Accident Analysis and Prevention 49 (2012) 186–192

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

The red-light running behavior of electric bike riders and cyclists at urban intersections in China: An observational study

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ARTICLE INFO

Article history:
Received 31 July 2010
Received in revised form 18 May 2011
Accepted 1 June 2011

Keywords:
Electric bike
E-bike
Bicycle
Two-wheeler
Red-light running
China

ABSTRACT

Electric bikes and regular bicycles play an important role in the urban transportation system of China. Red-light running is a type of highly dangerous behavior of two-wheeled riders. The main purpose of this study was to investigate the rate, associated factors, and behavior characteristics of two-wheelers' red-light running in China. A field observational study was conducted using two synchronized video cameras at three signalized intersections in Beijing. A total of 451 two-wheelers facing a red light (222 e-bike riders and 229 cyclists) were observed and analyzed. The results showed that 56% of the two-wheelers crossed the intersection against a red light. Age was found to be a significant variable for predicting red-light runners, with the young and middle-aged riders being more likely than the old ones to run against a red light. The logistic regression analysis also indicated that the probability of a rider running a red light was higher when she or he was alone, when there were fewer riders waiting, and when there were riders already crossing on red. Further analysis of crossing behavior revealed that the majority of red-light running occurred in the early and late stages of a red-light cycle. Two-wheelers' crossing behavior was categorized into three distinct types: law-obeying (44%), risk-taking (31%) and opportunistic (25%). Males were more likely to act in a risk-taking manner than females, and so were the young and middle-aged riders than the old ones. These findings provide valuable insights in understanding two-wheelers' red-light running behaviors, and their implications in improving road safety were discussed.

1. Introduction

Two-wheeled traffic (i.e., mainly regular bicycles and electric bikes[2]) plays an important role in urban transportation in China. The bicycle is the dominant two-wheeled vehicle and its total number was estimated to exceed 450 million nationally in 2004. According to a study in 2007, bicycles were used for more than 50% of trips in many large cities in China (Zhou et al., 2007). Meanwhile, the electric bike (e-bike, see Fig. 1) has emerged as a popular mode of transportation in many large cities during recent years (Weinert et al., 2007). Its use has experienced a tremendous growth. The estimated total number of e-bikes was over 120 million in 2010 (Xinhua news, 2010). As traffic congestion and air pollution are becoming growing problems in China, government agencies are showing an increasing interest in promoting two-wheeled traffic (e.g., China Daily, 2006; Government of Beijing, 2009).[3]

However, the growing popularity of two-wheeled traffic also entails safety concerns as observed in accident statistics. In 2004, 13,655 regular bicycle riders were killed and 54,286 were seriously injured in road accidents, representing 12.8% of all traffic fatalities and 11.3% of injuries (CRTASR, 2004). Traffic safety for e-bike riders is considered an even more severe problem as the number of fatalities and injuries has skyrocketed over the past few years. In 2004, 589 e-bikers were killed and 5295 were seriously injured. The corresponding figures increased to 2469 and 16,468, respectively, in 2007 (CRTASR, 2004, 2007).

Accident analysis reveals that over 60% of fatal crashes involving two-wheelers result from violation of traffic rules (CRTASR, 2004). One typical type of rule violation behavior is red-light run-

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[2] Motorcycles, another type of two-wheeled vehicles widely used in China, are banned or under strict restrictions from urban areas in most big Chinese cities (e.g., Beijing, Shanghai, Guangzhou, etc.) and thus are not included in this study.

[3] E-bikes are powered by rechargeable battery and are subjected to the national standards (General Technical Standards of E-Bike, 1999), which mainly include: (1) top speed ≤20 km/h, (2) maximum weight ≤40 kg, and (3) maximum power ≤240 W. The traffic law in China classifies e-bikes as non-motor vehicles (like regular bicycles), licenses and helmets are not required and e-bikes are operated in bicycle lanes (China Central Government, 2004).

