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The effects of sunshields on red light running behavior of cyclists and electric bike riders

Yiqi Zhang, Changxu Wu*

State University of New York at Buffalo, United States

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ABSTRACT

Bicycles held an important position in transportation of China and other developing countries. As accidents rate involving electronic and regular bicycles is increasing, the severity of the bicycle safety problem should be paid more attention to. The current research explored the effect of sunshields (a kind of affordable traffic facility built on stop line of non-motor vehicle lanes (According to National Standard in China, e-bikes share the non-motor vehicle lane with regular bikes.) which was undertaken to avoid riders suffering from sunlight and high temperature) on diminishing red light running behavior of cyclists and e-bike riders. An observational study of 2477 riders was conducted to record and analyze their crossing behaviors at two sites across the city of Hangzhou, China. Results from logistic regression and analysis of variance indicated a significant effect of sunshield on reducing red light infringement rate both on sunny and cloudy days, while this effect of sunshield was larger on sunny days than on cloudy days based on further analysis. The effect of intersection type in logistic regression showed that riders were 1.376 times more likely to run through a red light upon approaching the intersection without sunshields compared to with sunshields in general. The results of MANCOVA further confirmed that rates of running behaviors against red lights were significantly lower at the intersections with a sunshield than at intersections without sunshields when other factors including traffic flow were statistically controlled. To sum up, it is concluded that sunshields installed at intersections can reduce the likelihood of red light infringement of cyclists and e-bike riders on both sunny and cloudy days. For those areas or countries with a torrid climate, sunshield might be a recommended facility which offers an affordable way to improve the safety of cyclists and e-bike riders at intersections. Limitations of the current sunshield design and current study are also discussed.

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1. Introduction

Bicycling, including electronic bike riding, is beginning to receive renewed attention. This common means of transportation gets support from urban planners because it is non-polluting, energy-efficient, and space-efficient, regarded as a way to reduce roadway congestion (Vandenbulcke et al., 2009). There are programs and policies recommended bicycling as a mean of transportation proposed by department of city planning in United States. For instance, the Congestion Mitigation and Air Quality Improvement program (CMAQ, 2010) suggested by Department of Transportation in Wisconsin encourages efforts to enhance public transit, bicycle facilities, ridesharing programs and facilities, and technologies that improve traffic flow and vehicle emissions. Also the program about bicycles implement by the Department of City

* Corresponding author at: Cognitive System Lab at SUNY-Buffalo, 319 Bell Hall, State University of New York at Buffalo, 14260, USA.

Planning in New York City aims to reduce congestion by promoting cycling (BGP, 2012).

1.1. The situation of bike mode share in developed countries

It is known that bicycling is a general mode of transportation in most developing countries, while developed countries have also been experiencing a bicycling boom over the past three decades. Take the development of bicycling in the area of North America and Europe as example.

From 1980 to 1999, the number of bicycle trips in the United States has doubled. Moreover, the number of people choosing to commute to work or school by bicycle in the United States continues to rise in recent years. The 2008 national bicycle commuter mode share of 0.5%, though small, represents 720,000 commuters, an increase of almost 200,000 people in three years (Pucher et al., 1999). US Census Bureau's American Community Survey (ACS) reports twice as many daily bike commuters in 2009 as in 2000 and an increase in bike mode share to 0.6%. At the same time, the data from the Canadian Census reveals a 42% increase in the

E-mail addresses: seanwu@buffalo.edu, changxu.beijing@gmail.com (C. Wu).

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number of daily bike commuters between 1996 and 2006 (Pucher et al., 2011).

In the same period, bicycling has increased significantly in Europe (Pucher et al., 1999), for instance, in Denmark, Germany, Switzerland, and the Netherlands (Dutch Ministry of Transport, 1995; Zegeer, 1994; Tolley, 1997; Pucher, 1997). The number of bicycle trips has grown substantially in these countries and, in many cities, cycling's share of travel has risen as well. In Germany, for example, bicycling modal share for urban trips rose by half between 1972 and 1995, from 8% to 12% (Pucher, 1997). The annual survey reported a tripling rise in bike mode share of work commuters from 3% in 2000 to 8% in 2008 (City of Portland, 2008). Bicycling is also thriving in Scandinavian countries such as Sweden, where older persons commonly use bicycles. The nine million Swedes have more than six million bicycles (Scheiman et al., 2010).

1.2. The situation of bike mode share in developing countries

Compared to these developed countries, developing countries usually regarded bicycling as one of major types of transportation. The participation of bicycling in Bogota, Columbia grew from 5000 in 1974 to over 400,000 in 2005 (Pucher et al., 2010). Bogota has the world's fifth largest intensive bicycle transportation network with 268 km of bicycle paths, and are still building a more intensive and safe bicycle network (Li, 2008). China, taken as another example, has a much higher rate of commuter bicycling. In general, average bicycling modal share for urban trips in China accounts for 38% (Zhang and Lu, 2010). In 2000, ten million people from the age of 15 to 64 in the city of Beijing had 15-20 million bicycles (Zhao and Rong, 2010). Currently, cycling still makes up a large percentage of all modes of travel, such as in Tianjin with a portion of its transportation as large as over 60 percent. Moreover, electric bicycles (e-bike) appeared in south China since 1997 and had become popular in China within a few years (Yao and Wu, 2012), since ebikes are suitable for urban transportation in south China where there are a lot of cities with around million people. For example, Suzhou city¹ keeps 180,000 pieces of e-bike currently, where 1.5 million e-bikes were sold in 2002 and 3.6 million or more were sold in 2003 (Zhen et al., 2006). Sales of e-bikes reached 15 million in 2005, which made electric bicycles now become a real industry and business (Zhang, 2006). According to the statistics published by the government of Hangzhou city,² its ownership of e-bikes has exceeded 50 million units till the end of 2006, where four of every ten families use e-bikes (Wang, 2007). This illustrates how electric bicycles have become one of the vital means of transportation of Hangzhou.

