International Journal of Industrial Ergonomics 89 (2022) 103292

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

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

Exploring the factors influencing e-bike road safety: A survey study based on the experiences of Taiwanese cyclists

Fei-Hui Huang

Asia Eastern University of Science, Marketing and Distribution Management, New Taipei City, Taiwan

ARTICLE INFO

Keywords:
E-bike cyclists
Cycling safety
Mental workload
User experience

ABSTRACT

The Taiwanese government has implemented a subsidy strategy to encourage the purchase of e-bikes, thus reducing the overall amount of air pollution emitted by fueled vehicles. However, e-bikes are relatively new vehicles that are associated with road safety risks. With increased sales, cycling safety has become an emerging public health challenge. This survey study adopted mental workload measures, including the Driving Activity Load Index (DALI) and Rating Scale Mental Effort (RSME), and used subjective perception measures, including user experiences (UXs) and the feeling of risk, to investigate the factors influencing cycling crashes. We recruited cyclists who visited repair stations to maintain their e-bikes. Results showed that the model constructs of UX pragmatic quality and speed were useful predictors of e-bike crashes in traffic environments. Moreover, the DALI scores showed significant differences at different speed levels, while DALI and anxiety exhibited a highly positive correlation. Respondents who cycled with higher pragmatic quality satisfaction and at speeds less than 25 km/h were less prone to traffic crashes. Further, speed was connected to mental workload and anxiety when riding an e-bike. A mobile self-reporting option is proposed to enhance the engagement of cyclists in road safety while better achieving self-managed vehicle speed.

1. Introduction

Road safety for electric bicycle (e-bike) cyclists constitutes an emerging public health challenge in countries that promote the use of two-wheeled low-carbon vehicles. The E-bikes are low-cost, relatively low-tech, and low-carbon innovations in the context of urban mobility. E-bikes are among the most energy-efficient modes of motorized transport due to both their lightweight and efficient drive trains (Cherry et al., 2016) and environmental superiority when compared to the emissions produced by other motorized modes of transport. A wide variety of e-bikes are commercially available, with varying performance and design characteristics (Cherry et al., 2009; Rose, 2012). E-bike designs can roughly be divided into three types, including bicycle-style, scooter-like, and motorcycle-like. Among these, bicycle-style e-bikes are popularly sold throughout areas of Asia (Wu et al., 2012) and Europe (Fyhri and Fearnley, 2015). Worldwide, more than 40 million e-bikes were sold in 2015, with 37 million sold in China. As the market share of e-bikes continues to rise, the number of related deaths and injuries e-bike will also increase. Taking China as an example, national e-bike-related deaths increased almost seven times between 2004 and 2010, moving from 589 to 4,029, respectively. Taking Netherlands as an example, e-bike deaths increased nearly doubled between 2016 and 2017 (Hurford,). This is because e-bikes can reach higher maximum speeds (reaching 40 km/h or more) through motor support when compared to conventional bicycles (Bai et al., 2013; Chaloupka-Risser and Risser, 2011; Weinert et al., 2007). These higher speeds may result in riskier behaviors, especially in complex traffic situations that require operators to quickly process information (Vlakveld et al., 2015), thus increasing the potential for severe crashes and injuries. Further, it is unclear how e-bikes alter the crash risks when compared to conventional cycling and motorcycle riding. However, e-bikes are already considered dangerous (Popovich et al., 2014).

1.1. Road safety for e-bike cyclists

Road traffic injuries claim more than 1.2 million lives each year globally. Most of these deaths occur in low- and middle-income countries, which lose approximately 3% of total GDP as a result (World

Abbreviations: DALI, Driving Activity Load Index; RSME, Rating Scale Mental Effect; UX, user experience; GDP, gross domestic product; TCI, task-capability interface; TD, task demands; C, driver capability; TLX, Task Load Index; ANOVA, analysis of variance.

E-mail address: fn009@mail.aeust.edu.tw.

https://doi.org/10.1016/j.ergon.2022.103292
Received 23 June 2021; Received in revised form 3 March 2022; Accepted 29 March 2022
Available online 28 April 2022
0169-8141/

Health Organization, 2015). As traffic crashes entail socioeconomic costs and create heavy burdens for society, road safety is a major concern throughout the world.

Most traffic accidents are predictable and preventable, with about 90% being caused by human failure (Treat et al., 1979; Lewin, 1982; Ferrara, 1987). Insufficient sleep and fatigue have been verified as important factors in fatal and serious-injury crashes (Horne and Reyner, 2001; Johns, 2000; Stutts et al., 2003), while visual searching, speed, attention, and avoidance behaviors are known to have negative impacts on traffic safety. Many countries have adopted traffic laws to enforce safety interventions. For instance, there are restrictions and prohibitions on speed, driving after consuming alcohol, helmet usage, seat-belts, and child restraints, each of which are designed to target human risk factors and prevent road traffic injuries and deaths (World Health Organization, 2018). Among these factors, the speed at which a vehicle travels directly influences the risk of a crash as well as the severity of any related injuries, including the likelihood of death. More than half of road traffic deaths occur among vulnerable road users, especially motorcyclists, cyclists, and pedestrians (World Health Organization, 2018). More attention must be given to the needs of these users. It is therefore crucial to make walking and cycling safer (World Health Organization, 2018).

