194	39.51
Tertiary degree	279	58.00	297	60.49
Household income				
Low and middle (<20 million VND) ^a	302	62.79	304	61.91
High (≥20 million VND)	179	37.21	187	38.09
Living area				
Urban district	299	62.16	297	60.49
Nonurban district	182	37.84	194	39.51
Riding experience^b				
≤2 years	207	43.04	197	40.12
>2 years	274	56.96	294	59.88
Amount of daily travel^c				
<10 km	174	36.17	112	22.81
10–19 km	176	36.59	187	38.09
20–29 km	88	18.30	137	27.90
30+ km	43	8.94	55	11.20

^a\$1 equals about 23,000 Vietnamese dong (VND).

^bRiding experience is operationalized as years holding a motorcycle riding license.

^cAmount of daily travel is measured as total daily distance traveled.

(2018) selection process: First we fitted 2 full models with all the potential predictors and then we refitted the models keeping only statistically significant variables. In the resulting parsimonious models, all predictors remained statistically significant. The final lists of independent variables is as follows:

1. EM sample: (a) age, (b) frequency of speeding, (c) frequency of smoking, (d) frequency of neglecting turn signals, and (e) frequency of running red lights.
2. CM sample: (a) living area, (b) amount of daily travel, (c) frequency of speeding, (d) frequency of smoking, and (e) frequency of neglecting turn signals.

We checked for multicollinearity among predictors by computing the variance inflation factor values (Table 1B, see online supplement). With all variance inflation factor values <2, we concluded that there was insignificant multicollinearity (Vatcheva et al. 2016).

Findings

Descriptive statistics

The sociodemographic characteristics of the survey participants are shown in Table 1. The 2 samples are similar in

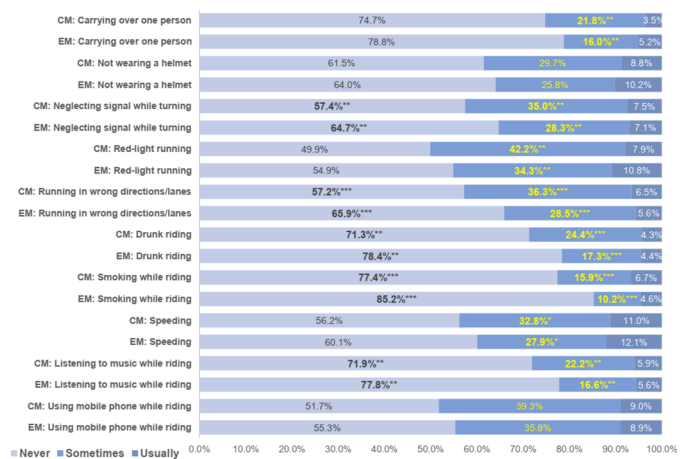


Figure 2. Frequencies of adopting risky riding behaviors among EM and CM riders. * $P < .1$. ** $P < .05$. *** $P < .01$.

terms of gender, education, occupation, living area, and income distribution. On average, EM riders are slightly older and have less experience riding motorcycles than CM riders. The amount of travel done by the 2 groups differs as well, with CM users traveling much more on a daily basis. This may be simply due to a limited battery range in e-motorcycles.

Figure 2 shows how often CM and EM riders engage in a number of risky riding behaviors. The graph suggests that, in general, EM users adhere better to road regulations and safety guidelines. A significantly higher percentage of EM users, compared to CM users, reported never neglecting turn signals, riding in the wrong lane or direction, drunk riding, or smoking and listening to music while riding. For the remaining unsafe riding behaviors, the proportion of EM riders running red lights, carrying more than 1 person, and speeding “sometimes” is also significantly lower compared to CM riders. However, the differences in the rates of “usually” engaging in risky riding behaviors between the 2 rider groups are statistically insignificant.

Table 2 shows that crash prevalence is high in both groups, but it is 6.2% lower for EM riders compared to CM riders, with statistical significance at a low confidence level. EM riders also have significantly lower rates of minor and serious crashes resulting in injury or hospitalization compared to CM users. However, the difference in the percentages of respondents not experiencing vehicle-only crashes is insignificant between 2 groups. The full table of descriptive statistics (Table 1C, see online supplement) shows that EM users who were involved a crash in the last 12 months tend to be male, around 32.819 years old (SD 14.411), university educated, employed, and urban and have higher incomes. They have had a motorcycle license for 1 to 2 years and travel 10 to 20 km per day on average. Where they adopt risky riding behaviors, even if occasionally, their crash rate is higher. For example, the prevalence of crashes among those who never ignore turn signals is nearly 32.79% (95% CI 27.60–38.32) compared to just 57.35% (95% CI 48.59–65.78) and 91.17% (95% CI 76.32–98.14) among those who “sometimes” or “usually” do so. The crash statistics for CM riders are similar; however, in this case, a higher number of crashes is also due to more travel overall.