1.3. Cycling accident and the major reason: red light running behavior

Although bicycle commuting is believed to be beneficial to the health of both the individual and the community, the potential for fatalities and injuries also exists (Hoffman et al., 2010). In 2004, the number of regular bicycle riders killed in accidents was 13,655 which account for 12.8% of all traffic fatalities (CRTASR, 2004). Accordingly, the number of e-bikers being killed rose from 589 to 2469 in three years since 2004 (CRTASR, 2004, 2007). According to statistics published by the Hong Kong government in 2006, bicycle related events accounted for 7.4% of all traffic incidents and 6.3% of all traffic-related fatalities (Yeung et al., 2009).

Currently, increasing rates of misconduct of cyclists and e-bike riders, especially electric bicycles (E-bike), have led to an increase in transportation accidents aroused public concern nationwide.³ Data of traffic accidents collected in Zhejiang Province, for example, further illustrates the safety condition of electric bikes: 430 e-bike riders were killed and 3957 accidents referred e-bikes, representing 5% of all traffic fatalities and 10.8% of all accidents that occurred in 2006. The corresponding figures increased to 798 (14.0%) and 5434 (23.2%) after three years in 2009. As the capital city of Zhejiang Province, Hangzhou's overall accident rate has declined year by year since 2008, but the rate of accidents caused by electric bicycles has increased (Chen, 2010). Looking more closely at the data collected in the year of 2008 (Ding, 2009), the number of traffic fatalities involving e-bikes in Hangzhou rose from 108 to 152, up by 40.74% compared to the previous year, which accounts for 17.63% of total traffic fatalities and 48.41% of traffic fatalities involving bicycles (including e-bikes). In the year of 2010, Hangzhou had 178 fatalities due to e-bikes, representing 23.4% of the total traffic fatalities and 1012 traffic accidents caused directly by electronic bicycles, which grew by 16.19% over the same period of last year. Therefore, the studies about regular bicycle and e-bikes safety are necessary in China to improve the overall traffic safety condition.

Among the reasons, cyclists' and e-bike riders' violation of road traffic law (red light running behaviors or called red light infringement) is the major factor contributing to such vehicle related accidents (Spence et al., 1993). Based on the statistics published by the traffic police department in Hangzhou,⁴ red light running behaviors of e-bike riders contributes to 15% of accidents (Hua, 2010). Red light infringement was ranked as the top four reasons resulting in traffic accident referring cyclists and e-bike riders (Everyday Economic News, 2011). Another report shows that red light running is responsible for around 80% of accidents involving e-bike riders in Shaoxing (Another city in Zhejiang province) (Pei, 2011). Cyclists' non-compliance is also viewed as the typical and most annoyed by vehicle drivers (Basford et al., 2002; O'Brien et al., 2002). However, there are only a few studies focused on the red light running behavior of cyclists and e-bike riders. Johnson et al. (2011) observed non-compliance behavior of 4225 cyclists and concluded that travel directions, the presence of other road users, and the volume of cross traffic are three main predictive indexes for the infringement behavior. Wu et al. (2012) observed 451 two-wheeled riders and explored the rate, related factors, and characteristics of two-wheel riders' infringement behavior in China. Accordingly, studies about reducing rate of running behavior on red light of cyclists and e-bike riders might help to improve safety at urban road intersections.

1.4. Improve cycling safety: the facility of sunshield

Recently researchers start to focus on how to improve cycling safety. A few studies about interventions improving safety cyclists come from North-Western Europe, mainly from countries such as the Netherlands, Denmark, and Germany (Wegman et al., 2012). Two subjects related to cyclist safety that have been discussed thoroughly in peer-reviewed literature are bicycle helmets and roundabouts. Aultman-Hall and Kaltenecker (1999) compared differences between collision, fall and injury rates for bicycle commuting on-road, off-road and on sidewalks in Toronto and indicated that moving cyclists away from automobile traffic onto pathways is not, on its own, the solution to the bicycle safety problem. They

 $^{^{1}\,}$ Located between Shanghai and Nanjing, with population of half million in the down town area.

² Hangzhou is the first city install sun-shield facility for riders in bicycle track.

³ E-bike belongs to non-motor vehicle according to National Standard in China.

⁴ There is no national official data published by China Statistical Yearbook Database. Therefore, we use data from traffic police department of Hangzhou to describe the effect of red light running behavior on traffic accidents.

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Fig. 1. A sunshield on a bicycle track in Hangzhou city.

suggested that many paths are possibly not built for the volume of non-motorized traffic they carry and off-road facilities might be improved in the future. Teschke et al. (2012) compared cycling injury risks of 14 route types and concluded that quiet streets and busy streets along with bike-specific infrastructure support the route-design approach used in many northern European countries. Also, in some cities of China, traffic police worked in the intersections to supervise crossing behaviors of cyclists and e-bike riders, costing manpower and material resources.

