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Left-turning vehicle-pedestrian conflicts at signalized intersections with traffic lights: Benefit or harm? A two-stage study

Yi-Ling He [a, b, 1], Ruo-Tong Li [b, 1], Li Li [b], David C. Schwebel [c], He-Lai Huang [d], Qing-Yi Yin [d], Guo-Qing Hu [b, *]

[a] School of Public Health, Sun Yat-sen University, Guangzhou 510080, China
[b] Department of Epidemiology and Health Statistics, Xiangya School of Public Health, Central South University, Changsha 410078, China
[c] Department of Psychology, College of Arts and Sciences, University of Alabama at Birmingham, 1720 2nd Avenue South, HHB 560, Birmingham, AL, 35294, USA
[d] Urban Transport Research Center, School of Traffic and Transportation Engineering, Central South University, Changsha 410075, China

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ABSTRACT

Purpose: Vehicle-pedestrian conflicts are common at road intersections when traffic lights change. However, the impact of traffic light on transportation safety and efficiency remains poorly understood.
Methods: A two-stage study was used to survey the proportion of intersections with conflicting traffic lights and the related transportation efficiency and safety were evaluated as well. First, a cross-sectional study estimated the proportion of signalized intersections with conflicting left-turning vehicle-pedestrian traffic lights in Changsha city, China. Second, a natural experiment compared transportation efficiency and safety between intersections with and without conflicting left-turning vehicle-pedestrian traffic lights. Risky conflicts, where motor vehicles violated laws and failed to yield to pedestrians in crosswalk were used as a surrogate for transportation safety. The number of motor vehicles and pedestrians passing through the intersections per second and per meter were used to estimate transportation efficiency. Data were collected and analyzed in 2015 (from March to December). A search of online news from domestic media sources was also conducted to collect pedestrian injury data occurring at the intersections.
Results: About one-fourth (57/216) intersections had conflicting left-turning traffic lights (95% *CI*: 20.5%, 32.3%). Risky vehicle-pedestrian conflicts were more frequently observed at intersections with conflicting lights compared to those without (incidence rate ratio (IRR) = 3.13; pedestrians: IRR = 4.02), after adjusting for type of day (weekday vs. weekend), the time period of observation, and motor vehicles traffic flow. Intersections without conflicting vehicle-pedestrian traffic lights had similar transportation efficiency to those with conflicting lights after controlling for covariates ($p > 0.05$). The systematic review of news media reports yielded 10 left-turning vehicle-pedestrian crash events between 2011 and 2017, involving 11 moderate or severe pedestrian injuries and 3 fatal pedestrian injuries.
Conclusion: Over one-fourth of road intersections in Changsha city, China have conflicting left-turning traffic lights. Conflicting traffic lights cannot improve transportation efficiency, but increase risky conflicts between vehicles and pedestrians.

Introduction

Road design and traffic light configurations play an important role in traffic safety and transportation.[1] When facilities such as sidewalks, bicycle lanes and signalized crossings are absent, inadequate or in poor condition, the injury risk for pedestrians and cyclists rises greatly.[2] Of particular interest at present is the role of signalized crossings, as road traffic crashes and pedestrian injuries often occur at road intersections. In the United States, 22.0%–24.8% of pedestrian fatalities occurred at intersections during 1998–2007.[3] According to Canadian statistics, almost 30% of road traffic deaths and 40% of serious injuries happen at intersections[4]; moreover, over 76% of pedestrian-motor vehicle collisions in Toronto occurred at signalized intersections.[5]

* Corresponding author.
E-mail address: huguoqing009@gmail.com (G.-Q. Hu).
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[1] Equal contributors.

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Separation of vulnerable road users from motor vehicles is widely documented as an effective method to reduce road traffic injuries.[6] Well-designed signal lights effectively prevent conflicts between motor vehicles and pedestrians at road intersections, thereby protecting the safety of those pedestrians. However, conflicting vehicle-pedestrian traffic lights are common at intersections in many locations around the world, including China. Current Chinese regulations allow right-turning motor vehicles to proceed through the intersection when it does not interfere with pedestrians or others.[7] In the most Chinese cities, some traffic lights also allow pedestrians and left-turning motor vehicles to proceed through the intersections simultaneously. Such traffic design is based on the assumption that conflicting signal lights could increase the transportation efficiency of motor vehicles and pedestrians without sacrificing road traffic safety. However, this assumption has not been rigorously examined.