Table 2. Crash prevalence by crash type.

Crash type	Number of crashes	Number of respondents experiencing crashes		Prevalence (%)		P value
		EM (n=481)	CM (n=491)	EM	CM	
Crash in general	0	270	245	56.1	49.9	*
	≥1	211	246	43.9	50.1	*
Minor crash	0	331	297	68.8	60.5	***
	1	79	94	16.4	19.1	
	2	33	39	6.9	7.9	
	3	20	25	4.2	5.1	
	4+	18	36	3.7	7.3	**
Vehicle-only crash	0	331	326	68.8	66.4	
	1	92	84	19.1	17.1	
	2	30	40	6.2	8.2	
	3	15	15	3.1	3.1	
	4+	13	26	2.7	5.3	**
Crash with injury	0	389	355	80.9	72.3	***
	1	53	73	11.0	14.9	*
	2	18	32	3.7	6.5	**
	3	11	14	2.3	2.9	
	4+	10	17	2.1	3.5	
Crash with hospitalization	0	438	405	91.1	82.5	***
	1	21	44	4.4	9.0	*
	2	4	24	0.8	4.9	*
	3	7	9	1.5	1.8	
	4+	11	9	2.3	1.8	

*P < .1. **P < .05. ***P < .01.

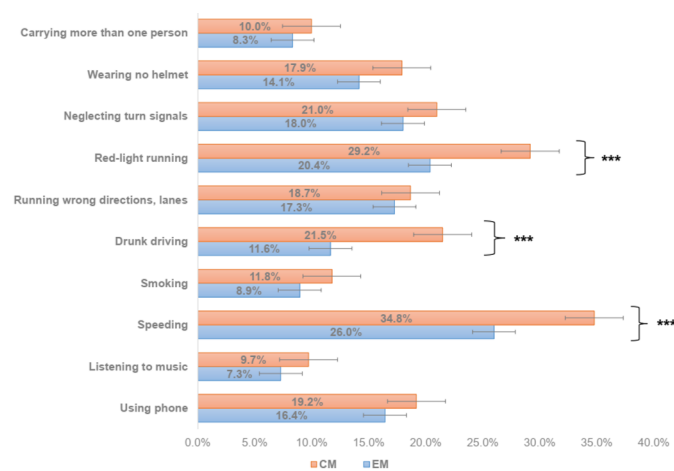


Figure 3. Prevalence of risky riding behaviors leading to crashes. *P < .1. **P < .05. ***P < .01.

Figure 3 shows that for both samples the top 3 dangerous behaviors directly leading to crashes are speeding, running red lights, and neglecting turn signals. However, risky riding behaviors among CMs are more likely to leading to crashes, and the differences are substantial in the case of speeding, drunk riding, and running red lights.

Logit regression

The results of the binary logit regressions for EM riders and CM riders are presented in Table 3. Both models generated similar results in terms of frequencies of speeding, smoking, and neglecting turn signals. All of these behaviors were risky for both EM and CM riders in that they led to more crashes in the past 12 months. A motorcyclist who did not ride over the speed limit was less likely to be involved in a crash in the last 12 months in comparison with those who sometimes (odds ration for EMs [OR_{EM}]=3.615; odds ratio for CMs

Table 3. Factors leading to crashes.

Independent variables	Dependent variable involvement in a crash in the past 12 months					
	Model 1: EM riders (N=481)			Model 2: CM riders (N=491)		
	OR	SE	p	OR	SE	p
Age	1.021**	0.007	0.006	Not included		
Living area	Urban districts			Reference		
	Non-urban districts			0.573*	0.138	0.021
Amount of daily travel	<10 km			Reference		
	10–19 km			3.094***	0.961	0.000
	20–29 km			4.110***	1.413	0.000
	30+ km			6.160***	2.686	0.000
Speeding (frequency)	Never			Reference		
	Sometimes			3.615***	0.892	0.000
	Usually			3.341**	1.494	0.007
Smoking (frequency)	Never			Reference		
	Sometimes			1.710	0.660	0.165
	Usually			6.798*	5.533	0.019
Neglecting turning signals (frequency)	Never			Reference		
	Sometimes			1.800*	0.435	0.015
	Usually			8.096**	5.366	0.002
Running red lights (frequency)	Never			Reference		
	Sometimes			1.587	0.382	0.055
	Usually			2.817*	1.353	0.031
Constant	0.120	0.039	0.000	0.123	0.037	0.000
Log-likelihood	-261.3405			-236.6851		
Likelihood ratio	LR chi ² (9) = 136.87			LR chi ² (10) = 207.30		
Prob > chi ²	0.0000			0.0000		
Pseudo R ²	0.2075 [†]			0.3046 [†]		

Notes: (1) never (nearly 0% of trips); (2) sometimes (<30% of trips); and (3) usually (≥30% of trips). OR: Odds Ratio; SE: Standard Error; p: significance value *p < 0.05; **p < 0.01; ***p < 0.001. [†]Pseudo R² falls within recommended range (0.2–0.4) (Hensher et al. 2015), confirming model goodness-of-fit.