In the present study, we explore another traffic facility-sunshields, set-up on the non-motor vehicle lanes and test its effect on diminishing the rate of red light running behavior. Promoting bicycling as an environmentally friendly mode of transportation, sunshields first appeared at waiting lines of main intersections in Hangzhou (see Fig. 1). This special transportation facility was used only in summer and was designed to help protect riders from sunlight and high temperature. Take the index of temperature in the main district of Hangzhou in 2010, for example, which had 40 days with temperatures over 35°C and a full week with temperatures above 39°C. Current statistics suggest that time limit of waiting at red lights is usually 70-90 s in Hangzhou (Liu et al., 2008); however, people are likely to lose patience when exposed to scorching sunlight, consequently leading to an increased rate of red light running behavior more than usual in summer (Larsen and Sunde, 2008).

Although sunshields were design for humanity friendly consideration previously, it was reported to affect the red light running behaviors in practical use. This facility emerged only in recent years and has never been studied before. Hangzhou is the first city where the sunshield was experimented on non-motor vehicles lanes in 2007 with four sunshields set-up at the Zhonghe–Tiyuchang intersection (Shi, 2007). In 2009, 450 easily assembled sunshields were chosen as the final type and were installed in 127 main roads of Hangzhou. Hangzhou, being the city where sunshields first appeared and developed (while scarce in other cities in China or in other countries), was chosen as the test city.

The purpose of this study was to examine the effects of sunshield facility on decreasing the rate of red light running behavior of cyclists and e-bike riders in Hangzhou. In the present study, we will explore its influence on riders' behavior both on sunny and cloudy days. Since sunshields have worked as a facility to eliminate sunlight for riders waiting at the stop line, as we mentioned above, we assumed that it would be more effective on sunny days. As these kinds of facilities are installed only in summer every year, we collected data only in summer from July to September. If this function of sunshields was proved to be effective, it could be a better choice to reduce the rate of red light running behaviors at intersections. The unit price of a sunshield is \$400–500 approximately. It indicates that this facility is an easy and low-cost option for countries which have bike paths like China, Australia, Germany, and the Netherlands. The findings of this research might provide new information on improving the safety of cyclists and e-bike riders.

2. Methods

2.1. Test sites

Among 112 intersections being observed in 5 main districts in the city of Hangzhou, there are 11 intersections without sunshields and 10 intersections partially with sunshields while the other intersections are fully equipped with sunshields in four directions. As the purpose of the research is to compare the running behavior under the situation with or without sunshields, two criteria were used for selecting the observational sites. First, the sites selected should fit the requirement of experiment design, namely, having a junction with sunshield and another junction without sunshield. Second, there had to be a considerably high number of bicycle traffic (including both electric bikes and regular bicycles) during the observation period. Before the final intersection was chosen, four intersections were observed and tested.

Two typical four-armed signalized regular intersections on Huanchengbei Road were finally chosen as the observation site after the pilot. The east-west orientated Huanchengbei Road and the north-south orientated Jianguo Road and Huanchengdong Road are all main thoroughfares in Hangzhou (see Fig. 2). The observation was conducted from the end of July to the end of September at Huanchengbei–Jianguo Intersection and Huanchengbei–Huanchengdong Intersection in 2011. The data collection was conducted from approximately 11:30 AM to 12:30 PM. As these observations were conducted during peak hours it could be assumed that cyclists and e-bike riders were commuters.

2.2. Video data collection

Two synchronized video cameras (Sony HDR-X100E, Sony Corporation) were used to collect data of riders' crossing behavior. One was positioned on a tripod next to the roadway where the entire crossing process could be viewed. The other footage was taken on the intersecting road just after the right turn to observe the detailed rider's behavior at the stop line. The install of cameras was hid behind the intersection stop line so that the awareness of the camera would be decrease in that case. Since the study aims to investigate the effects of sunshield use on red light running behavior, we collected the data both on sunny and cloudy days.

2.3. Videotape coding

The variables were coded based on the videotape for riders who arrived at the intersections during the red light and flashing light phases (see Table 1).

Riders (both e-bike riders and cyclists) making left-turns were excluded because of the limitation of camera field view, while those making right-turns were excluded because they are not subjected to the red light control according to the traffic rules in China. In order to avoid potential bias in coding, 1-h video recordings (including 72 valid observations) were coded by two independent 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 0.87 to 0.99, indicating that the coding process was reliable.

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A. Huanchengbei-Jianguo Intersection

Fig. 2. Picture of Huanchengbei–Jianguo intersection and Huanchengbei–Huanchengdong intersection.

Table 1

Definition of variables coded.

