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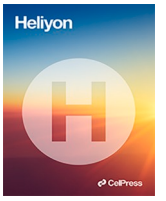

Research article

Riding practices of e-bike riders after the implementation of electric bike management regulations: An observational study in Hangzhou, China

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ABSTRACT

Objective: This study aimed to understand the riding behaviors of electric bike (e-bike) users in Hangzhou after the "Regulations of Zhejiang Province on the Administration of Electric Bicycles".
Methods: The study consisted of two parts, including a questionnaire survey of local e-bike users in Shangcheng District and Jiande County in Hangzhou City, and a cross-sectional observational study of 16 intersections.
Results: A total of 789 e-bike riders participated in the questionnaire survey, and the riding behavior of 99,407 e-bike users was observed. The main purpose of using e-bike was work and daily life, 46.0% of them used e-bikes more than 5 days a week, and 58.5% used e-bikes for less than 30 min each time. A vast majority (81.7%) of e-bike riders believe that the implementation of Zhejiang Regulations has significantly improved the safety level of e-bike riding in the region. The field survey found that the correct rates of helmet wearing by e-bike riders and passengers were 78.83% and 42.27%. The main violations were invalid/non-helmet wearing (21.17%), followed by carrying passengers and running red lights (7.94% and 4.26%). The rates of invalid/non-helmet wearing and running red lights were significantly higher during non-morning rush hour, weekends, and roads without separate non-motorized vehicle lanes than in other conditions (all $P < 0.05$). Additionally, sunny days and crossroads were risk factors for passenger-carrying and invalid/non-helmet wearing compared to rainy/cloudy days and T-intersections.
Conclusions: The phenomenon that e-bike users' correct practice lags far behind the awareness of various violations has shown some improvement. To further enhance safety measures for e-bike riders, it is necessary to promote education, improve infrastructure, and strengthen law enforcement, in support of the "Zhejiang Regulations" and behavioral interventions.

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1. Introduction

Road traffic injuries are a pressing public health concern and are the primary cause of injury-related fatalities in China [1]. The National Injury Surveillance System in China indicates that road traffic injury represents 20.90% of all injuries. In recent years, as society and economy develops, e-bike has increasingly become an important means of travel for the general public [2]. At present, China has nearly 300 million e-bikes [3]. Being small, quick, agile and cheap, e-bikes are very popular among the general public [4,5]. Although cycling is overall highly accepted transport with a beneficial value for mobility, sustainability and users' economy [6,7], individual willingness to cycle can decrease for different reasons. Standard-exceeding e-bikes are prevalent in the market. Due to their poor stability, high speed, and frequent violation of regulations, the number of e-bike accidents and related casualties has maintained a momentum of rapid growth. For instance, in 2008, 5.4% of all traffic fatalities in China were caused by e-bike riders, which increased to 7.8% in 2012 and 12.0% in 2016 [8]. According to statistics [9], Zhejiang province had 9.718 million cases of non-motor vehicle violations, mainly due to e-bikes, in 2019. The number of deaths and injuries in non-motor vehicle traffic accidents accounted for 47.4 % and 59.7 % of the total number of deaths and injuries in all traffic accidents, respectively.

As vulnerable road users, e-bike riders are prone to serious injury or even death in traffic accidents, due to lack of self-protection measures. Hu et al. [10] found that the probability of severe injury for e-bike accidents was nearly 2 times that of regular bicycle accidents. Baschera et al. [11] found that people who ride e-bikes had a much higher risk of moderate to severe brain injury than those who ride bicycles. Meanwhile, e-bike users have a higher rate of traffic violations. Relevant data show that craniocerebral injury is the main cause of death caused by e-bike traffic accidents. The use of safety helmets is the most effective means to reduce head injuries and other fatal injuries of motorcycle and non-motor vehicle riders [12]. Studies have shown that motorcycle riders who use safety helmets have 69% lower risk of head injury and 42% lower risk of death [13,14]. It is suggested that improving the wearing proportion of helmets of e-bike riders is one of the important intervention measures to prevent and reduce e-bike traffic injuries. In addition, road safety education and enforcing traffic laws are highlighted by existing studies as potentially pertinent alternatives to increase risk perception, and reduce risky behaviors, road conflicts and crash likelihood among e-bike riders [2].