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doi:10.1016/j.aap.2011.06.001

Fig. 1. A typical e-bike in China.

ning. Because of the poor law enforcement and peoples' low safety awareness, red-light running is rather prevalent and represents a substantial safety problem in Chinese urban intersections. For example, the traffic police department in Hangzhou (the capital city of Zhejiang province) ranked red-light running as one of the top four reasons for traffic accidents involving two-wheeled riders (City News in Hangzhou, 2010). Red-light running was reported to be responsible for 76.9% of accidents leading to injury or fatality among e-bike riders in Haikou (A city in Hainan province) (Nanguo City Newspaper, 2008). Red-light running behavior of two-wheelers is also perceived by vehicle drivers as irresponsible and dangerous (Basford et al., 2002; O'Brien et al., 2002). Therefore, research on two-wheeler's red-light running behavior will shed light on the safety problems.

Unfortunately, only a few studies have investigated the red-light running behavior of two-wheeled riders. Johnson et al. (2011) observed 4225 cyclists' crossing behaviors when facing a red light, and found that the main predictive factor for infringement was the direction of travel, the presence of other cyclists and vehicles, and the volume of cross traffic. Previous research on drivers and pedestrians also points to several variables of interest regarding red-light running behaviors. Individual characteristics, such as gender and age, are found to be effective in predicting both driver and pedestrian's decisions to cross against a red light or not. Studies for vehicle drivers in the United States (Porter and Berry, 2001) and pedestrians in Israel (Rosenbloom, 2009) have found that males violate the traffic light more frequently than females, and younger road users violate the traffic light more frequently than the older ones. In addition, situational factors, such as the presence of other road users, group size, and traffic volume are found to have an effect on self-reported or field-observed road crossing decisions too. Rosenbloom (2009) examined pedestrians crossing behaviors as both individuals and members of a group and found that pedestrian's tendency to cross on red was greater when there were fewer people waiting, and when there had been an occurrence of another pedestrian crossing against the red light.

Besides focusing on factors that are associated with red-light running decisions, several studies have also investigated the behavior characteristics when crossing on red. Johnson et al. (2008) identified three distinct types of red-light running cyclists that are exposed to different levels of risk: racers, impatients, and runners. Yang et al. (2006) classified pedestrians into law-obeying ones and opportunistic ones according to their behavior differences when facing a red light and the classification helped build a micro-simulation model of pedestrian crossing behaviors.

To the best of our knowledge, few studies have ever focused on red-light running behavior of two-wheelers in China or other developing countries. The red-light running is often reported as highly dangerous (e.g., City News in Hangzhou, 2010; Nanguo City Newspaper, 2008), but we are not exactly sure who the red-light runners are, what factors affect their red-light running decisions, and what the behavior characteristics are. Answers to these questions will definitely help us improve road safety of two-wheelers.

In addition, two-wheeled traffic in most Chinese cities is comprised of a high volume of e-bikes and regular bicycles. According to traffic laws in China, both e-bikes and regular bicycles are operated in the same lanes and are subjected to the same traffic rules. However, most e-bikes on the road exceed the performance limits of the national standard and travel much faster than regular bicycles (Weinert et al., 2007). As a result, e-bikes are often perceived as more dangerous and raise more safety concerns. So it is of interest to know if there are any differences on red-light running behaviors between e-bike riders and cyclists.

Accordingly, the aim of this study is to investigate the rate, associated factors and behavior characteristics of both e-bike rider and bicycle riders' red-light running behaviors in China. The findings will imply some effective countermeasures for improving the road safety of urban intersections in China as well as other developing countries.

2. Methods

The field observation approach was used in this study. It has been widely used to study road user behaviors in actual traffic situations (Tiwari et al., 2007; Johnson et al., 2011; Phillips et al., 2011). For example, Tiwari et al. (2007) used a video camera to examine pedestrians' crossing behavior in signaled intersections in Delhi, India. Johnson et al. (2011) used video recordings to analyze urban commuter cyclists' red-light running behaviors in Melbourne, Australia. The field observation approach was also used by researchers studying the influence of cycle paths on accident numbers (Phillips et al., 2011).