This study focused on issues related to e-bikes safety in traffic environments. A report by the Taiwanese National Police Agency, Ministry of the Interior, indicated that e-bike injuries increased almost three-fold from 2014 to 2018, moving from 1179 to 3,292, respectively. Several critical factors have been found to cause e-bike traffic injuries, including human failures such as inattention, distraction, blind spots, and traffic violations. The Taiwanese government further revised its traffic laws to promote road safety in 2019. This includes vehicle inspections and road-user laws designed to develop correct riding attitudes among e-bike operators while reducing traffic crashes and injuries caused by human failures. More specifically, the inspection laws have implemented quality manufacturing standards, including restrictions on the weight of the e-bike body and maximum driving speeds. To complement this, the road-user laws include license plate registrations, mandatory insurance, helmet usage, a minimum riding age of 14 years, prohibitions on modifications to increase speed, and rider restrictions limiting occupancy to one adult and one child. Like most other countries, Taiwan also treats e-bikes similarly to regular bicycles, and does not require a separate operating license. However, with the increase in e-bike traffic injuries, the Taiwanese Ministry of Transportation and Communications has considered enacting a decree that requires a driver's license to operate an e-bike on the road.

1.2. The TCI model

This study used the task-capability interface (TCI) model (Fuller, 2005), which is a theoretical framework for driver behavior, to explain the crash risks presented to e-bike cyclists. One of the concepts used in the TCI model entails that task difficulty is closely related to the feeling of risk, subjective risk, and speed. The feeling of risk is an important source of information for task difficulty (Fuller, 2005). In addition, the driver's own assessments of subjective risk can accurately reflect objective risk in related segments while determining fear responses and behavioral adjustments (Wilde, 2001). More specifically, drivers are sensitive to task difficulty, and therefore attempt to maintain a level of difficulty that reflects their experiences within a margin of acceptability. At the same time, drivers incur the levels of anxiety they wish to experience while driving, and then drive to maintain them (Taylor, 1964). Finally, speed choice is the primary solution to both the problem of maintaining task difficulty and the level of anxiety within selected boundaries. The driver may also adjust their speed to deal with hazards or potential difficulties when responding to variations in task difficulty. Vehicle driving and speed choice are dynamic control activities in a continuously changing environment. Task difficulty and feelings of risk are highly interrelated when a critical speed is reached. At this time, task demands (TD) approaches the boundary of driver capability (C). In this study, the feeling of risk was assessed based on perceived arousal, the impact intensity of task difficulties was assessed based on the perceived level of anxiety, and the task difficulty was assessed based on speed.

1.3. Mental workload measurement

The concept of task difficulty exists in a different guise; namely, that of mental workload. Mental workload refers to a set of factors that affect mental information processing, and which thus lead to decision-making and individual reactions within the working environment. Workload depends upon both the individual involved and interactions between the operator and task structure. Therefore, the same TDs do not result in equal workloads for all individuals. Task complexity is directly related to TD. Both TD and complexity are mainly external, but also depend upon individual goal-setting for task performance, which varies between individuals. Therefore, mental workload depends upon the TDs in relation to the amount of resources the operator is willing or able to allocate (Meijman and O'Hanlon, 1984). Most mental workload assessment methods fall into the three categories (Meshkati et al., 1995) of (a) performance-based measures, (b) subjective measures, and (c) physiological measures. Among these, subjective (i.e., self-reported) measures are important system evaluation tools, and have been used extensively to assess workload. NASA-TLX (Task Load Index) (Hart and Staveland, 1988) is one of the most outstanding subjective multidimensional measures. TLX is the best measure with respect to workload sensitivity (Hill et al., 1992) and used to assess perceived mental workload widely (Wickens et al., 2015). The Driving Activity Load Index (DALI), which is a revised version of the TLX, was specifically created for the driving context (Pauzié and Marin-Lamellet, 1989). DALI and TLX use the same basic principle. There are six pre-defined DALI factors for evaluating a driver's mental workload, including effort of attention, visual demand, auditory demand, temporal demand, interference, and situational stress. In addition, Rating Scale Mental Effort (RSME) is a unidimensional instrument to evaluate subjective mental workloads (Zijlstra and Van Doorn, 1985; Zijlstra, 1995). It consists of a line measuring 150 mm in length that is marked with nine anchor points, each of which are accompanied by a descriptive label indicating the degree of effort and the associated increase in mental effort. The scale is scored by measuring the distance from the origin to the mark in millimeters.

1.4. Study objectives

This study explored perceived task difficulty, feeling of risk, and user experiences (UX) among cyclists as reported while riding e-bikes on the road. This was aimed at describing the relationship between the perceived difficulty of e-bike riding and cycling crashes. An anonymous survey among e-bike riders was therefore conducted in the Taiwanese context. This study used user-perceived feeling as the main axis of research, while a TCI model was used as a reference when designing the questionnaire. Hence, DALI and the feeling of risk were used to predict e-bike traffic crashes. The concept of UX involves the user's subjective viewpoints; that is, the perceptual and emotional aspects related to the specific property of an object in a certain context at a specific moment. Therefore, self-reported quantitative ratings were designed based on long-term usage and questionnaire items associated with attractiveness, pragmatic quality, and hedonic quality, which gauged the UXs for how riders thought, felt, and perceived of that result from a given e-bike interaction. Another goal of this study was to provide a framework for the various psychological correlates of traffic crashes. This may be used to guide future research while providing a basis for the development of practical road safety interventions.