Variables	Descriptions
Independent variables Intersection type Weather	With sunshield: 1; without sunshield: 0 General description: sunny: 1, cloudy: 0; temperature; UVI (ultraviolet rays index): low, moderate, high
Dependent variables	
Crossing behavior Safety margin	Red light laws obey: (); red light running: 1 Gap between the time a bicycle crosses before a vehicle and the time it arrives at the crossing point (recorded only for red light running behavior) (Zhuang and Wu, 2011)
Other factors	
Gender	Male: 0, female: 1
Age group	Estimated age group: young (<30): 0, middle-aged (30–50): 1, elderly (>50): 2 (Yao and Wu, 2012)
Rider type	Electric bike riders:0, regular bicycle riders: 1; e-tricycle riders: 2; tricyclists: 3
Time	Arrival time at the stop line, departure time from the stop line
Traffic light status	Red light status; flashing light status ^a
Cross traffic flow	It is the number of motor vehicles passing the intersection from either direction during the red light status of one cycle, and is measured every 3 s
Group size	Data coding only those who move straight in intersections. Left-turners were excluded because they were in a different roadway, while riders making right turns were also ignored because they were not subject to the traffic signal control according to the road rules in China.

^a This is a special red light status in China indicating that the light will change from red to green status with a count down in the last 10 s of the red light.

3. Results

3.1. Descriptive statistics

Demographics data were coded for those arrived on red light phases including both red and flashing light statuses. A total of 2477 valid observations were recorded and presented in Table 2. Observations took at intersections with and without sunshield are presented separately. Within each condition the descriptive statistics for two weather conditions were divided as well. It shows a majority of riders were e-bike riders (71.6% at intersections with a sunshield and 80.8% of that without a sunshield) among the rider type group and males (71.5% and 78.2% on two different types of intersections) within the gender group. Since the number of e-bike riders and cyclists accounted for more than 95% of all riders, we defined these two as major rider types in our following discussions. Young and middle aged riders accounted for more than 90% of the total riders on both types of intersections. The numbers of riders collected on intersections with and without a sunshield are not significantly different (1266 vs. 1211, p > .05, chi-square test), while within each intersection category, the number of riders recorded on sunny and cloudy days are significantly different (757 vs. 509 and 673 vs. 538, p < .05). We paid more attention to sunny days than to cloudy days since sunshields will become more effective during sunny weather, as we hypothesized.

B. Huanchengbei-Huanchengdong Intersection

Table 3 lists the statistical summary of the running behaviors against traffic lights including both sunny and cloudy conditions. In this summarization, we concerned the proportion of running behaviors happened from the whole crossing behaviors in different intersection and weather conditions. A chi square analysis was used to analyze categorical variables (such as rider type, gender, and estimated age groups) for the different intersections under both weather conditions. In general, the overall proportion of e-bike riders' running behaviors is significantly larger than cyclists' in both kinds of intersections, with and without sunshields. Nevertheless, male riders are more likely to go against red lights than female riders (42.8% vs. 33.8%) a significant difference only at intersections with sunshields. The rates of running behaviors of different age group are also significantly different only at intersections with sunshields.

3.2. Logistic regression analysis

According to the format of the dependent variable defined in Table 1, crossing behavior was coded as a dichotomous variable (red light laws obey: 0 and red light running: 1) as well as the variable of weather condition (cloudy: 0 and sunny: 1) and the variable of intersection type (without sunshield: 0 and with sunshield: 1). In this case, the dependent variable we want to predict is the crossing behavior (whether violate or obey the red light laws), which is a categorical variable. Therefore, a logistic regression was conducted to predict the probability that red light running behaviors occur. It is a generalized linear model used for binomial regression in which intersection types and weather condition so as other

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Table 2

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Frequency of the observations in each descriptive category.

Intersection type	With sunshield			No sunshield		
Weather	Sunny	Cloudy	Total	Sunny	Cloudy	Total
Rider type						
E-bike riders	535(70.7%)	371 (72.9%)	906(71.6%)	532(79.0%)	446(82.9%)	978 (80.8%)
Cyclists	209(27.6%)	120(23.6%)	329(26.0%)	108(16.0%)	75(13.9%)	183(15.1%)
E-tricycle riders	5(0.7%)	3(0.6%)	8(0.6%)	9(1.3%)	1(0.2%)	10(0.8%)
Tricyclists	8(1.1%)	15(2.9%)	23(1.8%)	24(3.6%)	16(3.0%)	40(3.3%)
Gender						
Male	536(71.0%)	368(72.3%)	904(71.5%)	532(79.0%)	415(77.1%)	947 (78.2%)
Female	217(28.7%)	138(27.1%)	355(28.1%)	136(20.2%)	121 (22.5%)	257 (21.2%)
Age group						
Young	294(38.9%)	233 (45.8%)	527(41.7%)	227 (33.7%)	256(47.6%)	483 (39.9%)
Middle-aged	382(50.5%)	227 (44.6%)	609(48.1%)	375 (55.7%)	237(44.1%)	612 (50.5%)
Elderly	78(10.3%)	46(9.0%)	124(9.8%)	66(9.8%)	43(8.0%)	109(9.0%)
Overall	757	509	1266	673	538	1211

Table 3

Proportion of red light running behaviors in each descriptive category.