We conducted a two-stage study in Changsha city, China to address two research questions: (a) how many road intersections are equipped with conflicting left-turning vehicle-pedestrian signal lights? And (b) do conflicting left-turning vehicle-pedestrian traffic lights influence transportation efficiency and safety at intersections? The first question was addressed using a cross-sectional observational study and the second question via natural experiment. We also conducted a review of online media sources to obtain information about left turning vehicle-pedestrian injuries between 2011 and 2017 in China.

Methods

A two-stage study was designed to achieve the research questions. At stage one, a cross-sectional study investigated the proportion of intersections with conflicting left-turning vehicle-pedestrian traffic lights. At stage two, a natural experiment compared transportation safety and efficiency between intersections with and without conflicting left-turning vehicle-pedestrian traffic lights.

Stage one: a cross-sectional study

Study setting and selection of road intersections

We conducted the study in Changsha city, China, which is an urban city with about 2.1 million inhabitants. According to *The Statistics of Road Traffic Lights of Changsha City in 2008*,[8] there are 434 road intersections in Changsha city. Thirty-nine intersections were excluded because of no traffic light for pedestrians, lack of electric power, or being under road maintenance when our study was conducted. In total, 395 intersections were eligible for enrollment. A pilot survey of convenient intersections indicated 31 (26.3%) out of 118 intersections had conflicting left-turning traffic light. Using these data, $p = 0.263$, $\alpha = 0.05$, $\varepsilon = 0.15$, and $n = 395$, a minimum sample size of 216 road intersections was required to accomplish the goals of our cross-sectional study. Simple random sampling was used to select 216 intersections from the 395 eligible intersections.

Outcome measure

Conflicting left-turning vehicle-pedestrian traffic lights were defined based on the following situation: when the green lights flash for vehicles to turn left, pedestrians simultaneously have a "walk" signal to proceed. This creates a conflict between motor vehicles and pedestrians who are using the same area in the roadway.

The proportion of intersections with conflicting left-turning vehicle-pedestrian lights was calculated as: number of intersections with conflicting lights/total number of observed intersections × 100%.

Data collection

Researchers personally visited all 216 road intersections and judged whether the intersections had conflicting left-turning vehicle-pedestrian lights or not. Conflicting left-turning vehicle-pedestrian road intersections included three types of intersection: 4-leg intersections, T-intersections and mid-block U-turns (Note: mid-block U-turns were situations when motor vehicles make a U-turn to the left lane, crossing over crosswalks) (Fig. 1). Data were collected from March 1, 2015, to April 30, 2015.

Statistical analysis

We calculated the proportion of road intersections with conflicting left-turning vehicle-pedestrian lights, and 95% confidence interval (95% *CI*). Data were analyzed from September 1, 2015 to December 31, 2015.

Stage two: a natural experiment

Setting and selection of intervention and control intersections

Based on results from stage one, we selected three pairs of the 216 road intersections. Pairs were selected through a series of four steps designed to reduce bias in intersection selection. First, each pair was selected to include one intersection with conflicting left-turning vehicle-pedestrian traffic lights and one without conflicting traffic lights. Second and most important, the intersections were paired based on the best possible match of pedestrian flow per second and type of intersection ("4-leg intersections" or "T-intersections"). After

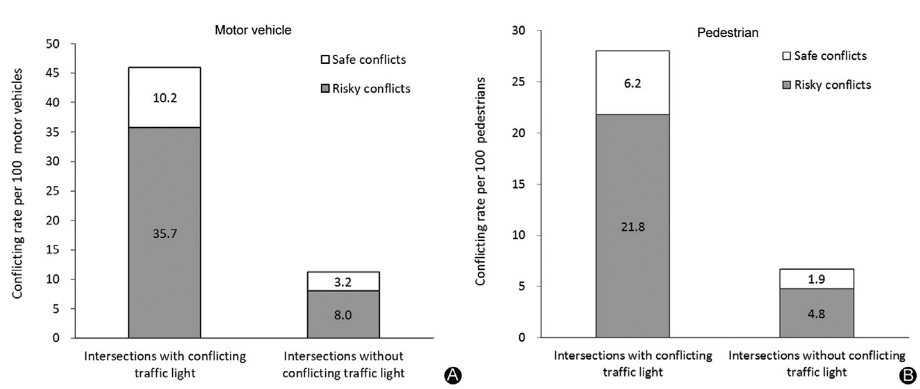

Fig. 1. Incidence of left-turning vehicle-pedestrian conflicts at road intersections for motor vehicles (A) and pedestrians (B) in Changsha city, China.