2.1. Site characteristics

A cross-sectional observational study was conducted at three four-armed signalized intersections in Beijing.[4] Two criteria were used to select the observational sites. First, the selected sites should represent the typical intersection design characteristics and traffic conditions of urban areas in Beijing. Second, there have to be a reasonably high number of two-wheeled traffic (both electric bikes and regular bicycles) during the observation period for the data extraction effort to be efficient. Table 1 summarized the key operational and geometrical design characteristics of the three observed sites.

2.2. Video data collection

Two synchronized video cameras (Sony HDR-X100E) were used to collect data of two-wheeled riders' crossing behaviors. One was positioned on a tripod next to the roadway where the entire length of the leg of interest could be viewed and recorded (Camera A, see Fig. 2). The other camera gathered footage in the opposite direc-

[4] Beijing, the capital city of China, has a population of over 17 million in 2010 and over 4 million registered motor vehicles (Beijing Municipal Bureau of Statistics, 2009). The estimated numbers of bicycles and e-bikes are about 10 million and over 0.7 million, respectively.

Table 1
Summary of the intersections observed.

Observed direction[a]	Site *Y–Y* Yuanda Rd.–Yuanda Middle Rd. East–West	Site *Z–X* Zhongguancun S St.–Xueyuan South Rd. North–South	Site *X–Z* Xueyuan Rd.–Zhixin Rd. North–South
Traffic volume per hour (off-peak hour)[b]			
Motor vehicle	740	800	2800
Non-motorized vehicle[c]	240	300	850
Intersection characteristic			
Motor vehicle lanes	6 (N–S), 8 (W–E)	10 (N–S), 6 (W–E)	10 (N–S), 8 (W–E)
Crossing distance (m)	37.0	27.0	48.0
Other	No physical barriers between motor and non-motorized vehicle lane	No dedicated non-motorized vehicle lane, but shared with the motor vehicles; With Subway exit nearby	Physical barriers between motor and non-motorized vehicle lane; On-street parking lot; Supermarket nearby, thus relatively high volume of pedestrian flow
Signal phase (s)[d]			
	33.5	67.9	57.0
	4.1	4.0	3.9
	47.3	68.0	85.1

[a] Only one direction was observed at each intersection and it was selected based on the ease of video collection.
[b] Volume data are tentative. They were obtained by averaging the results of three 10-min sampling processes.
[c] Non-motorized vehicles includ e-bikes, bicycles, and tricycles.
[d] Signal phase for non-motorized traffic in the observed direction.