[OR_{CM}]=5.033) or usually (OR_{EM} = 3.341; OR_{CM} = 15.035) engaged in this behavior. Notably, among CM riders, those who usually sped had a far higher crash risk compared to EM riders (OR_{EM} = 3.341; OR_{CM} = 15.035). Usually smoking while riding resulted in a higher probability of involving a

crash (relative to never doing so), and the risk for EM riders was double that for CM riders ($OR_{EM} = 6.798$; $OR_{CM} = 3.377$). Ignoring the use of turn signals involved significant risks of experiencing crashes whether this occurred sometimes ($OR_{EM} = 1.800$; $OR_{CM} = 1.916$) or usually ($OR_{EM} = 8.096$; $OR_{CM} = 9.168$). Age and a tendency to run red lights were significant predictors of crash prevalence among EM riders only (with higher age posing a higher risk). The living area and the amount of daily travel affected CM riders only. Urban dwellers and those who traveled more on a daily basis were at higher risk. In the following section, we unpack these results and compare them to the findings of previous studies.

Discussion

EMs are a technological solution to the environmental impacts of fuel-based mobility in motorcycle-dependent countries (Eccarius and Lu 2020). Nonetheless, it is important to investigate whether the benefits EMs offer in terms of environmental sustainability might result in conflicts with other values such as safety. The current research investigates the similarities and differences in the self-reported crash records between EM riders and CM riders to provide a better understanding of EM riders' safety.

The key finding from the present investigation suggests that EMs may be safer than CMs, as indicated by the prevalence of different crash types (Table 2). We expected to find that riding an EM inherits all the risks of riding a CM and even introduces new risks pertaining to their nearly silent operations and lighter structure. In some of our (unpublished) previous surveys (Minh Hieu et al. 2023), EM users (particularly females and middle-aged and older individuals) reported concerns about the silent operation, rapid acceleration, and potential stability issues due to their lightweight design. Perhaps EM users are aware of these novel risks and consequently ride more carefully, as reflected in the significantly lower prevalence of EM riders who report never or sometimes engaging in various risky riding behaviors (Figure 2). However, this explanation requires further empirical examination. Another consideration is that early adopters of EMs might differ from CM users in terms of risk tendencies, meaning the comparison may not involve individuals with similar risk profiles (Oviedo-Trespalcacios and Scott-Parker 2018). Additionally, there could be an adaptation period when transitioning from one technology to another, during which behaviors and safety practices are not fully developed. This phenomenon of behavior change following an engineering or technological shift is referred to as "behavioral adaptation" (Oviedo-Trespalcacios and Scott-Parker 2018). For most respondents, EMs were newly purchased vehicles, so they might not yet feel confident enough to take risks in traffic, or they might be particularly cautious with such vehicles due to their high cost. These factors could also contribute to the observed differences in crash prevalence.

Consistent with other studies (Elliott et al. 2007; Nguyen-Phuoc et al. 2019), we find that more travel leads to more crashes, likely because spending more time on the

road increases exposure to potential risks and hazards. The longer a rider is in traffic, the greater the likelihood of encountering challenging situations, such as interactions with other vehicles, changing road conditions, or unexpected events, which heighten crash risks. Additionally, the findings confirm that the adoption of risky riding behaviors is the primary reason why motorcyclists experience crashes (Elliott et al. 2007; Gulliver and Begg 2007; Nguyen-Phuoc, De Gruyter, Nguyen et al. 2020). Frequent speeding, smoking, and neglecting turn signals significantly increase the likelihood of crashes for both EM and CM riders in this study. Speeding, in particular, significantly increases the risk of crashes for CM riders compared to EM riders, likely due to the lower maximum attainable speeds of EMs (Figure 3). Most EMs in Vietnam can reach 80 km/h at most, and if a passenger is onboard, EMs accelerate slowly and only reach 65 to 70 km/h at most. In contrast, CMs can run at 80 to 90 km/h or even faster. Possibly because of the significantly lower frequency of speeding ("sometimes") and lower maximum speed levels, crashes related to EMs are less likely to involve hospitalization and injury (Schepers et al. 2014).