2. Materials and methods

2.1. Measurements

Participating cyclists were recruited after repairing their e-bikes at one of 16 e-bike repair stations in Taiwan. The questionnaire contained the following eight sections: (1) personal information, including four items designed to collect sociodemographic data on gender, age, occupation, and possession of a Taiwanese scooter driver's license; (2) E-bike riding experience, including six items designed to collect data on e-bike style, riding experience, riding frequency, daily riding distance, riding speed, and e-bike usage; (3) traffic crash experiences, including four items designed to collect data on the number of traffic crashes experienced, locations of the traffic crashes, cause of the traffic crashes, and injuries resulted from the traffic crashes; (4) DALI, which were assessed using a 10-point Likert scale; (5) RSME; (6) risk estimate, including two items designed to measure the respondent's levels of subjective anxiety and subjective arousal, which were assessed using a 10-point Likert scale ranging from very high to very low; (7) UXs, which were assessed using a 10-point Likert scale ranging from extremely satisfied to extremely dissatisfied; and (8) behavioral intention/satisfaction. The study was approved by the Research Ethics Committee of the National Tsing Hua University (IRB protocol number 11002EC017).

2.2. Participants

A total of 273 individual e-scooter owners completed a paper-and-pencil version of the survey, which resulted in 220 valid questionnaires that were used for analysis (80.5% of questionnaires were fully complete). Respondent demographic information is shown in Table 1.

2.3. Data analysis

Analyses were conducted using SPSS software, Version 22.0. Variables were assessed using the chi-square test, *t*-test, Mann-Whitney *U* test, ANOVA, correlation analysis, ordinal logistic regression analysis, and multiple regression analysis. The two-tailed significance level was set at $p < 0.05$.

Table 1
Respondent demographic information.

Item	Frequency (N)	%
Gender		
Female	99	45%
Male	121	55%
Age		
<20	9	4.1%
20–29	43	19.5%
30–39	33	15.0%
40–49	44	20.0%
50–59	47	21.4%
60–69	36	16.4%
>70	8	3.6%
Occupation		
Government	7	3.2%
Communications/Journalism	8	3.6%
Business	4	1.8%
Computer sciences	3	1.4%
Culinary arts/Personal services	72	32.7%
Freelance	16	7.3%
Agriculture	3	1.4%
Retired/Homemaker	45	20.5%
Medical/Health	3	1.4%
Engineering	38	17.3%
Students	13	5.9%
Other	8	3.6%

3. Results

3.1. Descriptive statistics

Descriptive statistics for respondents' e-bike riding experience are shown in Table 2. Regarding DALI, this was added to the scale score for each dimension and then divided by 6 to obtain a total workload score of 29.32 (see Table 3). The mean RSME score was 18.43 (see Table 4).

3.2. Chi-square test

The chi-square test results indicated that riding speed [$\chi^2(2) = 8.31$, $p = 0.016$] and e-bike style [$\chi^2(2) = 39.45$, $p = 0.000$] differed significantly according to traffic crash experiences. Respondents who used to ride e-bikes at high speeds (72.7%; AR = 2.8) showed a higher percentage of traffic crash experiences when compared to those who rode at medium-high speeds (18.2%; AR = −2.7). In addition, respondents who rode modified e-bikes (72.7%; AR = 6.3) showed a higher percentage of traffic crash experiences when compared to those who rode scooter-style e-bikes (27.3%; AR = −2.3) and moped-style e-bikes (0%; AR = −2.1).

Chi-square test results also indicated that riding speed [$\chi^2(2) = 9.44$, $p = 0.009$] differed significantly according to gender. That is, female respondents (66.7%; AR = 2.1) tended to ride e-bikes at lower speeds than male respondents (33.3%; AR = −2.1). By contrast, male respondents (67.6%; AR = 2.7) tended to ride e-bikes at higher speeds than female respondents (32.4%; AR = −2.7).

3.3. *t*-test

The *t*-test results indicated that the DALI temporal demand ($F = 15.06$, $p < 0.001$; $t = 2.24$, $p = 0.026$) and UX attractiveness ($t = -2.47$, $p = 0.014$) differed significantly by gender. That is, male respondents tended to perceive a higher temporal demand ($\bar{X} = 35.12$, $\sigma = 31.04$) when riding e-bikes than female respondents ($\bar{X} = 26.87$, $\sigma = 23.59$). By contrast, female respondents tended to perceive a higher degree of satisfaction with the attractiveness of e-bike products ($\bar{X} = 7.61$, $\sigma = 2.36$) than male respondents ($\bar{X} = 6.77$, $\sigma = 2.62$).

3.4. Mann-Whitney *U* test

The results of the Mann-Whitney *U* test indicated that anxiety and UX pragmatic quality differed significantly between respondents based on whether they had experienced e-bike crashes (see Table 5). Specifically,

Table 2
Respondent e-bike riding experiences.

Item	Frequency (N)	%
E-bike style		
Bicycle-style	60	27.3%
Scooter-like	141	64.1%
Modified e-bikes	19	8.6%
Average riding speed		
<15 km/h (low speed)	21	9.5%
15–25 km/h (medium-high speed)	125	56.8%
>25 km/h (high-speed)	74	33.6%
E-bike usage		
Commuting	90	27.4%
Shopping	80	24.4%
Sports/leisure	78	23.8%
Taking child to/from school	42	12.8%
Work	32	9.8%
Other	6	1.8%
Driver's License		
Have	149	67.7%
Used to have	33	15.0%
Never had	38	17.3%

Table 3
Means, standard deviations (SDs), and total scores obtained for the DALI index.