controlling for type of intersection, we selected the pairs with the closest pedestrian flow match. Third, we required all three pairs of selected intersections to have relatively large pedestrian flow – during all observation periods, at least 10 pedestrians entered sidewalks during each light cycle (i.e., when the green lights flashed for vehicles to turn left at a conflicting traffic light intersection). Intersections with conflicting left-turning vehicle-pedestrian traffic lights were treated as the intervention group and those without conflicting traffic lights as the control group.

Outcome measures

We were interested in two primary outcomes, transportation safety and transportation efficiency.

National law specifies that motor vehicles should yield to pedestrians when a vehicle-pedestrian conflict occurs, so we divided vehicle-pedestrian conflicts into two categories: (1) safe conflicts, in which motor vehicles actively yielded to pedestrians in front of a conflict (slowed or stopped to let pedestrians pass by first); and (2) risky conflicts, in which motor vehicles did not yield to pedestrians so pedestrians yielded or altered their course. Specifically, we tallied conflicts when a pedestrian crossed the crosswalk during the time that the light was green (and therefore vehicles were turning left) and either the pedestrian or the motor vehicle stopped or slowed their moving speed to yield to the other. The proportion of conflicts for motor vehicles was calculated as the number of motor vehicles involved in conflicts/the total number of motor vehicles × 100%. Similarly, the proportion of conflicts for pedestrians was calculated as the number of pedestrians involved in conflicts/the total number of pedestrians × 100%.

Transportation efficiency was assessed based on the number of pedestrians and motor vehicles passing through the crosswalk per second per meter, which was calculated as 'number of pedestrians and motor vehicles passing through the crosswalk divided by total observation time (in seconds) and the width of road (in meters)'. The number of motor vehicles was converted to account for vehicle size (relative to a minibus) according to the standards recommended by Shen.[9]

Covariates

Based on the literature,[10–12] we included the total number of people crossing the street, the width of road, the type of day (weekday vs. weekend), the time period of observation (peak hours vs. off-peak hours), and the total number of motor vehicles and pedestrians as potential covariates.

Prior research suggested peak and off-peak hours in Changsha were best defined as follows:[13]

Peak hours in weekdays: 7:30–8:30 a.m., 11:00 a.m.-1:00 p.m., and 5:30–6:30 p.m.; weekends: 10:30 a.m.-12:30 p.m., 5:30–6:30 p.m.

Off-peak hours in weekdays: 9:30–10:30 a.m., 3:00–4:00 p.m.; weekends: 8:00–9:00 a.m., 3:00–4:00 p.m.

Data collection

Portable cameras recorded the traffic flow of pedestrians and motor vehicles at each selected intersection. Recording occurred during five periods on weekdays and four periods on weekend days, with each time period lasting one hour. Therefore, 54 h of data were collected. Data were collected from May 1, 2015 to August 31, 2015.

Statistical analysis

Trained research assistants assessed the video and coded the number of vehicle-pedestrian conflicts and the type of each conflict (safe or risky) using an objective coding system. Bar charts were graphed to demonstrate differences in transportation efficiency and safety between road intersections with and without conflicting left-turning vehicle-pedestrian traffic lights.

Random-intercept Poisson regression examined the relation between transportation safety and having conflicting traffic lights at intersections by controlling for covariates mentioned above. Generalized linearized random-intercept models examined the association of transportation efficiency of pedestrians (and motor vehicles) with having conflicting traffic lights at intersections by controlling for covariates. We calculated adjusted incidence rate ratio (IRR) and 95% *CI* to quantify the association. "$p < 0.05$" was considered as statistically significant. Data processing and statistical analyses were performed through Microsoft Office Excel 2010 and Stata/IC 12.1. Data were analyzed from September 1, 2015 to December 31, 2015.