A review of risky riding behaviors of urban e-bike riders showed that running red lights, speeding, illegal carrying, riding in the opposite direction, and illegally occupying motor vehicle lanes were the main risky riding behaviors of e-bikes, which increased traffic risk [4]. Similarly, a case-control study conducted in a capital city of a province showed that risky riding behaviors of bicyclists who violated traffic rules were important influences on traffic safety [10]. In addition, using a cell phone while cycling within 1 min of a traffic accident leads to a 3-fold increase in the probability of injury [15]. It has been demonstrated that the perceived rate of e-bike users is lower than that of other road transport vehicle users, which is one of the reasons for the significant increase in e-bike-induced crashes in recent years [16]. Scarano et al. [17] used a bibliometric approach to analyze cyclist safety studies over the last 10 years, and found that e-bike and behaviors were the main keywords, suggesting that there is an extra attention. For this reason, Zhejiang Province has formulated explicit regulations on e-bike-related behaviors to control and correct dangerous behaviors related to e-bike riders.

On July 1, 2020, the Regulations on the Management of Electric Bicycles in Zhejiang Province came into effect, requiring e-bike riders and passengers to wear helmets, not to carry passengers illegally, not to modify vehicle without authorization, and to purchase regular vehicles for registration, etc., and violators will be punished accordingly [18]. On the one hand, similar regulations on e-bikes have only been implemented in a few provinces in China. No study has evaluated how well the policy is known among e-bike riders and how it affects the traffic behavior of e-bike riders since its implementation. On the other hand, current research focuses on risky behaviors and prevalence profiling that affect traffic safety, and it is not known what factors influence the adoption of risky behaviors by riders. In order to better understand the current situation after the implementation of the regulations on e-bikes in Hangzhou City, including e-bike riders' knowledge of the regulations, riding experience, and road riding practices, we plan to conduct an on-site study that includes a questionnaire survey and roadside observations.

2. Methods

2.1. Study location

Hangzhou was chosen as the project area in Zhejiang Province under the guidance of the World Health Organization and the national and Zhejiang provincial center for disease control and prevention. According to the proportion of urban and rural areas, geographical distribution, economic level, population structure and other factors, we chose Shangcheng District (an urban area) and Jiande County (a rural area) as the two project sites in Hangzhou. Shangcheng District is the central urban area of Hangzhou, while Jiande County is located in the most remote suburb of Hangzhou. The two places have similar levels of transportation infrastructure, and there is no overlap in the management of electric bicycles. Electric bicycles are the main means of short-distance travel in both places, which can represent the traffic behavior of electric bicycles in urban and rural areas respectively. Located centrally in the Yangtze Delta Region near Shanghai, Hangzhou is "New-era Digital Governance Model City", with a resident population of approximately 12.2 million, population density of 724 persons per square kilometer. And the total number of e-bikes on Hangzhou's roads reached 6.8 million in 2020, an official report said [19]. The study protocol was approved by the Hangzhou Center for Disease Control Ethics Committee (20211231Y078).

2.2. Study setting

In June 2021, a cross-sectional observational study was conducted at 16 randomly selected intersections in Hangzhou during a 6-day period. This cross-sectional investigation was divided into 2 components: A questionnaire survey and a field observation. The questionnaire survey was conducted on e-bike users' knowledge and behavior on e-bike safety, and a further non-participant observation was conducted on the traffic behavior of e-bike riders and passengers. Stopping a passing vehicle to question a rider in detail about traffic behavior and knowledge during a traffic behavior investigation would be a very risky behavior, both for the rider and the investigator. And the effectiveness of the survey would be greatly affected. Therefore, we conducted a survey on traffic behavior and knowledge in the environment of new traffic regulations at the surrounding sites of non-participatory observation to reflect the current situation of local cyclists.