DALI Index	Mean (SD)
Auditory demand	39.82 (25.82)
Effort of attention	32.95 (24.53)
Temporal demand	31.41 (28.18)
Interference	26.68 (22.62)
Situational stress	23.14 (23.52)
Visual demand	21.91 (19.49)
Total score	29.32

Table 4
Frequencies, means, and standard deviations (SDs) obtained for the RSME scale.

RSME scale	Frequency (%)
Extreme effort	2 (0.9%)
Very great effort	2 (0.9%)
Great effort	8 (3.6%)
Considerable effort	5 (2.3%)
Rather much effort	8 (3.6%)
Some	26 (11.8%)
A little	22 (10%)
Almost no effort	50 (22.7%)
Absolutely no effort	97 (44.1%)
Mean (SD)	18.43 (24.97)

Table 5
Mann-Whitney *U* test and analysis of anxiety and pragmatic quality factors.

	Crash experience		Never crashed
Anxiety	Mean	4.27	2.20
	S.D.	3.61	2.26
	Z value	−2.29	
	p value	0.02	
	Effect size (r)	0.16	
Pragmatic quality	Mean	5.73	7.60
	S.D.	1.62	2.49
	Z value	−2.78	
	p value	0.005	
	Effect size (r)	0.19	

respondents with e-bike crash experiences were rated as having higher perceived anxiety (median = 2) than those without crash experiences (median = 1), while respondents without e-bike crash experiences were rated as having higher satisfaction levels for UX pragmatic quality (median = 6) than those with crash experiences (median = 8).

3.5. ANOVA

The results of a one-way analysis of variance (ANOVA) indicated significant mean differences in perceived anxiety [F (2, 217) = 5.54, p = 0.004], e-bike riding experience [F (2, 217) = 3.54, p = 0.031], DALI [F (2, 217) = 10.39, p = 0.000], visual demand [F (2, 217) = 8.74, p = 0.000], situational stress [F (2, 217) = 5.84, p = 0.003], effort of attention [F (2, 217) = 5.33, p = 0.005], and temporal demand [F (2, 217) = 7.58, p = 0.001] among the different riding speeds. Please refer to Table 6 for details (Scheffe's post hoc test). Fig. 1 shows comparisons of DALI, visual demand, situational stress, effort of attention, and temporal demand for each riding speed. As shown, riders gradually perceived increased mental workloads with increased riding speeds.

3.6. Correlation analysis

The correlation analysis results showed a positive correlation between riding speed, e-bike style, DALI, RSME, and anxiety. By contrast, the factors of e-bike style, DALI, and RSME were all negatively correlated with UX attractiveness, UX pragmatic quality, and UX hedonic quality. Next, anxiety was negatively correlated with UX pragmatic quality and UX hedonic quality, while arousal was positively correlated with both. Finally, there was a positive correlation between

Table 6
Significant differences in perceived anxiety, e-bike riding experience, DALI, visual demand, situational stress, effort of attention, and temporal demand.

Factors	ANOVA		Scheffe		
	F(2, 217)	*p* value	Levels	Mean(SD)	*p* value
Anxiety	5.54	0.004	High	3.03 (2.9)	0.009
			Medium-high	1.97 (1.9)	
Riding experience	3.54	0.031	High	3.34 (3.4)	0.05
			Medium-high	2.42 (1.9)	
DALI	10.39	0.000	High	40.0 (15.4)	0.001
			Medium-high	32.9 (10.8)	
			High	40.0 (15.4)	0.002
			Low	28.8 (8.4)	
Visual demand	8.74	0.000	High	29.2 (25.6)	0.001
			Medium-high	18.8 (14.9)	
			High	29.2 (25.6)	0.009
			Low	14.8 (8.1)	
Situational stress	5.84	0.003	High	30.5 (28.7)	0.006
			Medium-high	19.7 (19.5)	
Effort of attention	5.33	0.005	High	40.0 (27.9)	0.023
			Medium-high	30.2 (22.1)	
			High	40.0 (27.9)	0.032
			Low	24.3 (20.1)	
Temporal demand	7.58	0.001	High	40.1 (31.4)	0.020
			Medium-high	28.8 (26.6)	
			High	40.1 (31.4)	0.002
			Low	16.2 (11.6)	

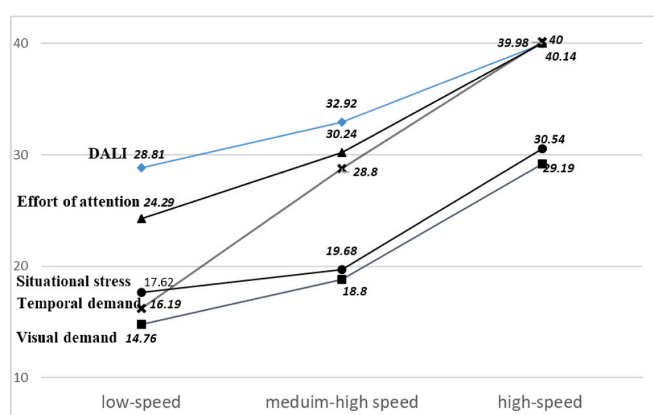

Fig. 1. Comparison of DALI, effort of attention, situational stress, temporal demand, and visual demand according to riding speed.

attractiveness, pragmatic quality, and hedonic quality (see Table 7).