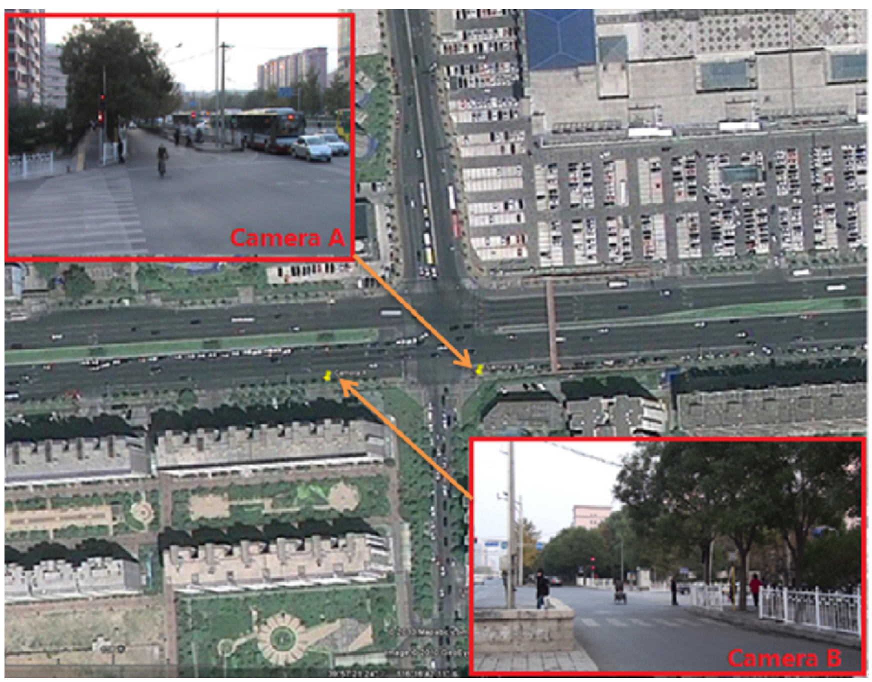

Fig. 2. The bird's eye view and two photos of camera view of site *Z–X*.

tion to film the rider's whole crossing process. The cameras were carefully placed so that the road users were unaware that they were being observed. The data collection was conducted on weekdays during daylight hours (i.e., 8:00 a.m. to 5:00 p.m.).[5] Scheduling of the observation was performed to avoid data collection in bad weather conditions (such as rain and extreme temperatures).

2.3. Videotape coding

All road users who entered the intersection were recorded on video, but only the riders (both e-bike riders and cyclists) arriving during red light phases were coded. We also restricted the coding process to include only riders traveling through the intersection. Left-turners were excluded because of the limited field of view of the cameras, while riders making right turns were also ignored because they are not subjected to the traffic signal control according to the road rules in China.

The following sets of variables were coded (see Table 2). The first set of variables described the riders' individual characteristics, including gender, estimated age group, and vehicle type. The second set of variables focused on the riders' movement information, including the times of arrival at and departure from the stop line, the time when crossing is completed, and the status of the traffic light at each of these times. The last set of variables of concern were situational factors, including cross traffic volume, group size, number of riders waiting upon arrival, and number of riders crossing against the red light.

In order to avoid potential coding bias, 1 h of video recordings (including 75 valid observations) were coded by two independent

[5] Peak hours (e.g., 7:00–8:00 a.m. and 5:00–6:00 p.m.) were not included because there would be traffic wardens that are dedicated to organize and maintain the order of two-wheeled traffic during that time.

Table 2
Definitions of variables coded.

Variables	Descriptions
Demographic information	
Gender	Male, female
Age group	Estimated age group: young (<30), middle-aged (30–50), old (>50)
Type	Electric bike, regular bicycle
Movement information	
Event time	Time stamp of arrival at and departure from the stop line, and the time when crossing is completed
Traffic light status	Traffic light status when the events mentioned above occur
Crossing behavior type	The two-wheeler's crossing behavior is categorized into three different types: law-obeying, risk-taking, and opportunistic (see Section 2.4.2 for details)
Situational factors	
Cross traffic volume	Cross traffic volume is defined as the number of motor vehicles that crossed the intersection from either direction during the time of the red light cycle when the two-wheeled rider arrives
Group size	Rider group size when approaching the intersection. Those riding side-by-side or within a distance of approximately two times the length of the two-wheeled vehicle are considered as belonging to the same group
No. of riders waiting upon arrival	The number of other riders that are waiting for a green light when arrives
No. of riders crossing upon arrival	The number of other riders that are crossing against the red light when arrives

research assistants. Cohen's kappa (for categorical variables) and one-way intraclass correlations (for continuous variables) were calculated as the coding reliability estimates. All the coefficients ranged from 0.85 to 0.99, indicating that the coding process was reliable.

2.4. Data analysis

2.4.1. Logistic regression analysis of red-light running

The outcome measure for the first part of data analysis was red-light compliance (yes/no). Non-compliance (red-light running) was defined as riding across the stop line when the traffic light is red.