The questionnaire items of knowledge, attitude and practice of e-bike users on e-bike safety were investigated by convenient sampling and face-to-face interview, and the location was selected as the relatively clustered area suitable for the survey. Investigators intercepted e-bike users at the bus stations, subway stations, supermarkets and other places near the field observation survey intersections, and gave explanations and questionnaires to the participants.

The field observational survey has been adopted to understand the occurrence of e-bike riders' and passengers' traffic behaviors, such as wearing helmets and red-lights running. It was conducted at 16 road intersections, including 8 urban areas and 8 rural areas in Hangzhou. The detailed survey sites in Hangzhou were shown in Table S1. E-bikes were chosen as investigated vehicles type, including standard-exceeding e-bikes. 16 observation points have been selected based on the road type and geographical locations. The requirements of the observation points include: (1) The observation points must be safe and have a good view; (2) The traffic lights should function well, and there is no traffic police or auxiliary police on duty in the vicinity (within a one-side distance of 200 m), no traffic control or road construction; (3) The road users observed are mostly local residents, but not tourists; (4) It is easy to observe e-bike users; (5) The traffic volume should basically reflect the actual local circumstances, but heavy-traffic areas should not be used for on-site observation.

2.3. Data collection procedure

The questionnaire survey mainly includes personal information, e-bike riding, e-bike safety knowledge, attitude and practice. In the non-participant observation, we used a pro-forma data collection checklist to record items including weather, day of week, time of day, average E-bike traffic volume per hour, carrying passengers, running red lights and helmet use. We conducted 6 separate 120-min survey (preparation, rest and change forms for 20 min, observation for 100 min) focusing on roadside observation from 7a.m. to 7p.m., Monday to Saturday. Each site can be surveyed twice a day for 6 days. At the same time, two surveys can be conducted for each time period at each site. See Table S2 for detailed schedules of the observation points.

Senior researchers and traffic policemen made each site visits and on-site audits to ensure accurate and appropriate data collection. Completed observational records were reviewed and fields with missing information were clarified by site observers. Double entry was used to reduce data entry errors.

2.4. Research sample

A total of 789 e-bike riders were investigated by on-site questionnaire, including 422 males and 367 females, with an average age of (43.09 $\pm$ 12.04) years (Table 1). In a non-participatory observation, we monitored the riding behavior of 99,407 e-bike riders. The Results section offers additional insights into the information of e-bike riders.

2.5. Statistical analysis

The interviewees were classified into 2 types: E-bike users and questionnaire survey participants. Pearson's chi-square test was used to assess the differences in frequency data between the 2 groups. *T-Test* was used to assess the differences in quantitative data. For all statistical tests, a P value < 0.05 was regarded as statistically significant. All analyses were performed with SPSS Ver. 22.

Table 1
Respondents' demographic characteristics.

	Gender		Age Groups			Education Level			Living duration locally in past 12 months	
	Male	Female	15-	30-	45-	basic	middle	high	<6 months	≥6 months
n	422	367	122	268	399	223	245	321	51	738
%	53.5	46.5	15.5	34	50.5	28.3	31.0	40.7	6.5	93.5

3. Results

3.1. Preliminary result

Of the participants who responded to the on-site questionnaire, 91.3% used e-bikes for work and daily life, 92.3% used them for more than 3 days per week, and 90.6% rode for less than 1 h each time. Registered e-bikes accounted for 91.3 percent, and 96.6% of the e-bikers said they normally wore helmets while riding. Furthermore, 83% of the participants were aware of the regulations on e-bikes, and 81.8% believed that the safety of e-bike riding had improved over the past 6 months (Table 2).

3.2. Non-participatory observation

The average e-bike traffic volume in Shangcheng District was found to be significantly higher than that in Jiande County, with an average volume of 410/hour compared to 209/hour, respectively (see Fig. 1 and Table 3). Furthermore, there was a large variation in e-bike traffic volume among observation points and time periods, ranging from a maximum of 3247/hour to a minimum of 24/hour during the 6 time sessions at 16 observation points (see Table 3). The peak traffic volume for e-bikes in both Shangcheng District and Jiande County was observed between 7 and 9 a.m., with the lowest traffic volume occurring between 1 and 3 p.m. (as shown in Fig. 1 and Table 3).