Intersection type	With sunshield	With sunshield			Without sunshield		
Weather	Sunny	Cloudy	Total	Sunny	Cloudy	Total	
Rider type							
E-bike riders	194(36.5%)	189(50.5%)	383(42.2%)	216(39.9%)	254(57.0%)	468 (47.2%)	
Cyclists	60(27.6%)	64(47.4%)	124(35.2%)	47 (35.6%)	42 (46.2%)	89(39.9%)	
X^2	5.384**	0.388	5.183*	0.823	3.478	4.296*	
Gender							
Male	199(37.1%)	188(51.1%)	387(42.8%)	210(39.5%)	231 (55.7%)	441 (46.6%)	
Female	55(25.3%)	65(47.1%)	120(33.8%)	52 (38.2%)	64(52.9%)	116(45.1%)	
X ²	9.591**	0.638	8.597**	0.070	0.291	0.683	
Age group							
Young	109(37.1%)	125(53.6%)	234(44.4%)	91 (40.1%)	148 (57.8%)	239(49.5%)	
Middle-aged	116(30.4%)	104(45.8%)	220(36.1%)	141 (37.6%)	125 (52.7%)	266(43.5%)	
Elderly	29(37.2%)	24(52.2%)	53(42.7%)	30(45.5%)	22 (51.2%)	52(47.7%)	
X^2	3.822	2.918	8.408*	1.561	1.562	4.034	
Total	254(33.5%)	253 (49.7%)	510(40.3%)	262(38.9%)	295 (55.0%)	557(45.9%)	
**							

** p<.01.

* *p* < .05.

Otherwise $p \ge .05$.

category variables were used as predictor variables. Crossing behaviors were analyzed in total conditions including red light and flashing light statuses in Table 4.⁵

The results indicate that both intersection type and weather condition were significant variables for predicting traffic light running behavior in total red light status (including both red light and flashing light statuses). The effect of intersection type showed that riders were 1.376 times more likely to run through a red light upon approaching the intersection without sunshields compared to with sunshields in general. On sunny days, the riders were 1.756 times more likely to run through a red light without sunshields compared to those with sunshields. On cloudy days, the riders were 1.223 times more likely run through a red light without sunshields compared to those with sunshields. For the variable of weather type, the results indicated that riders are 1.739 times more likely to run through a red light upon cloudy weather compared to sunny conditions.

In addition, rider type, gender and levels of cross traffic flow were identified as significant predictor variables on red light running behavior. E-bike riders were 1.834 times more likely to run against red light than cyclists, while male riders were 1.265 times more likely to have red light infringement behavior than female riders. Under low and median levels of traffic flow, riders were 1.406 and 1.556 times more likely to run against a red light compare to high level of traffic flow. However, age group could not serve as a significant variable for predicting red light running behaviors on either light condition.

3.3. Analysis of variance

The study aimed to explore the influence of sunshield on running behaviors of cyclists and e-bike riders. The rates of red light running behaviors in each group was defined as the proportion of riders going against red lights among the total riders over each red light waiting period in which the traffic light turned from red to green. As it shows in Fig. 3, cyclists and e-bike vehicle riders have a lower rate of running behaviors on the intersection with a sunshield than without one, especially in sunny weather.

The analysis of variance (ANOVA) was used to further analyze the influence of sunshields on red light running behaviors. ANOVA was conducted with intersection type and weather condition as independent variables and the rates of red light running behaviors as the dependent variable. Main effects of both

⁵ The logistic regression is not applied to analyze safety margin, since it is a continuous variable rather than a categorical variable. We will present the analysis of safety margin in the result of multivariate analysis of covariance (MANCOVA) later.

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Table	e 4
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Logistic regression results for traffic light running behaviors.

Light status		Adjusted OR	Adjusted 95% CI	Wald χ^2
Total (including	Intersection type			
both red light and	Without vs. with sunshield	1.376	1.124-1.168	9.562**
flashing light	Weather type			
statuses)	Cloudy vs. sunny	1.739	1.456-2.077	37.295***
	Rider type			
	E-bike rider vs. cyclist	1.834	1.030-3.264	4.250^{*}
	Gender			
	Male vs. female	1.265	1.028-1.558	4.926*
	Age group			
	Young vs. elderly	0.883	0.642-1.215	0.582
	Middle aged vs. elderly	0.749	0.544-1.033	3.113#
	Crossing traffic flow			
	Low vs. high	1.406	1.071-1.847	6.020*
	Median vs. high	1.556	1.216-1.992	12.312***
	Hosmer and Lemeshow test	14.680		

^{*} p<.05. ** p<.01.

*** p<.001.

.05 < p < .10.

Otherwise $p \ge .10$.

Otherwise $p \ge .10$

intersection type (F(1, 2473) = 23.128, p < .001) and weather condition (F(1, 2473) = 226.096, p < .001) were significant. This indicated that intersections with sunshields had a significantly lower rate of red light running behavior compared to that of intersections without sunshields. At the same time, the red light running behavior rate is lower in sunny weather than is on cloudy days. No significant interaction effect of intersection type × weather condition was revealed for rate of red light running behavior. In other words, the significant difference of red light running behavior rates caused by different intersection types (with and without sunshield) is not depended on weather types (sunny and cloudy weather).

Simple effect results indicated that the rates of running a red light were significantly lower at intersections with a sunshield than at intersections without one on both sunny days (F(1, 1428) = 13.191, p < .001) and cloudy days (F(1, 1045) = 11.535, p < .01). On sunny weather condition, the mean value of running behavior rates at intersections with sunshields is 5.5% less than that at intersections without sunshields. The same difference of red light running behavior rates between two types of intersections is 4.8% on cloudy weather condition.



Fig. 3. Rates of running behaviors at two types of intersections (with vs. without a sunshield, error bar: $\pm 2SE$).