3.7. Ordinal logistic regression analysis

An ordinal logistic regression analysis was conducted to predict traffic crashes (Y_1) using data obtained from the survey. The ordinal logistic regression revealed that the certain criteria were associated with e-bike traffic crashes that occurred for the respondent at the 0.05 level, $\chi^2_3 = 13.61$ ($p < 0.005$), Hosmer−Lemeshow $\chi^2_8 = 8.77$ ($p > 0.05$), Cox−Snell $R^2 = 0.06$, Nagelkerke $R^2 = 0.183$. The R^2 value of the model was very low. Any field that attempts to predict human behavior typically has R^2 values lower than 50%. This is essentially because human behaviors are more difficult to predict than physical processes (Frost, 2013). As such, the researcher can draw important conclusions about how changes in the predictor values are associated with changes in the response value as long as the model has statistically significant predictors, even with low R^2 values. Here, the criteria are listed as follows: UX pragmatic quality (OR = 1.319 [95% CI: 1.038–1.676], $p = 0.023$), speed (OR = 0.244 (0.071–0.838), $p = 0.025$), and gender (OR = 0.254 (0.065–0.998), $p = 0.05$).

3.8. Multiple regression analysis

A multiple regression analysis was conducted to predict e-bike riding speed (Y_2) based on data obtained from the survey ($F (3, 216) = 19.86$, $p < 0.001$, adjusted $R^2 = 0.205$). The variables considered to predict e-bike riding speed included e-bike style ($\beta = 0.33$, $t = 5.30$, $p = 0.000$, VIF = 1.08), DALI ($\beta = 0.179$, $t = 2.85$, $p = 0.005$, VIF = 1.10), and gender ($\beta = -0.19$, $t = -3.11$, $p = 0.002$, VIF = 1.02). All variables significantly contributed to the prediction ($p < 0.05$).

4. Discussion

4.1. Mental workload

This study adopted DALI and RSME measurements to obtain the overall task difficulty perceived by long-term e-bike cyclists. We then found the factors that appeared to cause e-bike crashes based on those that showed statistically significant differences in regard to the cyclist's workload. The total score for multidimensional DALI was 29.32, while the unidimensional RSME was 18.43. This indicates that respondents perceived the e-bike riding task as easy within the traffic environment. Respondents also perceived their capability to exceed the e-bike riding task demand in traffic. In addition, the DALI and RSME showed a moderate positive correlation. DALI and RSME measurements may both provide ways to determine mental workloads during riding tasks. However, the RSME results may only report effort levels related to the e-bike riding task; they may not reveal other statistical findings for further exploration. Compared with RSME, DALI may obtain more abstract aspects of the mental workload for further analysis and discussion. More specifically, gender differences were found in terms of DALI temporal demand (e.g., how many constraints owing to timing demand did you perceive during the e-bike ride?). Male cyclists tended to perceive greater amounts of time pressure than female cyclists. Results also revealed that the DALI and its subscales for visual demand, effort of attention, situational stress, and temporal demand were found to be statistically and significantly different between riding speeds. Cyclists who were accustomed to riding at high speeds tended to believe that riding an e-bike required greater visual activity, thinking, mental workload, and time pressure than those who rode at medium-high and low speeds. Moreover, high-speed cyclists perceived higher discouragement than medium-high speed cyclists. Results also revealed that DALI and speed had a low positive correlation. In other words, high-speed cyclists may believe they need more resources to process information that requires visual demands, effort of attention, situational stress, and temporal demand in order to ride an e-bike to their destination in traffic environments when compared to medium-high and low-speed cyclists. Based on this study's observations and Fuller's (2005) findings on task difficulty, movie-bike cyclists tend to perceive a low degree of mental workload, which may modestly and positively influence their choice and maintenance of a given speed.

4.2. Feeling of risk

Results showed that the average score for anxiety was 2.3, while the arousal level was 8.2. Respondents therefore perceived e-bike riding as both a low-anxiety and highly arousing experience. While the psychological arousal results did not reveal any further statistical significance, anxiety was found to significantly differ based on riding speed. Results specifically revealed that high-speed cyclists tended to perceive higher anxiety than medium-high speed cyclists. Anxiety is a complex emotional reaction or state (Freud, 2013) that varies in intensity and fluctuates over time as a function of intrapsychic stress (psychological stress) or situational stress (physical stress), which positively impinges upon an individual (Spielberger, 1966, 2010). This study's findings were consistent with Spielberger's arguments. In the e-bike riding context, high-speed (physical stress) cyclists may perceive higher anxiety and task difficulty (psychological stress) than medium-high or low-speed cyclists. Moreover, anxiety and DALI were highly and positively correlated, while anxiety and speed showed a low positive correlation. This verified that the influence intensity of the internal factor for psychological anxiety was greater than that of the external factor. In addition, many studies have applied the objective physiological measurement of electrodermal activity during driving to interpret driver anxiety (e.g., Taylor, 1964). The measured level of anxiety refers to a fear state that is coupled with a subjective estimate of the probability of collision. However, this study adopted psychological anxiety measurements. Results showed that cyclists with e-bike crash experiences perceived higher anxiety than those without crash experiences. This indicates that the self-reported measurement of anxiety is a useful tool for showing how e-bike cyclists perceive traffic risks. These data may also be used by researchers to further identify groups that may be at a higher risk of having e-bike traffic crashes.

Table 7
Variable correlations for speed, DALI, perceived pragmatic quality, arousal, and anxiety.