The helmet wearing proportion is 92.81% for e-bike riders and 47.11% for e-bike passengers (Table 4). However, the percentage of riders and passengers who wear helmets correctly is relatively low, with only 78.83% and 42.27% respectively. A considerable number of people wear helmets, but do not tie them up, or use helmets that do not meet safety standards. Table 3 shows that the percentage of wearing helmet correctly for e-bike riders and passengers in Jiande County are significantly higher than those in Shangcheng District (94.20% vs. 71.06% and 80.55% vs. 28.57% respectively). The proportion of passengers carried by e-bikes in Jiande County is lower than that in Shangcheng District (6.24% vs. 8.81%).

The main observation results are presented in Table 5, which shows the prevalence of riding with invalid/no helmets, running red lights, and carrying passengers to be 21.17%, 4.26%, and 7.94%, respectively. Significant differences were found in the rates of invalid/no helmet wearing, running red lights, and carrying passengers of e-bike riders based on weather, day of the week, time of day, lane separation, and intersection type (with the exception of the effect of weather on red light running).

Compared with Jiande e-bikers, Shangcheng e-bikers showed greater ORs of invalid/no helmets to wear (OR = 6.61, 95% CI 6.30 to 6.95), running red lights (OR = 2.87, 95% CI 2.63 to 3.12) and carrying passengers (OR = 1.45, 95% CI 1.38 to 1.53). Reduced ORs of invalid/no helmets to wear (OR = 0.69, 95% CI 0.66 to 0.72), running red lights (OR = 0.84, 95% CI 0.77 to 0.91) and carrying passengers (OR = 0.71, 95% CI 0.67 to 0.75) were found to be associated with weekday compared with those in weekend. Compared with cloudy/rainy days, e-bikers showed greater ORs of invalid/no helmets to wear (OR = 1.40, 95% CI 1.36 to 1.45) and carrying passengers (OR = 1.15, 95% CI 1.10 to 1.21). The highest elevated OR of carrying passengers (OR = 11.43, 95% CI 10.85 to 12.04) were observed among lanes separation compared with lack of lanes separation, while the OR values for invalid/no helmets to wear and running red lights were reduced (OR = 0.713, 0.69, respectively). E-bikers at T-shaped intersections had lower OR values for invalid/not wearing a helmet (OR = 0.66, 95%CI 0.64 to 0.68) and for carrying passengers (OR = 0.73, 95%CI 0.69 to 0.73) compared to cross-

Table 2
E-bike riders' cycling habits and awareness of the new legislation over the past 6 months.

Questions		n	%
The main purpose of riding e-bikes	Life	329	41.7
	Work	391	49.6
	Others	69	8.7
Average number of days per week for riding e-bikes (day)	0-	61	7.7
	3-	365	46.3
	6-	363	46.0
Average duration of a single ride (min)	0-	168	21.3
	15-	294	37.2
	30-	253	32.1
	60-	74	9.4
How many years have you used an e-bike as your main means of transportation? (year)	0-	164	20.8
	3-	104	13.2
	5-	242	30.7
	10-	279	35.3
Has the e-bike been registered?	Yes	720	91.3
	No	69	8.7
Do you wear a helmet when riding an e-bike?	Usually	762	96.6
	Seldom	27	3.4
Do you know Zhejiang Province has issued the "Zhejiang Province Electric Bicycle Management Regulations"?	Yes	655	83.0
	No	134	17.0
Do you think the regulation has improved the safety level of e-bikes?	Obvious	645	81.8
	Little	102	12.9
	No	42	5.3