Online search of pedestrian injury news

We also used two national Chinese databases, *China National Knowledge Infrastructures* (CNKI; http://www.cnki.net/) and Baidu News search dataset (http://news.baidu.com), to search Chinese media news related to left-turning vehicle-pedestrian crashes between 2011 and 2017. We adopted the strategies by Li et al.[14] to expand search terms. Identified documents were retrieved and reviewed in full text, removing news stories that did not meet the inclusion criteria, discussing crashes between left-turning vehicles and pedestrians but not consisting of detailed information about pedestrian injuries. We also removed that repeated news from previously-identified.

Ethical considerations

All videos were confidentially protected by the research group, and only used for this research. This study was approved by the Medical Ethics Committee of Central South University of China.

Results

Stage one

We surveyed 216 intersections, including 137 4-leg intersections, 75 T-intersections and 4 Mid-block U-turns (Table 1). A total of 57 intersections were equipped with conflicting left-turning vehicle-pedestrian traffic lights, accounting for 26.4% of all observed intersections (95% *CI*: 20.5%, 32.3%). Conflicting left-turning vehicle-pedestrian traffic lights were more common at 4-leg intersections than the other two types of intersections we observed.

Stage two

Transportation safety

Fig. 1A illustrates that motor vehicles had a much higher rate of experiencing both safe and risky conflicts with pedestrians at intersections with conflicting traffic lights than at those without

Table 1
Proportion of intersections with conflicting left-turning vehicle-pedestrian traffic lights in Changsha city, China.

Type of intersection	Number of intersections	Intersections with conflicting pedestrian-vehicle light	
		Number	Proportion (%, 95% *CI*)
4-leg intersections	137	48	35.0 (27.1, 43.6)
T-intersections	75	9	12.0 (5.6, 21.6)
Mid-block U-turns	4	0	0
Total	216	57	26.4 (20.6, 32.8)

conflicting lights (safe conflicting rate: 10.2% vs. 3.2%; risky conflicting rate: 35.7% vs. 8.0%). Similarly, pedestrians were at higher likelihood of conflicts with motor vehicles at intersections with conflicting lights than at those without conflicting lights (safe conflicting rate: 6.2% vs. 1.9%; risky conflicting rate: 21.8% vs. 4.8%) (Fig. 1B).

Using random-intercept Poisson regression, Table 2 extends the results shown in Fig. 1A, B and suggests motor vehicles and pedestrians were significantly more likely to experience or be involved in risky vehicle-pedestrian conflicts at intersections with conflicting lights compared to those without conflicting lights after adjusting type of day (weekday vs. weekend), time period of observation (peak hours vs. off-peak hours) and traffic flow of motor vehicles or pedestrians (motor vehicles: IRR = 3.13, 95% *CI*: 1.59–6.18; pedestrians: IRR = 4.02, 95% *CI*: 2.66–6.06).

Transportation efficiency

Univariate analysis showed that the mean numbers of pedestrians passing through the observed intersections per second per meter was not statistically significant between intersections with and without conflicting lights; the mean pedestrians and 95% *CI*, respectively, were 0.0103 (0.0084, 0.0121) and 0.0108 (0.0083, 0.0132) per second per meter. The difference in the mean number of motor vehicles passing through the observed intersections per second per meter was also insignificant; the mean numbers and 95% *CI* for intersections with and without conflicting traffic lights, respectively, were 0.0100 (0.0088, 0.0112) and 0.0130 (0.0101, 0.0159) per second per meter.

Multivariate general linearized random-intercept models showed use of conflicting vehicle-pedestrian traffic lights at road intersections did not significantly increase transportation efficiency, $p > 0.05$, even after controlling for type of day (weekday vs. weekend), time period of observation (peak vs. off-peak hours) and traffic flow of motor vehicles or pedestrians (Table 3).

Online pedestrian injury news search

Our systematic online search for news stories describing crashes between left-turning vehicles and pedestrians yielded 1868 records. Following full-text review, we identified 10 news that met all inclusion criteria and were published between 2011 and 2017. The ten involved 10 non-fatal and 3 fatal pedestrian injuries, with six injuries occurring in 2017 (Fig. 2).