To analyze the factors that are associated with red-light running behavior, a logistic regression analysis was conducted. The model included all variables simultaneously in order to determine the relationship between each predictor variable and the outcome measure (red-light running: yes = 1, no = 0), along with the statistical significance of the measured associations. Since all factors were included in the model simultaneously, each is automatically adjusted for confounding effects of the other predictor variables in the model.

Three groups of predictor variables were included: individual characteristics, situational factors, and control variables. Individual characteristics of two-wheeled riders were age, gender and rider type. Situational factors included group size, the number of riders waiting at the stop line after arriving, and the number of riders crossing against the red light. The Intersection site (represented as two dummy-coded variables) and cross traffic volume (categorized as low: <15/min, medium: 15–30/min, and high: >30/min) were also included in the model as control variables.

Another two models were constructed separately for e-bike riders and cyclists to understand the difference between the two groups. Models with selected interactions were also constructed.

Table 3
Red-light running rates by each subcategory.

	Rider type		Overall
	E-bike riders	Cyclists	
Gender			
Male	63% (114/181)	53% (78/146)	59% (192/327)
Female	59% (24/41)	43% (36/83)	48% (60/124)
Age group			
Young (<30)	68% (46/68)	46% (35/76)	56% (81/144)
Middle-aged (30–50)	62% (89/144)	58% (74/128)	60% (163/272)
Old (>50)	30% (3/10)	20% (5/25)	23% (8/35)
Overall	62% (138/222)	50% (114/229)	56% (252/451)

2.4.2. Crossing behavior characteristics

Besides the red-light running decisions, it is also of importance to know the behavior characteristics of those crossing against red lights, e.g., to know when they will cross and how they behave when crossing. Therefore, in the second part of the analysis, an in-depth investigation of crossing behavior was conducted.

Two-wheeled riders' behavior during the whole crossing process was carefully examined and categorized into three different types: law-obeying, risk-taking, and opportunistic (see also Johnson et al., 2008; Yang et al., 2006). If a two-wheeler stops at the intersection and waits until the red light turns green, he or she belongs to the law-obeying group; if he or she stops at intersection but does not wait until the light turns green, then that two-wheeler is an opportunistic one; if a two-wheeler never stops at an intersection when the light is red, she or he is classified as a risk-taking one. To examine if there are any sub-groups that will behave differently, a cross-tabulation analysis was conducted between behavior type and other individual variables (rider type, gender, and age group).

The time distribution characteristics of red-light violations were also examined. The number of red-light running violations were recorded and plotted along with the onset time of red light signal. Since each site has different red light durations, each red light cycle was divided into 10 equal time periods and the frequencies of red-light runners in each time period (from t_i to $t_i + 1$, e.g., from t_1 to t_2 $t_i - t_i + 1$) were calculated.

3. Results

A total of 7 h of video recordings (approximately 4 h for site *Y–Y* and 1.5 h for site *Z–X* and site *X–Z* respectively) were collected and 1124 crossing events were observed. Demographics and behavioral data were coded only for those arriving during the red light phases. Thus, a total of 451 (40%) valid observations were obtained (see Table 3).

3.1. Red-light running rates

3.1.1. Descriptive statistics

The proportions of red-light runners in each sub-group were presented in Table 3. The overall proportion of riders who cross against red lights was 55.9% and varied across sites from 46% to 61%. A higher proportion of red-light runners were observed for e-bike riders than cyclists (62% vs. 50%). In addition, male riders were found to be more likely to cross against a red light than females (59% vs. 48%). Red-light violation rates also differed by age group as a larger part of young and middle-aged riders failed to wait for a green light than the old ones (56% and 60% vs. 23%).

3.1.2. Logistic regression analysis

Table 4 shows the estimated parameters of the logistic model in predicting red-light running behavior. The overall predictive percentage of the model was 70.8%, sensitivity was 80.3% and specificity was 58.6%.

Table 4
Logistic regression values of the predicting variables.