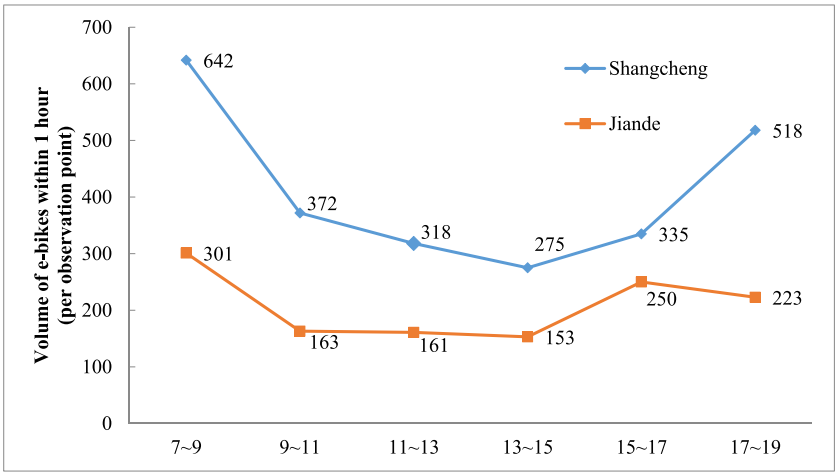

Fig. 1. Volume of E-bikes within one Hour per Observation Point in Shangcheng District and Jiande County of Hangzhou by time periods.

Table 3
Traffic volume of e-bikes at observation points in Shangcheng District and Jiande County of Hangzhou in different time periods (/per hour).

Areas	Observation Points	Time Periods						
		7:00~9:00	9:00~11:00	11:00~13:00	13:00~15:00	15:00~17:00	17:00~19:00	Average Volume
Shangcheng District	a	3247	1159	743	659	737	878	1237
	b	437	326	256	180	212	265	279
	c	33	24	35	28	29	33	30
	d	117	100	132	115	95	180	123
	e	537	563	564	508	746	1720	773
	f	314	335	410	409	418	587	412
	g	213	171	189	139	158	194	177
	h	239	300	217	165	284	284	248
	Average volume	642	372	318	275	335	518	410
Jiande County	a	340	123	114	125	190	160	175
	b	668	333	351	370	416	504	440
	c	201	111	131	114	171	175	151
	d	425	137	141	137	222	228	215
	e	388	334	260	231	429	378	337
	f	216	122	131	112	152	150	147
	g	110	100	123	96	123	147	117
	h	62	46	33	41	297	45	87
	Average volume	301	163	161	153	250	223	209

Table 4
Helmet wearing by e-bike riders and passengers in the project areas in Hangzhou.

Type	Project areas	Wearing helmets correctly (%)	Wearing helmets incorrectly (%)	Not wearing helmets (%)	Total
Riders	Shangcheng	46910(71.06)	12208(18.49)	6898(10.45)	66016
	Jiande	31454(94.20)	1687(5.05)	250(0.75)	33391
	Total	78364(78.83)	13895(13.98)	7148(7.19)	99407
Passengers	Shangcheng	1661(28.57)	261(4.49)	3892(66.94)	5814
	Jiande	1677(80.55)	121(5.81)	284(13.64)	2082
	Total	3338(42.27)	382(4.84)	4176(52.89)	7896

shaped intersections, except for running red lights (OR = 2.05, 95%CI 1.92 to 2.20). In addition, compared with the morning peak, the number of e-bike violations is significantly higher during other periods (Table 6).

4. Discussion

As people's living standard improves and the number of private cars increases, the road traffic congestion is worsening [20,21]. Being economical, environmentally friendly, and convenient, e-bike, as a new means of road transportation, has become an

Table 5
Cycling behavior composition of e-bike riders under different conditions.