Discussion

A number of studies have examined the optimization of signalized intersection design on transportation efficiency[15,16] and assessed its impact on safety using mathematical modeling.[17–22] We extended these studies by studying real-world behavior at matched intersections to determine both transportation efficiency and pedestrian safety at intersections with left-turning conflicts. A total of 26.4% of road intersections in Changsha city, China were equipped with conflicting left-turning traffic lights for pedestrians and motor vehicles. We found considerable reduction in transportation safety at intersections with conflicting left-turning traffic lights, as indicated by increased dangerous yielding from pedestrians to motor vehicles while engaged in the shared roadway environment. No evidence suggested that conflicting left-turning traffic lights at intersections significantly increased motor vehicle efficiency or pedestrian efficiency. As there was no statistics on pedestrian injuries occurring from left-turning vehicle-pedestrian conflicts, we conducted an online search of published news reports in China. That search identified several fatal and serious crashes at intersection in spite of a very small portion that actually occurred. It further provides strong evidence that conflicting left-turning traffic light is potential risky even which should be taken seriously by the government authorities.

Our study was focused only in Changsha city, but the results indicated some concerns about signalized intersection design and safety across China. Since almost all roads in urban areas of China was built based on the national construction standards,[23] and all roads are managed by the road police department according to national transportation law,[7] many road designers and police officers in China believe that conflicting vehicle-pedestrian traffic lights would increase transportation efficiency without substantially lowering transportation safety. Our results contradict this belief. No doubt, safe design and use of traffic turn signals may improve safety for all road users,[24] however the conflicting intersection traffic lights may have a negative impact on road safety without improving road efficiency. Alternative designs such as separation of pedestrians from vehicles by using exclusive pedestrian signal phases, early release signal timing, and pedestrian overpasses/underpasses[25] could be considered to improve transportation efficiency and minimize the harm.

Our results also yielded several secondary findings. Consistent with previous studies, we showed that transportation efficiency of motor vehicles is high when there are fewer pedestrians crossing the road.[26,27] We further found that slow traffic flows were associated with fewer risky vehicle-pedestrian conflicts. Interestingly, in our study, weekday and peak hours were also associated with fewer risky vehicle-pedestrian conflicts. These findings are at odds with results which concerned red-light running and common traffic violations among bus drivers in Changsha (lower risks were found in off-peak hours (with adjusted violation rate ratio (VRR) of 0.94) and during weekend (IRR = 0.92)).[13,28] The inconsistencies may be due to different driving behavior of bus drivers versus other drivers, or our strategy to assess transportation safety using risky

Table 2
Random-intercept Poisson regression models for risky left-turning vehicle-pedestrian conflicts at road intersections.

Dependent variable	Independent variable	IRR (95% *CI*)	*p* value
Vehicle-pedestrian conflicts[a]	Weekday (Ref. = weekend)	0.85 (0.79, 0.92)	<0.0001*
	Peak hours (Ref. = off-peak hours)	0.82 (0.76, 0.89)	<0.0001*
	Intersection with conflicting light (Ref. = intersection without conflicting light)	3.13 (1.59, 6.18)	<0.0001*
	Total number of motor vehicles passing through crosswalk	1.0007 (1.0005, 1.0009)	<0.0001*
	Constant	0.09 (0.06, 0.15)	<0.0001*
Vehicle-pedestrian conflicts[b]	Weekday (Ref. = weekend)	0.90 (0.84, 0.96)	0.002*
	Peak hours (Ref. = off-peak hours)	0.82 (0.75, 0.89)	<0.0001*
	Intersection with conflicting lights (Ref. = intersection without conflicting lights)	4.02 (2.66, 6.06)	<0.0001*
	Total of pedestrians passing through crosswalk	1.0007 (1.0003, 1.0011)	<0.0001*
	Constant	0.05 (0.04, 0.07)	<0.0001*

Random part of random-intercept Poisson regression: model 1: alpha = 0.18, 95% *CI*: 0.06–0.55. Likelihood-ratio $\chi^2 = -181.791$, $p < 0.001$; model 2: alpha = 0.06, 95% *CI*: 0.02–0.21. Likelihood-ratio $\chi^2 = 152.63$, $p < 0.001$.
*$p < 0.05$. IRR: incidence rate ratio.
a Dependent and exposure variables were “risky vehicle-pedestrian conflicts” and “total number of motor vehicles passing through the crosswalk”, respectively.
b Dependent and exposure variables were “risky vehicle-pedestrian conflicts” and “total number of pedestrians passing through the crosswalk”, respectively.