	Adjust. OR[a]	Adj. 95% CI[b] for OR	Wald χ^2
Rider type			
E-bike riders vs. Cyclists	1.524	0.960–2.418	3.191$^{\#}$
Gender			
Male vs. female	1.447	0.870–2.408	2.025
Age group			
Young vs. old	7.634	2.544–22.910	13.14***
Middle-aged vs. old	7.917	2.741–22.864	14.621***
Group size	0.573	0.414–0.793	11.274**
No. of riders waiting upon arrival	0.724	0.583–0.899	8.610**
No. of riders crossing against traffic light	2.410	1.665–3.488	21.760***
Intersection site			
Y–Y vs. *X–Z*	0.648	0.455–1.632	0.208
Z–X vs. *X–Z*	0.690	0.361–1.960	0.160
Cross traffic volume			
Low vs. high	3.648	1.802–7.803	12.942***
Median vs. high	1.947	1.009–3.758	3.850*

$^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$, $.05 < ^{\#}p < .10$ and otherwise $p \geq .10$.
[a] Adjust ORs (odds ratio) predicted red-light running.
[b] Confidence interval.

Age group was found to be a significant variable for predicting red-light runners. The young and middle-aged riders were 7.63 and 7.92 times more likely to run against a red light than the old ones. However, the results failed to support gender and rider type as significant variables for predicting red-light runners after all of other variables were statistically controlled.

In addition, the results also showed that all of the situational factors (group size, the number of riders waiting for green light, and number of riders crossing against the red light) had a significant influence on red-light running behaviors (p's < .01) even after the cross traffic volume and other factors were statistically controlled. The odds ratios showed that the smaller the group size, the less people waiting at the stop line, and the more other riders crossing against the red light, the more likely a rider would run a red light.

In order to investigate the interactions between rider type and other predicting variables, two separate logistic regression models were constructed for e-bikes riders and cyclists, respectively. The results were the same with those presented above. Additional models were constructed to analyze interactions between all combination of gender, age, and other factors. None of the interactions tested was statistically significant.

3.2. Crossing behavior characteristics

3.2.1. Types of crossing behavior on red light

A close examination of crossing behavior showed that two-wheeled riders facing a red light would behave in three distinct ways. The first type was the law-obeying ones. These riders would cross the intersections without violating the traffic light. The second type, the risk-taking ones, would ignore the red light and ride through the intersection without stopping. The third group, the opportunistic ones, would initially wait at the stop line for the signal to change to green, but after waiting for a certain period of time, they become impatient and start to look for gaps in the cross traffic stream for opportunities to cross.

Table 5
Percentages of different types of crossing behaviors.

	Law-obeying	Risk-taking	Opportunistic
E-bike riders (n = 222)	37%	35%	28%
Cyclists (n = 229)	49%	28%	23%
Male (n = 327)	41%	35%	24%
Female (n = 124)	49%	22%	29%
Young (n = 144)	44%	33%	24%
Middle-aged (n = 272)	39%	34%	27%
Old (n = 35)	77%	1%	22%
Overall (n = 451)	44%	31%	25%

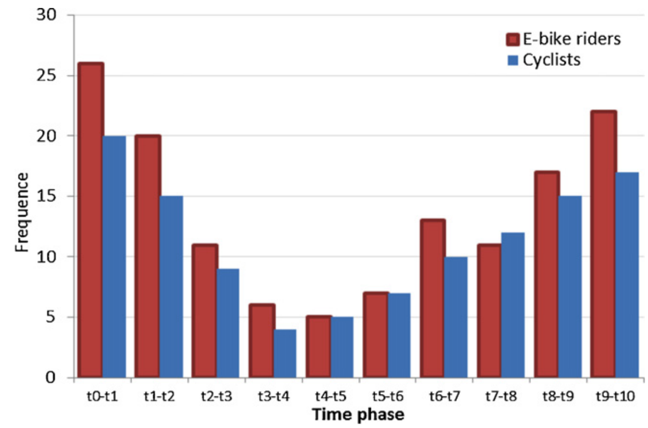

Fig. 3. Time distribution of red-light running behavior. Since each site has different red light durations, a red light cycle was divided into 10 equal time periods and the frequencies of red-light runners in each time period (from t_i to t_{i+1}, e.g., from t_1 to t_2, i.e., $t_1 - t_2$ $t_i - t_i + 1$) were calculated.