Variables	Number	Invalid/No helmets [n (%)]	χ^2 &P	Running red lights [n (%)]	χ^2 &P	Carrying passengers	χ^2 &P
Project areas							
Shangcheng	66016	19106(28.94)	7115.69	3582(5.43)	650.93	5814(8.81)	200.57
Jiande	33391	1937(5.80)	<0.001	656(1.96)	<0.001	2082(6.24)	<0.001
Weather							
Sunny	59641	13941(23.37)	434.91	2540(4.26)	0.01	4984(8.36)	34.87
Cloudy/Rainy	39766	7102(17.86)	<0.001	1698(4.27)	0.93	2912(7.32)	<0.001
Weekday							
Yes	85819	17388(20.26)	309.70	3570(4.16)	16.43	6490(7.56)	124.43
No	13588	3655(26.90)	<0.001	668(4.92)	<0.001	1406(10.35)	<0.001
Time periods							
7:00~9:00	25156	4196(16.68)	566.99	874(3.47)	181.81	1559(6.20)	359.16
9:00~11:00	14284	3362(23.54)	<0.001	682(4.77)	<0.001	1073(7.51)	<0.001
11:00~13:00	13458	3506(26.05)		741(5.51)		1110(8.25)	
13:00~15:00	9903	2288(23.10)		554(5.59)		566(5.72)	
15:00~17:00	16848	3557(21.11)		725(4.30)		1728(10.26)	
17:00~19:00	19758	4134(20.92)		662(3.35)		1860(9.41)	
Lanes separation							
Yes	76434	15129(19.79)	374.71	2972(3.89)	113.93	5734(24.96)	11831.75
No	22973	5914(25.74)	<0.001	1266(5.51)	<0.001	2162(2.83)	<0.001
Type of intersections							
T-shaped	53037	9529(17.97)	698.50	2947(5.56)	465.89	3630(6.84)	187.75
Cross-shaped	46370	11514(24.83)	<0.001	1291(2.78)	<0.001	4266(9.20)	<0.001
Total	99407	21043(21.17)		4238(4.26)		7896(7.94)	

Table 6
Odds Ratios (95% CI) for helmet use and road rule violations among e-bikers.

Variables	Invalid/No helmets to wear	Running red lights	Carrying passengers
Project areas			
Shangcheng	6.61(6.30–6.95)	2.87(2.63–3.12)	1.45(1.38–1.53)
Jiande	Reference		
Weather			
Sunny	1.40(1.36–1.45)	1.00(0.94–1.06)	1.15(1.10–1.21)
Cloudy/Rainy	Reference		
Weekday			
Yes	0.69(0.66–0.72)	0.84(0.77–0.91)	0.71(0.67–0.75)
No	Reference		
Time periods			
7:00~9:00	Reference		
9:00~11:00	1.54(1.46–1.62)	1.39(1.26–1.54)	1.23(1.13–1.33)
11:00~13:00	1.76(1.67–1.85)	1.62(1.47–1.79)	1.36(1.26–1.47)
13:00~15:00	1.50(1.42–1.59)	1.65(1.48–1.84)	0.92(0.83–1.01)
15:00~17:00	1.34(1.27–1.40)	1.25(1.13–1.38)	1.73(1.61–1.86)
17:00~19:00	1.32(1.26–1.39)	0.96(0.87–1.07)	1.57(1.47–1.69)
Lanes separation			
Yes	0.71(0.69–0.74)	0.69(0.65–0.74)	11.43(10.85–12.04)
No	Reference		
Type of intersections			
T-shaped	0.66(0.64–0.68)	2.05(1.92–2.20)	0.73(0.69–0.76)
Cross-shaped	Reference		

indispensable travel tool for the general public in China [22]. However, e-bike riders and passengers, being a vulnerable group, face many hidden safety hazards on the road [4,23,24]. Millions of E-bikes operate on roads and many associated deaths and injuries have been reported [25]. The road traffic injuries related to e-bikes have become one of the important public health problems that threaten people's lives [26]. Fortunately, Zhejiang Province took the lead in implementing the "Regulations of Zhejiang Province on Administration of Electric Bicycle" in 2020. E-bikers' on-road practices are rarely characterized and no direct observational studies have been performed since the regulation was implemented. This study describes the riding behaviors of e-bike riders after the implementation of the regulations and investigates the factors that influence these behaviors in order to prevent injuries and improve conditions of compliance with regulations.