The effects of intersection type and weather condition on safety margin were analyzed as well. The safety margin in this observation was defined as the time from which a rider crossed the intersection to the time the next vehicle arrived at the crossing point. This dependent variable could be measured to evaluate the relative safety of running behaviors against red lights. Significant effects of two independent variables were revealed on safety margin, including intersection type (F(1, 855) = 65.034, p < .001) and weather condition (F(1, 855) = 10.725, p < .01). Result showed significant interaction effects of intersection type and weather condition on safety margin (F(1, 855) = 8.014, p < .01). Simple effect results indicated that the safety margin were significantly larger at intersections with a sunshield than at intersections without one on both sunny days (F(1, 374) = 36.850, p < .001) and cloudy days (F(1, 481) = 23.610, p < .001). In addition, significantly larger safety margin is indicated on sunny days than on cloudy days only at the intersections with a sunshield (F(1, 405) = 10.181, p < .01). These results revealed that potential danger of running behavior, which is indicated by the variable of safety margin, is smaller on intersections with a sunshields than that on intersections without one.

3.4. Multivariate analysis of covariance

Traffic flow was supposed to be a preliminary predictor of red light running behaviors. During the observation, it is found that red light running behavior happened more frequently when there is relative low cross traffic at the intersection. Result from logistic regression also suggested that traffic flow is a significant predictor of red light running behavior. Therefore, in this section, multivariate analysis of covariance (MANCOVA) was conducted with intersection type (with sunshield vs. without sunshield) and weather condition (sunny weather vs. cloudy weather) as betweensubjects factors and the rates of red light running behaviors and safety margin being analyzed as dependent variables with traffic flow being considered as a covariant.

Both effects of two independent variable on rates of red light running behavior were significant, including intersection type (F(1, 853) = 4.293, p < .05) and weather condition (F(1, 853) = 85.294, p < .001). No significant interaction effect of intersection type and weather condition was revealed for rate of red light running behavior (F(1, 853) = 0.255, p > .05). Simple effect results indicated that the rates of running a red light were significantly lower on intersection with sunshield than on intersections without

sunshield on both sunny days and cloudy days. The lower rates were also indicated on sunny days than on cloudy days. Significant effects of two independent variables were revealed on safety margin, including intersection type (F(1,853) = 60.768, p < .001) and weather condition (F(1,853) = 9.052, p < .01). Result showed significant interaction effects of intersection type and weather condition on safety margin (F(1, 853) = 7.307, p < .01). Simple effect results indicated that the safety margin were significantly larger on intersection with sunshield than that on intersections. The larger safety margin on sunny days than on cloudy days was only indicated at the intersection with sunshields.

There was one significant effects of covariant indicated by this step of analysis, namely, traffic flow (F(1, 853) = 9.149, p < .01) on rates of running behaviors, whereas the effect of traffic flow on safety margin is not significant (F(1, 853) = 0.453, p > .05). Simple effect results indicated that intersection with median traffic flow had highest red-light running rates compare to intersection with low or high traffic flow.

Furthermore, the MANCOVA was conducted with rider type, gender, and estimate age group input as covariates as well to avoid the any potential confounding effects from these factors. The results of these covariates showed no significant effect on either of the two dependent variables. The effects of rider type (F(1, 851) = 1.901, p > .05), gender (F(1, 851) = 1.041, p > .05), and estimate age group (F(1, 851) = 0.249, p > .05) on red light running rate are not significant, respectively; while the effects of these covariates on safety margin, including rider type (F(1, 851) = 0.221, *p* > .05), gender (*F*(1, 851) = 0.953, *p* > .05), and estimate age group (F(1, 851) = 0.034, p > .05) are neither significant. In addition, the significant results of effects of independent variables on both red light running rate and safety margin are not affected with all these covariates (including traffic flow, rider type, gender, and age) input into the model. The main effects of two independent variables on red light running rates were significant, including intersection type (F(1,851) = 4.373, p < .05) and weather condition (F(1,851) = 85.872, p < .05)p < .001). No significant interaction effect of intersection type and weather condition was revealed for rate of red light running behavior (*F*(1, 851) = 0.358, *p* > .05). Significant effects of two independent variables were also revealed on safety margin, including intersection type (F(1, 851) = 60.791, p < .001) and weather condition (F(1, p) < .001) (851) = 8.938, p < .01). Result showed significant interaction effects of intersection type and weather condition on safety margin (F(1,851) = 7.518, p < .01).

3.5. Results summary from the three analyses above

Results from logistic regression and analysis of variance reached almost the same conclusion: Riders are significantly less likely to run through a red light at intersection with a sunshield compared to that without one both on sunny and cloudy days. And this effect of sunshield on reducing red light running rates was larger on sunny days than on cloudy days. Furthermore, after other factors (e.g., traffic flow, ride type, etc.) were statistically controlled, this effect of sunshield in reducing red light infringement rates was confirmed on both sunny and cloudy days according to the result of MANCOVA. All in all, we can conclude that sunshields installed at intersections are able to reduce the likelihood of red light infringement of cyclists and e-bike riders on both sunny and cloudy days.