The percentages of these different types of crossing behaviors were cross-tabulated with individual variables (rider type, gender, and age group), and are presented in Table 5. The chi-square tests showed that males were more likely to behave in a risk-taking manner than females, and so were the young and middle-aged riders than the older ones (p's < .05).

3.3. Time distribution of red-light running

The time distribution of red-light running behaviors showed a similar pattern for e-bike riders and cyclists (Fig. 3). The majority of red-light running (69% for e-bike riders and 70% for cyclists) occurred during the early and late stages (e.g., time $t_0 - t_2$ and $t_7 - t_{10}$) of a red-light cycle.

4. Discussion

This study examined the rate, associated risk factors, and behavior characteristics of two-wheeled riders' red-light running behaviors in China. A total of 451 two-wheelers were observed (222 e-bike riders and 229 cyclists). Over all, more than half (56%) of the two-wheelers crossed the intersection against a red light. The results identified several significant predictors for red-light running behaviors.

Age was found to be significantly associated with red-light running. A lower proportion of older riders ran against the red lights than that of the younger groups. This is in line with the general fact that older road users act more cautiously than younger ones as showed by other studies (Bernhoft and Carstensen, 2008; Porter and Berry, 2001). The fear of getting involved in an accident and respect for laws may be part of the reasons for the more careful behavior for older riders (Bernhoft and Carstensen, 2008).

The results of present study also indicated that situational factors, e.g., the presence of other two-wheelers (group size) and how they act (waiting for a green light or crossing against the red light), would influence a two-wheeler's crossing decision. After the other variables including cross traffic volume were statistically controlled, the logistic regression analysis showed that a two-wheeler was most likely to run a red light when she or he was alone, when there was no one waiting, and when there was presence of other riders crossing on red. Such kinds of possible social influence on road-crossing behavior are also reported in other studies (e.g., Rosenbloom, 2009; Yagil, 2000). Rosenbloom (2009) argued that, when being in groups, people would feel more committed to social norms and were less likely to break the laws (e.g., running a red light), while for those riding alone, they were less concerned with the social criticism and violate the law more easily. The conformity tendency on traffic light violation may be well explained by the psychosocial phenomenon known as diffusion of responsibility (Latane and Nida, 1981), according to which, people would feel less responsible for violate the social norms (e.g., traffic law) if she or he was just following another one's behavior. However, it is worth to note that even though cross traffic volume was included as a control variable in the logistic regression model, it is still possible that the current results may just reflect an influence of traffic conditions at intersections. For example, it may not be conformity that makes a two-wheeler infringe a red light following other red-light runners, but just because there is no cross traffic or the gap in the cross traffic is large enough for a safe crossing at that moment. Thus, further investigation of crossing decisions is needed to better understand the influence of other road users' behavior on red-light infringement.

The rider type (e-bike riders vs. cyclists) failed to predict red-light running decisions after the effects of other variables were statistically controlled. This may be due to several reasons. First, though having great differences in physical performance, both e-bikes and regular bicycles are classified as non-motor vehicles according to the traffic law in China: they are operated in the same lane and are subjected to the same traffic rules. Thus, they may influence each other in the mixed traffic and show similar behaviors as a result. Second, red-light running is very common and the runners rarely receive traffic tickets or other penalties from traffic police officers in China. Many people (both e-bike riders and cyclists) would consider it as normal but not risky behavior. Third, it is also possible, however, that the lack of significant difference between e-bike riders and cyclists may be related to the relatively small number of observations in the current study.