The results of the questionnaire show that e-bikes are mainly used for daily short-distance driving, primarily for work and life purposes. 91.3 percent of e-bikes were officially registered, and 96.6 percent of riders said they would use helmets while riding. This is a significant improvement compared to Suzhou city before the policy's implementation, where only 86.0% of e-bikes were registered, and only 58.04% of riders wore helmets in Shantou city [27,28]. This suggests that the habit of wearing helmets among e-bike riders

has significantly improved. Moreover, 83.0% of riders know about Zhejiang Regulations, and 81.8% approve of them. This indicates that e-bike management in Hangzhou is relatively standardized, and riders generally comply with the related laws and regulations. The implementation of Zhejiang Regulations has a positive impact on improving the safety level of e-bikes. It also reminds us that the publicity of Zhejiang Regulations should be carried out on an on-going basis so that the general public will understand and abide by laws.

Over the past year, all districts and counties in Hangzhou have carried out specialized management of e-bikes, and continuously constructed a comprehensive management landscape for road traffic safety through intelligent management and control, management of hidden dangers, and responsibility fulfillment. As a result, the proportion of e-bike riders and passengers wearing helmets keeps rising. Unsurprisingly, our finding of helmet use was much higher (92.81%) compared with an observed helmet use (9.0%) in Suzhou [27], because of compulsory helmet laws for e-bikers in Zhejiang Province since 2020. This is similar to the fact that mandatory use of motorcycle helmets has led to a significant increase in the number of motorcycle riders using helmets in China [29]. However, it is 3.19% lower than the self-reported 96% helmet wearing rate in the questionnaire, which suggests that behavioral change is more difficult than in thought change. Yang J indicated that poor safety practice was common (e.g., speeding, violations of road rules, and little use of helmets), but this did not vary between rural and urban areas [30]. However, there were statistical differences in the incidences of wearing helmets, running red lights and carrying passengers among e-bike riders in Shangcheng and Jiande regions. This show that people's cycling habits were similar before the regulation. The rider's riding practice is obviously affected by the law enforcement intensity and has not formed a good habit. The regional differences require attention. Analytical surveys indicate that this is linked to the extent to which the relevant local governments value this issue and the corresponding measures taken, the law enforcement environment and difficulties faced by the traffic police. Jiande County combined the implementation of Zhejiang Regulations with its "civilized city" campaign, taking multiple measures simultaneously. Targeted publicity combined with strong law enforcement, comprehensive intervention has achieved tangible results. Moreover, there was a high incidence of ineffective helmet wearing among e-bike riders. About 13.98% of e-bike riders and 4.84% of passengers wore helmets incorrectly, which can be fatal in serious crashes. It has not been a concern in previous studies. This phenomenon can be explained in the early days of the policy, when e-bike riders wore helmets for some reason to avoid inspection. In the event of traffic accidents and the consequent strong crashes, helmets can protect brains from fatal injuries [31]. During the interviews with traffic police, officers pointed out that most individuals involved in e-bike accidents did not wear helmets correctly. After serious crashes, helmets had flown off before bodies fell, and could not offer protection. Wearing helmets correctly can reduce deaths by 40% and serious brain injuries by 70% [32]. Therefore, increasing the proportion of e-bike riders and passengers who wear helmets correctly is crucial.