Results from ANOVA and MANCOVA regard to safety margin are also similar. The safety margin is significantly larger at intersections with a sunshield than at intersections without one on both sunny days and cloudy. Also, significantly larger safety margin on sunny days than on cloudy days is only indicated at the intersections with a sunshield. These results revealed that potential danger of running behavior, which is indicated by the variable of safety margin, is smaller on intersections with a sunshields than that on intersections without one.

4. Discussion

Bicycling actually held an important position in transportation in China and is involved in a great many accidents, as we mentioned above. In light of these conditions, more and more researchers focus on ways to decrease the rate of accidents caused by bicycling. The present study examined the efficacy of sunshields, a traffic facility installed at intersections, on diminishing the rates of red light running behavior under both sunny and cloudy weather conditions by observing a total of 2477 bicycles (including regular bikes and e-bikes). Overall results highlighted that the main effect of intersection type (with vs. without sunshield) was significant on the bicycles' propensity to ride through intersections against a red light especially in sunny weather, meaning that sunshields do help to decrease the rates of red light running behaviors.

Demographic results in Table 2 provide a basic description of bicycles (including regular bikes and e-bikes) crossing intersections during our observations. There was no significance between the number of riders crossing intersections with or without sunshields. Under both types of intersections, the size of the male group passing by was larger than the female one, as was the size of middle-aged group and e-bike riders group compared to other groups under the same subcategory.

By controlling other variables (including cross traffic flow), the logistic regression analysis was conducted to explore estimated parameters in predicting red light running behaviors. Both intersection type and weather were found to be significant variables to predict red light running behaviors. Results of intersection types suggested that riders are 1.376 times more likely to run against traffic light upon intersection without sunshields than with shields, which prove a valid function of sunshields in reducing rates of red light running behaviors. Moreover, the riders were 1.756 times more likely to run through a red light without sunshields compared to those with sunshields on sunny days. Findings on cloudy days were similar, and the only difference was that odds of infringement on intersection without sunshield decreased to 1.223 times more likely compare with those on intersections with sunshields on cloudy day. A conclusion was revealed accordingly that effect of sunshield was larger on sunny days than on cloudy days.

In the further analysis of red light statuses, a conflicting result for the independent variable of intersection type was found: that the rates of running behaviors happened at intersections with sunshields are less than those without sunshields upon flashing light conditions. This was the opposite upon the red light condition. The reason for this contradiction may be due to the significant difference between running behavior rates on flashing light status and on red light status (t = 2.980, p < .05). In other words, riders were more likely to run against traffic lights on flashing light status than on red light status. In short, the general effect of sunshields on diminishing running behaviors against traffic light is effective, especially on flashing light status.

Moreover, the main effect of intersection type (with sunshield vs. without sunshield) and its interaction effect with weather condition (sunny weather vs. cloudy weather) were shown in Fig. 3. Cyclists and e-bike riders had a significantly lower rate of running behaviors at intersections with a sunshield than without in both sunny and cloudy weather (F(1, 2473) = 23.128, p < .001). The interaction effect of intersection type and weather condition was not significant and results from simple effect indicated that the rates of running a red light were significantly lower at intersections with a sunshield than at intersections without one on both sunny days (F(1, 1428) = 13.191, p < .001) and cloudy days (F(1, 1045) = 11.535,

p < .01). Consequently, the effectiveness of sunshields on reducing the rate of red light infringement was supported by this result. Finally, considering riders' crossing behaviors were related to the factor of traffic flow and the variable of safety margin was used to evaluate the relative safety of running behaviors against red light, the multivariate analysis of covariance (MANCOVA) was conducted to further analyze the effect of intersection type with other factors statistically controlled. The main effect of sunshields on reducing running behavior rates which we focused on is significant (F(1,(853) = 4.293, p < .05) and significant effects of weather condition (F(1, 853) = 85.294, p < .001) and traffic flow were indicated (F(1, p < .001))(853) = 9.149, p < .01). The rates of running a red light were significantly lower on sunny days than on cloudy days, while intersection with median traffic flow had highest red-light running rates compare to intersection with low or high traffic flow. Therefore the results of the effect of sunshields on diminishing the likelihood of red light running were consistent with ANOVA results when other factors (including traffic flow, rider type, gender and age) were being controlled.

The results of safety margin indicated that red light running behaviors at intersections with a sunshield have larger safety margin compare those at intersections without a sunshield. As the indicator of potential danger of running behavior, the results showed that the red light running behaviors were less danger at intersections with a sunshield compare to those at intersections without one. These results further indicated that intersections with a sunshield installed had less dangerous red light running behaviors and therefore provided supplementary evidence that sunshields can used to improve the safety of cyclists and e-bike riders.

As a consequence, the effective influence of sunshields on reducing the rate of red light running behaviors of e-bike riders and cyclists was confirmed completely in this study combining the results from logistic regression, ANOVA and MANCOVA. When bicycle riders were exposed to higher temperatures and more sunlight, they prefer waiting under the shade of sunshields which lead to the decrease rate of running behavior. This conclusion supports our previous viewpoint that the facility of a sunshield will improve the safety of intersections for bicycling on both sunny and cloudy days. Consistent results that sunshields were shown as being more effective on sunny days than cloudy days were obtained from logistic regression and analysis of variance.