Table 3
General linearized random-intercept models for transportation efficiency at road intersections.

Transportation efficiency	Independent variable	Coefficient	SE	*p* value
Pedestrians[a]	Weekday (Ref. = weekend)	0.0002	0.0013	0.871
	Peak hours (Ref. = off-peak hours)	0.0013	0.0015	0.401
	Intersection without conflicting lights (Ref. = intersection with conflicting lights)	−0.0005	0.0034	0.889
	Total number of motor vehicles passing through the crosswalk	3.80×10^{-6}	6.93×10^{-6}	0.583
	Constant	0.0089	0.0031	0.004*
Motor vehicles[b]	Weekday (Ref. = weekend)	−0.0001	0.0009	0.938
	Peak hours (Ref. = off-peak hours)	0.0010	0.0010	0.326
	Intersection without conflicting lights (Ref. = intersection with conflicting lights)	−0.0031	0.0042	0.467
	Total number of pedestrians passing through the crosswalk	-3.38×10^{-6}	2.46×10^{-6}	0.169
	Constant	0.0141	0.0032	<0.0001*

*$p < 0.05$.
[a] Transportation efficiency for pedestrians: Total number of pedestrians passing through crosswalk divided by time span of green traffic light (in seconds) and by the width of road (in meters); transportation efficiency for motor vehicles: Adjusted number of motor vehicles passing through crosswalk divided by time span of green traffic light (in seconds) and by half the width of road (in meters).
[a] Random part of general linearized model: model 1: sigma_u = 0.0038, sigma_e = 0.0048, rho (fraction of variance due to u_i) = 0.3842; model 2: sigma_u = 0.0050, sigma_e = 0.0032, rho (fraction of variance due to u_i) = 0.7156.

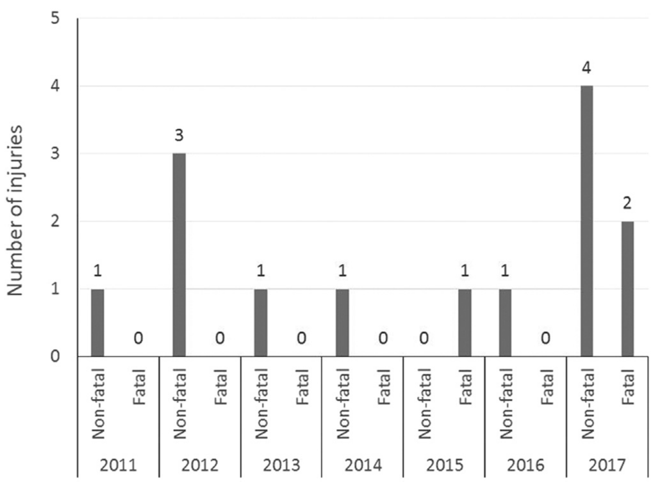

Fig. 2. Pedestrian injuries from left-turning vehicle-pedestrian conflicts at road intersections for pedestrians in China, reported in the online media, 2011–2017.

vehicle-pedestrian conflicts rather than actual crashes or injuries. Considering the substantial public health burden from road traffic crashes,[29] conflicting traffic lights should be minimized to reduce risky vehicle-pedestrian conflicts that likely result in unwanted road injuries and deaths.

Our study has its limitations. First, we observed intersections only in one city in China. Second, we only studied risky conflicts between motor vehicles and pedestrians because actual crashes, injuries and deaths are rare events that occur too infrequently to provide adequate data. Last, we did not study the impact of conflicting right-turn vehicle-pedestrian traffic lights, which may lead to similar threats to pedestrians.

We conclude that over one-quarter of intersections in Changsha, China were equipped with conflicting left-turning vehicle-pedestrian traffic lights. The conflicting lights significantly increased the probability of dangerous conflicts between vehicles and pedestrians that required one or both parties to yield. Transportation efficiency for neither motor vehicles nor pedestrians was improved at intersections with conflicting left-turning vehicle-pedestrian traffic lights. Road engineers and policymakers should reconsider the value of conflicting left-turning vehicle-pedestrian traffic lights at road intersections.

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Ethical statement

This study was approved by the Medical Ethics Committee of Central South University of China.

Conflicts of interest

There are no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cjtee.2018.07.007.

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