Variables	1	2	3	4	5	6	7	8	9
1. Speed	–								
2. E-bike style	.38**	–							
3. DALI	.29**	.27**	–						
4. RSME	.35**	.25**	.57**	–					
5. Arousal	-.11	-.10	-.10	-.13	–				
6. Anxiety	.21**	.23**	.71**	.49**	-.08	–			
7. Attractiveness	-.09	-.14*	-.18**	-.22**	.12	-.05	–		
8. Pragmatic quality	-.01	-.20**	-.31**	-.32**	.27**	-.25**	.67**	–	
9. Hedonic quality	-.08	-.20**	-.28**	-.31**	.21**	-.23**	.72**	.79**	–

Notes: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

4.3. E-bike traffic crashes

A total of three predictive relationships were supported through the Y_1 model, with UX pragmatic quality, speed, and gender all uniquely contributing to e-bike crashes. This study offers several suggestions based on the factors of UX pragmatic quality and speed.

Regarding UX pragmatic quality, results showed a significant relationship between UX pragmatic quality and e-bike traffic crashes, with a regression coefficient of 1.319. This indicates that pragmatic quality was the strongest predictor, thus suggesting that respondents perceived e-bike utility and usability is the most important factors influencing their traffic crashes. UX is dominated by the subjective aspects of human perception (Wright and McCarthy, 2010; Hassenzahl, 2010). In this study, three different dimensions (attractiveness, pragmatic quality, and hedonic quality) were used to elicit perceptions about long-term interactions with e-bike products in traffic environments. Results clearly showed that the three dimensions were highly and positively intercorrelated. Moreover, cyclists with e-bike crash experiences had lower satisfaction with pragmatic quality than those without crash experiences. Here, pragmatic quality refers to the user's perception of the e-bike product's ability to support the achievement of their goals; that is, reaching a destination. Pragmatic quality refers to the product's utility and usability in relation to potential riding tasks; that is, to facilitate cyclists in reaching their goals. This means it is critical to create a good pragmatic quality experience for e-bike cyclists while they are on the road. Moreover, consumer feedback provides valuable information for improving product designs and marketing strategies (Finch, 1999). E-bike products should therefore be integrated with smartphone application technology in order to provide mobile services for cyclists and professionals, who then provide e-bike maintenance services at repair stations. In this regard, they can provide feedback about any flaws they may find at different e-bike usage stages. E-bike manufacturers can use these suggestions to sustain product improvement measures while providing cyclists with better opportunities to discuss flaws. Users can thus interact with manufacturers to further increase their confidence in the product and brand.

Regarding speed, results showed a significant relationship between speed and e-bike traffic crashes, with a regression coefficient of 0.244. For respondents who had e-bike crash experiences, the highest rate of traffic crashes was found among high-speed cyclists, followed by medium-high speed (18.1%) and low-speed (9.1%) cyclists. Moreover, e-bike riding experience significantly differed according to riding speed. That is, high-speed cyclists tended to have more e-bike riding experience than medium-high speed cyclists. This means that cumulative e-bike riding experience positively affects speed, which is consistent with the World Health Organization (2018) assertion that speed is one of the most important human risk factors during vehicle operation. Indeed, it may directly influence road traffic injuries and deaths. This study therefore investigated the factors influencing speed choices. A total of three of model Y_2's predicted relationships were supported, with e-bike style, DALI, and gender all uniquely contributing uniquely to speed choice. The correlation analysis results also showed that e-bike style was modestly and positively correlated with DALI ($r = 0.266$, $p < 0.001$). Regarding E-bike style, results revealed that the scooter-style e-bike had a 2.1% traffic crash rate, while the modified e-bike had a 42.1% rate. This is because modified e-bikes can travel up to 45 km/h, which is much higher than the legal speed of 25 km/h. Moreover, the traffic crash rate of modified e-bikes was more than 20 times higher than that of e-bikes which were in compliance with regulations. It is illegal to modify e-bikes, which do not undergo professional evaluations and detections to ensure that they still comply with road safety measures. The appearance of the e-bike alone may not indicate whether it has been modified to increase speed. It is therefore highly recommended that e-bike products should be strictly prohibited from modification services. Regarding DALI, cyclists who ride e-bikes at high speeds may perceive higher mental workloads than those who ride at medium-high or low speeds. In addition, male cyclists may perceive higher temporal demands than female cyclists. Results showed that males tended to ride at significantly higher speeds than females. In general, the policies for managing road speeds are focused on the external stages; for example, providing maximum/minimum speed limit signs to remind road users, enforcing speeding laws, and implementing high fines to discourage speeding.

We propose that government agencies should encourage cyclist self-management to achieve proper vehicle speeds. A mobile self-reporting service may be a useful tool for cyclists to use in items of DALI, anxiety, and UXs before riding their e-bikes. The service should provide customized advice to these cyclists based on their inputs. In addition, a smartwatch or portable induction device with a mobile physiological anxiety reporting service may be used to continuously monitor physiological feedback while the wearer rides their e-bike. A sound or vibration alarm can be triggered to alert the user when anxiety levels exceed the caution threshold. These suggested mobile services can help establish the cyclist's internal cognition, thus making them aware of their physical and psychological states while e-bike riding. This will assist in good self-management practices.