The result also indicated that there were more red-light running events on cloudy days as compared to sunny days considering the effect of weather condition on red light running behavior. There might be possible reasons for this result and further studies are needed. As we inferred, it is possible that riders do not need sunshield to avoid sunlight on cloudy days comparing to sunny days, which explained the higher traffic violation percentage on cloudy days than that on sunny days at intersections with sunshield. As for that higher violation percentage at intersection without sunshield, we found riders are easy to get tired due to the higher temperature and strong sunlight. Sunny weather in the summer in Hangzhou city usually has a higher temperature than cloudy days, and high temperature was reported to have a negative effect on human performance (Pilcher et al., 2002). Therefore, we infer that the velocity of riding may be higher on cloudy days (better riding performance), which may increase their difficulty to stop bikes near an intersection when traffic light is changing from green to red. Meanwhile, upon flashing light status, riders may estimate that they can cross the road quicker without hitting by vehicles on cloudy days due to higher riding velocity in cloudy and cooler weather situations, creating higher rate of red-light running behavior. Both of these reasons may increase possibility to run against red light on cloudy days compare to that on sunny days at intersections without sunshield. While there may be numerous reasons for this finding of the weather effect, the effectiveness of sunshield, which is the focus of current study, is verified in both sunny and cloudy weather conditions.

In addition, the effects of other factors including rider type, gender, age and traffic flow were also summarized. Table 3 tallied frequency and proportion of red light running behaviors in each category. In particular, e-bike riders were more likely running against red lights than cyclists in both types of intersections (with and without sunshields), which was consistent with the result of Wu et al. (2012). As regard other factors, the rates of running behaviors of different gender and age group were only significant on intersection with sunshields. It is revealed that male riders were more likely run against red light than female riders. As concerns the effect of age, middle-aged riders were less likely run against red light compare to young and elderly riders. From the MANCOVA result, the effect of rider type, gender, age on red light running rate are not significantly different at two sites (with vs. without sunshields) or under two weathers (sunny vs. cloudy) with other variables statistically controlled.

By controlling other variables statistically (including cross traffic flow), results of logistic regression (see in Table 4) revealed that factors such as rider types (e-bike riders vs. cyclists), gender (male vs. female), and traffic flow (low, median, and high) were all significantly associated with red light running, while age (young, middle-age, and elderly) was not a significant predictor in red light running behavior. The predicable effect of rider types revealed that e-bike riders are more likely to go against red light than cyclists, which was discordant with previous study (Wu et al., 2012). This inconsistency may due to the relatively larger number of observations in the current study compared to previous studies, which were also mentioned as one reason that rider type was failure in prediction in their paper. Results of significant differences were concluded on gender that males are more likely running against red light. A consistent result of traffic flow indicated that riders showed more likelihood of red light infringement under low and median levels of traffic flow than under high level of traffic flow (Wu et al., 2012). Moreover, there was potential for some errors in the subjective classification of rider age which may contribute to the failure of age in prediction of red light running behavior.

Although the current study validated the effectiveness of sunshields on reducing the frequency of red light running behavior of riders, there are still several problems of the current design of the sunshields and limitations of the current work. In our observations, we found that a few riders stopped across the stop line of intersections which might disturb the vision of crossing motor vehicles from other directions upon a green light. If there was a small distance between the position of sunshield installed and the stop line, riders might more likely stop before stop lines. This standpoint could be a direction for improvement this facility in further studies. We were also concerned that sunshields on the non-motor vehicle lanes may interrupt the view of drivers who turned right on red light, which might need further exploration. In addition, our observations did not include data taken on rainy days since the facility is designed to protect riders on hot, sunny days, such as in the summer from June to early October (after the rainy season of Hangzhou). During our observations, sunshields were dismantled temporarily because of the heavy rainfall brought by No. 9 Typhon of the year of 2011. Future studies could provide observation data on rainy days to evaluate the effects of the facility more comprehensively.

All in all, the present work proves that, in practice, the use of a sunshield installed on non-motor vehicle lanes reduces cyclists' and e-bike riders' red light running behavior rates in both sunny and cloudy weather condition. Compare to traffic police supervising the red light running behaviors in the intersection, sunshields is an affordable facility without employing manpower. This type of facility could be applied to non-motor vehicle lanes at the intersection

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for those areas and countries with hot climate for both safety and humanity friendly consideration.

5. Conclusion

The present study proved the effective influence of sunshield on reducing the rate of red light running behaviors of e-bike riders and cyclists at least on sunny days in a field study by which intersection type (with sunshield vs. without sunshield) and weather condition (sunny vs. cloudy) were examined as independent variables. The result also indicated that there were more red-light running events on cloudy days as compared to sunny days considering the effect of weather condition on red light running behavior. Main results of ANOVA indicated that intersections with sunshield had a significantly lower rate of red light running behavior, compared to that of intersections without sunshields. Moreover, intersection type was proved to be a significant predictor in logistic regression analysis for red light running behavior rates, which were lower at intersections with sunshields than intersections without one. The results of MANCOVA further confirmed that rates of running behaviors against red lights were significantly lower at the intersections with a sunshield than at intersections without sunshields by taking traffic flow into consideration. Based on these result, it is concluded synthetically from the present study that sunshield showed significant effectiveness in reducing the frequency of red light running behavior on both sunny and cloudy days. These findings demonstrated that sunshields installed for cyclists and e-bike riders, besides acting as a traffic facility for humanity friendly consideration, helps to diminish the likelihood of red light infringement.

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