The issue of e-bike road safety remains a serious and complex problem, influenced by various factors [23,24,33,34]. In over 77.58% of electric bike-related road traffic crashes, riders were determined by the police to be responsible for the crash [35]. In this survey, in addition to the helmet wearing problems, other dangerous behaviors have also be detected, such as running red lights and illegally carrying passengers. The vulnerable groups, in particular, remain at risk. The survey found that significantly fewer e-bike riders are running red lights and carrying passengers than in the past [26]. But the violations were linked to a number of factors. The study found that riders wearing helmets increased on rainy days, while carrying passengers decreased, consistent with previous findings [36]. This may be because helmets can prevent the head from getting wet and passengers choose other means of transportation to travel. On weekdays and during the morning rush hour, e-bike riders have fewer road violations. This is similar to the findings of Huang, J [28]. They reduce road risk-taking in the face of heavy traffic because they know the risks are too high. But risk taking in low-risk situations doesn't lessen the damage once it happens. Therefore, riders should be responsible for themselves and obey the traffic rules is the guarantee of safety. We can strengthen law enforcement, separate e-bikes from motor vehicles and reconstruct intersection types, but we cannot change weather, travel peaks and work schedules. To make matters worse, the survey found an increasing number of e-bikes carrying passengers on non-motorized lanes, which are separate from motorized lanes. Similarly, in a survey in Tianjin, 68.8% of people knew that adult riders could only carry one child under 12 years old, but only 25.9% implemented this correctly [16]. This calls for better education and enforcement for riders dealing with multiple environments. To let them know the risk factors of different scenarios and limit them to take risk behaviors. In a word, measures tailored to local conditions should be taken to identify the difficulties and pain points in the local implementation of Zhejiang Regulations, and comprehensive intervention measures contribute positively to increasing the local e-bike safety level.

5. Study limitations

To the best of our knowledge, there is no study on the riding behavior of electric bikes after the implementation of the regulation on electric bicycles in Zhejiang Province. However, there are some key limitations worth acknowledging. First of all, it is a cross-sectional study that can only establish associations between traffic behavior and environmental factors but cannot infer causation. Secondly, the roadside observation study may have been limited by the manual counting of cyclists' riding behaviors by observers, potentially leading to inaccuracies and omissions in the data. Thirdly, common methodological biases (recall bias etc.) and social issues (which we won't delve into because they are outside the scope of this article) may have influenced the self-reported behavioral outcomes of our participants. While all the efforts depending on us were made to reassure participants of the anonymity of their responses, we cannot ensure all responses were unbiased. Nonetheless, the study findings provide an informative snapshot of diverse safety issues for E-bikes on-road practice, which clearly emphasizes the need for future intervention. We focused on cyclists' safety perceptions and riding behaviors while neglecting some factors that may influence those behaviors, such as using mobile and speeding, which can be further explored in the future.

6. Implications for practice

Regarding the road traffic violation and injury of e-bikes, the following recommendations are put forward to continuously improve the comprehensive road traffic safety management landscape and build a prevention and control management system: (a) Strengthen the development of supporting policies for laws, and promulgate technical standards and entry standards related to e-bike safety (b) Conduct cross-departmental collaboration for e-bike road traffic injury data governance (c) Strengthen road infrastructure for traffic safety (d) Strengthen traffic safety publicity and law enforcement.

7. Conclusion

The phenomenon that e-bike users' correct practice lags far behind the awareness of various violations has shown some improvement. To further enhance safety measures for e-bike riders, it is necessary to promote education, improve infrastructure, and strengthen law enforcement, in support of the "Zhejiang Regulations" and behavioral interventions.

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Ethics approval and consent to participate

All protocols were approved by the Hangzhou Center for Disease Control Ethics Committee (20211231Y078) and were conducted in accordance with their regulations and guidelines. All respondents signed an informed consent form.

Data availability statement

Data included in article/supplementary material/referenced in article.

CRediT authorship contribution statement

Jue Xu: Writing – original draft, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Cuirong Ji:** Writing – original draft, Supervision, Software, Methodology, Data curation, Conceptualization. **Biao Li:** Writing – original draft, Supervision, Software, Methodology, Data curation, Conceptualization. **Peng Jiang:** Writing – review & editing, Investigation, Data curation. **Kang Qin:** Writing – review & editing, Investigation, Data curation. **Zhimin Ni:** Writing – review & editing, Investigation, Data curation. **Xuyun Huang:** Writing – review & editing, Investigation, Data curation. **Rongwan Zhong:** Writing – review & editing, Investigation, Data curation. **Lian Fang:** Writing – review & editing, Investigation, Data curation. **Ming Zhao:** Writing – review & editing, Supervision, Resources, Methodology, Formal analysis, Conceptualization.

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.

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Appendix A. Supplementary data

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