4.4. Road safety for e-bike riders

This survey study found cyclists who are accustomed to speeding or have low levels of satisfaction with the e-bike product's pragmatic quality may constitute a high-risk group for e-bike traffic crashes. E-bike product quality is the most important factor for traffic safety. The early stage of product design and development is essential for establishing basic e-bike product quality, thus promoting perceived riding quality among users. E-bike brands and manufacturers should strengthen their product designs to satisfy functional needs and further create good UXs. Important roles are also played by the government agencies that are responsible for determining whether e-bikes comply with legal standards prior to mass production and market launch. For example, this includes the Taiwanese Vehicle Safety Certification Center (VSCC). Speed is another important issue. The Taiwanese government implemented maximum e-bike speeds of 25 km/h to promote road safety. Notably, the chances of survival for an unprotected pedestrian that is struck by a vehicle diminish rapidly at speeds greater than 30 km/h (Wramborg, 2005). In addition, small decrements in speed produce substantial reductions in trauma (OECD, 2008). This study also verified that e-bikes crashes were 20 times more likely at speeds between 25 and 45 km/h than at speeds lower than 25 km/h. However, there are still some road safety issues with the 25 km/h speed limit. In Taiwan, for example, e-bikes and pedestrians share the same lanes. The government has thus established a maximum speed limit of 6 km/h. However, the government does not force scooters to adhere to the 25 km/h speed limit in lanes shared with e-bikes. Scooters are currently a mainstream two-wheeler product with maximum speeds ranging from 70 to 120 km/h. Cyclists who ride their e-bikes on roads that allow cars and scooters may therefore become very vulnerable, especially on roads that allow large trucks.

Furthermore, this survey study showed that 91% of those with e-bike crash experiences were caused by human failures, while 9% were caused by e-bike malfunction. We thus recommended that relevant government agencies invest in road and roadside infrastructure, provide e-bike traffic safety education and training, and engage in appropriate road planning. Regarding education and training, safety ratings should be defined based on the physical/psychological conditions of e-bike cyclists. The education and training contents can then be tailored to individual physical and psychological states in order to promote the learning effects. Regarding planning, it is recommended to plan separate lanes for low-noise and low-speed e-bikes. For example, research conducted in Denmark showed a 35% reduction in cyclist casualties after cycle tracks were constructed alongside urban roads (World Health Organization, 2018). For general roads that allow open e-bike riding, maximum and minimum speeds for all traveling vehicles should be restricted to ensure the safety of all road users. Moreover, e-bike manufacturers should implement visual/auditory functions to help other drivers and road users detect and estimate the speeds of e-bikes.

5. Conclusion

This study conducted a quantitative analysis of experiences reported by e-bike cyclists using subjective rating scales, including mental workload measures, UXs, and feeling of risk. The subjective rating scales were used to investigate psychological factors in the e-bike riding context; that is, the factors that predicted e-bike crashes in traffic environments. Results showed the usefulness of subjective measurements and objective measurements for increasing our understanding of the factors contributing to e-bike traffic crashes. More specifically, this study found that UX pragmatic quality was the strongest subjective index in regard to e-bike traffic crashes, while speed was an important objective index. This study also provided evidence that the DALI index positively influences e-bike riding speed. Taken together, these results led to several recommendations for increasing the perspectives held by cyclists, e-bike manufacturers, related government agencies, and app software system developers. These findings and suggestions should help promote traffic safety among e-bike users.

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.

References

Bai, L., Liu, P., Chen, Y., Zhang, X., Wang, W., 2013. Comparative analysis of the safety effects of electric bikes at signalized intersections. Transport. Res. Transport Environ. 20, 48–54. https://doi.org/10.1016/j.trd.2013.02.001.

Chaloupka-Risser, C., Risser, R., 2011. Verkehrspsychologie. Grundlagen und Anwendungen.

Cherry, C., Yang, H., Jones, L.R., He, M., 2016. Dynamics of electric bike ownership and use in Kunming, China. Transport Pol. 45, 127–135. https://doi.org/10.1016/j.tranpol.2015.09.007.

Cherry, C.R., Weinert, J.X., Xinmiao, Y., 2009. Comparative environmental impacts of electric bikes in China. Transport. Res. Transport Environ. 14 (5), 281–290. https://doi.org/10.1016/j.trd.2008.11.003.

Ferrara, S.D., 1987. Alcohol, drugs and traffic safety. Br. J. addict. 82 (8), 871–883. https://doi.org/10.1111/j.1360-0443.1987.tb03907.x.

Finch, B.J., 1999. Internet discussions as a source for consumer product customer involvement and quality information: an exploratory study. J. Oper. Manag. 17 (5), 535–556. https://doi.org/10.1016/S0272-6963(99)00005-4.

Freud, S., 2013. The Problem of Anxiety. Read Books Ltd.

Frost, S., 2013. Museums and sexuality. Mus. Int. 65 (1–4), 16–25. https://doi.org/10.1111/muse.12029.

Fuller, R., 2005. Towards a general theory of driver behaviour. Accid. Anal. Prev. 37 (3), 461–472. https://doi.org/10.1016/j.aap.2004.11.003.

Fyhri, A., Fearnley, N., 2015. Effects of e-bikes on bicycle use and mode share. Transport. Res. Transport Environ. 36, 45–52. https://doi.org/10.1016/j.trd.2015.02.005.

Hart, S.G., Staveland, L.E., 1988. Development of NASA-TLX (task Load index): results of empirical and theoretical research. Adv. Psychol. 52, 139–183. North-Holland.

Hassenzahl, M., 2010. Experience design: technology for all the right reasons. Synth. Lect. Human-Cent. Inf. 3 (1), 1–95.

Hill, S.G., Iavecchia, H.P., Byers, J.C., Bittner Jr., A.C., Zaklade, A.L., Christ, R.E., 1992. Comparison of four subjective workload rating scales. Hum. Factors 34 (4), 429–439.

Horne, J., Reyner, L., 2001. Sleep-related vehicle accidents: some guides for road safety policies. Transport. Res. F Traffic Psychol. Behav. 4 (1), 63–74.