When the crossing behavior was examined, it was found that the majority of red-light running occurred in the early and late stages of a red-light cycle. The high number of red-light infringements in the first few seconds may result from the fact that many riders would accelerated to pass the intersection when the traffic signal changes from yellow to red. The high numbers of latter infringements are probably caused by those aggressive riders who attempt to cut in between gaps of vehicle traffic. Once successfully cutting in, vehicles are forced to yield and other riders would join the violation.

Two-wheeled riders' crossing behaviors were also categorized into three distinct types (law-obeying, risk-taking, and opportunistic), a higher proportion of males than females, and also higher proportion of young and middle aged riders than the old ones, was found to behave in a risk-taking manner. This group of riders crossed the intersection without stopping or slowing down and may expose themselves at high risk for leaving less time to take necessary maneuvers to avoid accidents.

The current findings might be useful in proposing several practical countermeasures to improve traffic safety. First, the high rate of red-light runners among two-wheelers suggests the need for an increase in penalties and stricter enforcement for red-light running behaviors. A license system might be imposed to enhance the enforcement and promote two-wheelers' responsibility for road safety. Second, safety education and other intervention programs may use the positive influences of groups to promote law-obeying behavior since our study found that other road users' behavior may influence riders' red-light infringement. Third, the current findings as regarding the time distribution characteristic of red-light running and the classification of different types of crossing behaviors can also be used to simulate two-wheelers' crossing behavior in training drivers (especially new drivers) via virtue driving simulators, and to build computational behavior models of two-wheelers in mixed traffic situations (Wu and Liu, 2007; Wu et al., 2008).

There are several limitations in the present study which should be addressed in future work. First, the field observation approach used in this study does not allow for an exploration of the underlying mechanism involved in red-light running. Future studies using questionnaire surveys or lab-based experiments are needed to better understanding why the red-light running behavior happens. Second, it is not quite clear based on the current study what the consequences of red-light running will be. An observational sample size of 451 does not cover enough number of conflicts between two-wheelers and other roaders to draw safety related conclusions. An increased sample size may capture more number of conflicts to evaluate the consequences of red-light running behaviors. Third, the observation was conducted in three intersections during good weather conditions and during off-peak hours. It is unknown how well the findings can be generalized to other samples, thus, video recordings from more sites and under a wider variety of time intervals and weather conditions are needed for further analysis.

5. Conclusions

This study examined the rate, associated risk factors, and behavior characteristics of two-wheeled riders' red-light running behaviors in China. A total of 451 two-wheelers (222 e-bike riders and 229 cyclists) facing a red light were observed. The results showed that more than half (56%) of the two-wheelers crossed intersections against a red light. Age was found to be a significant variable for predicting red-light runners, with the young and middle-aged riders being more likely than the older ones to run against a red light. The logistic regression analysis also indicated that the probability of a rider running a red light was higher when she or he was alone, when there were fewer riders waiting, and when there were riders already crossing on red. Further analysis of crossing behavior revealed that the majority of red-light running occurred during the early and late stages of a red-light cycle. Two-wheelers' crossing behavior was categorized into three distinct types: law-obeying (44%), risk-taking (31%) and opportunistic (25%). Males were more likely to act in a risk-taking manner than females, and so were the young and middle-aged riders than the old ones.

These findings enhance our understanding of two-wheelers' red-light running behavior and may help policy makers and traffic managers develop effective education and intervention programs to reduce the frequency of this dangerous behavior. However, more studies are needed to learn why two-wheeled riders run against the red lights and how other road users (e.g., pedestrians and vehicle drivers) perceive and interact with these red-light runners.

Acknowledgements

We appreciate the support of this work from NSF and Chinese Academy of Sciences. We also appreciate the two anonymous reviewers for their valuable suggestions in improving this work and the great help of Mr. Maximillian Brzozowski at SUNY in editing the manuscript.

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