Motorcyclists in more urbanized areas face a higher risk of crashes, likely due to the increased congestion and more complex traffic conditions found in these areas (Keall and Newstead 2012). However, in our sample, these factors are only significant among CM riders, who travel longer distances overall. It may be that, when faced with longer trips, riders tend to accelerate more to save time. CMs' higher engine capacity enables dangerous speeding, thus leading to more collisions. EMs are much more prevalent in urban districts, but this factor was not linked to the risk of crashes for this group. Interestingly, running red lights is a clear issue for EM riders (but not for CM riders), in terms of both frequency and associated risk of crashes. Perhaps other riders have more difficulty detecting a silent vehicle (i.e., an EM) running a red light (compared to a CM). Another potential explanation for this is that traffic police officers tend to be more lenient toward EM users, partly because these vehicles are less common and resemble e-bikes, contributing to a disparity in enforcement. Generally, police enforcement in Vietnam does not seem to be effective in preventing risky driving behaviors (Nguyen-Phuoc, De Gruyter, Oviedo-Trespalcacios et al. 2020). Possibly due to the higher frequency of red light running, CM users reported a significantly higher rate of crashes associated with this behavior.

A positive link between the age of EM riders and crash prevalence may be explained by a lack of experience with electric vehicles among older adults. Though they are quite interested in these new modes (Le et al. 2021), they may have difficulty in switching to lighter vehicles with very limited auditory cues. Prior studies have similarly reported more crashes and other traffic concerns when older persons begin using e-bikes (Haustein and Møller 2016). In contrast, studies of CM riders have found that the likelihood of crashing decreases with age (Elliott et al. 2007). It is important to emphasize that this finding is particularly concerning for safety, because older adults are at a significantly higher risk of fatal injuries (Rod et al. 2021). Further work on the prevention of crashes among this group is needed.

Some limitations need to be considered when interpreting the findings. Firstly, the self-reported data on crashes are likely to contain errors and omissions (af Wählberg 2003). As a typical example, af Wählberg and Dorn (2015) highlighted the low reliability of drivers' self-reports on crashes and violations. However, these types of data are frequently used in road safety studies (C. Y. H. Wu and Loo 2016; Nguyen-Phuoc et al. 2019; Truong and Nguyen 2019) and are often the only available source of data in low- and middle-income countries (Haghani et al. 2022). Similarly, convenience sampling tends to introduce bias. On the positive side, both of our samples have similar demographic distributions, which enables reliable and consistent comparisons. It is important to note that the variables included in this study are not the only predictors of crashes. The attributes of the motorcycles themselves, such as brand, wear and tear, and engine capacity, may also have an impact (Lin and Kraus 2009; Wong et al. 2010). Our decision to avoid psychological constructs means that our study cannot provide explanations for why safety performance may differ between riders of conventional or electric vehicles. As suggested by a reviewer, the relatively long duration (12 months) of recalling safety records and aberrant riding behaviors, although utilized frequently in the earlier research on motorcyclists (Nickenig Vissoci et al. 2020; Nguyen-Phuoc, De Gruyter, Nguyen et al. 2020; M. H. Nguyen et al. 2023), may decrease reliability. Additionally, in Vietnam, the uptake of EMs is still low (Le et al. 2021), which limits the transferability of our findings to other contexts. Another limitation is related to the definition of speeding behavior used for this study. We only considered speeding as riding faster than the speed limit but ignoring the particular contexts wherein riders are having difficulty controlling their motorcycles (Høye 2020). Future research should be conducted in other settings to validate and extend our findings. Further studies could benefit from the use of objective data and explore psychological and behavioral factors affecting rider safety, as well as the impact of motorcycle attributes on crash rates. This would provide a more comprehensive and reliable understanding of factors contributing to motorcycle safety and help develop targeted interventions to improve road safety for all users. If the use of EMs influences changes in riding behaviors (e.g., more cautious riding), it would be interesting to investigate whether these changes are temporary or permanent, especially in relation to advancements in EM technology.

The present research provides empirical evidence suggesting that EMs may have better safety outcomes than CMs in Vietnam, highlighting their potential to contribute to improved road safety if they replace the current CM fleet. However, it is important to recognize that EMs are not without risks. EM riders still engage in certain risky behaviors, some of which violate Vietnamese traffic laws. Additionally, the current licensing and testing system, designed primarily for CM users, should be expanded to include EM riders, ensuring that they are adequately trained to operate these vehicles safely. This is particularly crucial for older riders, who were found to be more prone to crashes, underscoring the importance of tailored training and education programs to help them navigate electric vehicles effectively in heavy

traffic conditions. Though promoting EM adoption could enhance safety, it is equally vital to address behavioral adaptation and ensure that early adopters maintain safe riding practices. This shift is not just about reducing motorcycle crashes; it represents an opportunity to create a safer, more inclusive road environment for all users. By implementing these recommendations, Vietnam could achieve a dual benefit of improved road safety and progress toward environmental sustainability goals.

Author contributions

Conceptualization, MHN and QDN-P; methodology, MHN and QDN-P; data collection, all authors; formal analysis, all authors; writing, all authors. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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