Hurford, M.. How to Ride an E-Bike Safely – electric bikes are seriously fun as long as you don't get seriously injured. Bicycling, last. https://www.bicycling.com/culture/g20085571/ride-electric-bike-safely/. (Accessed 24 December 2020).

Johns, M.W., 2000. A sleep physiologist's view of the drowsy driver. Transport. Res. F Traffic Psychol. Behav. 3 (4), 241–249. https://doi.org/10.1016/S1369-8478(01)00008-0.

Lewin, I., 1982. Driver training: a perceptual-motor skill approach. Ergonomics 25 (10), 917–924. https://doi.org/10.1080/00140138208925051.

Meijman, T.F., O'Hanlon, J.F., 1984. Workload. An introduction to psychological theories and measurement methods. Handb. work Organiz. Psychol. 1, 257–288.

Meshkati, N., Hancock, P.A., Rahimi, M., Dawes, S.M., 1995. Techniques in Mental Workload Assessment.

Organisation for Economic Co-operation and Development (OECD), 2008. Towards Zero: Ambitious Road Safety Targets and the Safe System Approach. Organisation for Economic Co-operation and Development.

Pauzié, A., Marin-Lamellet, C., 1989. September. Analysis of aging drivers' behaviors navigating with in-vehicle visual display systems. In: Conference Record of Papers Presented at the First Vehicle Navigation and Information Systems Conference. IEEE, pp. 61–67. https://doi.org/10.1109/VNIS.1989.98741. VNIS'89).

Popovich, N., Gordon, E., Shao, Z., Xing, Y., Wang, Y., Handy, S., 2014. Experiences of electric bicycle users in the Sacramento, California area. Travel Behav. Soc. 1 (2), 37–44. https://doi.org/10.1016/j.tbs.2013.10.006.

Rose, G., 2012. E-bikes and urban transportation: emerging issues and unresolved questions. Transportation 39 (1), 81–96. https://doi.org/10.1007/s11116-011-9328-y.

Spielberger, C.D., 1966. Theory and research on anxiety. Anxiety Behav. 1 (3).

Spielberger, C.D., 2010. State-Trait anxiety inventory. Corsini Encycl. Psychol. https://doi.org/10.1002/9780470479216.corpsy0943, 1–1.

Stutts, J.C., Wilkins, J.W., Osberg, J.S., Vaughn, B.V., 2003. Driver risk factors for sleep-related crashes. Accid. Anal. Prev. 35 (3), 321–331. https://doi.org/10.1016/S0001-4575(02)00007-6.

Taylor, D.H., 1964. Drivers' galvanic skin response and the risk of accident. Ergonomics 7 (4), 439–451. https://doi.org/10.1080/00140136408930761.

Treat, J.R., Tumbas, N.S., McDonald, S.T., Shinar, D., Hume, R.D., Mayer, R.E., Castellan, N.J., 1979. Tri-level Study of the Causes of Traffic Accidents: Final Report. Executive Summary. Indiana University. Institute for Research in Public Safety, Bloomington. http://hdl.handle.net/2027.42/64993.

Vlakveld, W.P., Twisk, D., Christoph, M., Boele, M., Sikkema, R., Remy, R., Schwab, A.L., 2015. Speed choice and mental workload of elderly cyclists on e-bikes in simple and complex traffic situations: a field experiment. Accid. Anal. Prev. 74, 97–106. https://doi.org/10.1016/j.aap.2014.10.018.

Weinert, J., Ma, C., Cherry, C., 2007. The transition to electric bikes in China: history and key reasons for rapid growth. Transportation 34 (3), 301–318. https://doi.org/10.1007/s11116-007-9118-8.

Wickens, C.D., Hollands, J.G., Banbury, S., Parasuraman, R., 2015. Engineering Psychology and Human Performance. Psychology Press.

Wilde, G.J., 2001. Target Risk 2: a New Psychology of Safety and Health: what Works? what Doesn't? and Why–. Pde Publications, Toronto.

World Health Organization, 2015. Global Status Report on Road Safety 2015. World Health Organization.

World Health Organization, 2018. Global Status Report on Road Safety 2018. World Health Organization. Summary (No. WHO/NMH/NVI/18.20).

Wramborg, P., 2005. A new approach to a safe and sustainable road structure and street design for urban areas. In: Proceedings of the Road Safety on Four Continents Conference, 13. Conference Sponsor, 12p–12p.

Wright, P., McCarthy, J., 2010. Experience-centered design: designers, users, and communities in dialogue. Synth. Lect. Hum. Centered Inf. 3 (1), 1–123. https://doi.org/10.2200/S00229ED1V01Y201003HCI009.

Wu, C., Yao, L., Zhang, K., 2012. The red-light running behavior of electric bike riders and cyclists at urban intersections in China: an observational study. Accid. Anal. Prev. 49, 186–192. https://doi.org/10.1016/j.aap.2011.06.001.

Zijlstra, F.R.H., 1995. Efficiency in Work Behaviour: A Design Approach for Modern Tools.

Zijlstra, F.R.H., Van Doorn, L., 1985. The Construction of a Scale to Measure Perceived Effort. University of Technology.

Fei-Hui Huang is an Associate Professor of the Department of Marketing & Distribution Management at Asia Eastern University of Science and Technology (since 2007). She received his Ph.D. in Industrial Engineering and Engineering Management from the Tsing Hua University in 2006. Her research interests include user experience (UX), human-system interaction (HSI), user interface (UI), and mental workload.