A Study of Injury Risk of Bicyclist and Pedestrian in Traffic Accidents in Changsha of China

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Abstract-The objective of the study is to measure the risk of pedestrian and bicyclist in urban traffic through an analysis of real-world accident data. The kinematics and injury mechanisms for both pedestrian and bicyclists are investigated to find the correlation of injury risks with injury related parameters. For this purpose, firstly 338 cases are selected as a sample from an IVAC accident database based on the In-depth Investigation of Vehicle Accident in Changsha of China. A statistic measurement of the fatality and serious injury risks with respect to impact speed was carried out by logistic regression analysis. Secondly, 12 pedestrian and 12 bicyclist accidents were further selected for reconstruction with MADYMO program. A comparative analysis was conducted based on the results from accident analysis and computer reconstructions for the injury risk, head impact conditions and dynamic response of pedestrians and bicyclists. The results indicate that bicyclists suffered lower risks of severe injuries and fatalities compared with pedestrians. The risks of AIS 3+ injury and fatality are 50% for pedestrians at impact speeds of 53.2 km/h and 63.3 km/h, respectively, while that for bicyclists at 62.5 km/h and 71.1 km/h, respectively. The findings could have a contribution to get a better understanding of pedestrians' and bicyclists' exposures in urban traffic in China, and provide background knowledge to generate strategies for pedestrian protection.

Key Word: pedestrian; bicyclist; injury risk; dynamic response

1 INTRODUCTION

As the vulnerable road users, pedestrians and bicyclists represent the population with high risk of traffic fatalities and injuries since they are unprotected in vehicle collisions. In 2010, in traffic accidents there are reported fatalities of 16281 for pedestrians and 4616 for bicyclists (TAMPS 2010), respectively, based on police data in China. In total of the killed pedestrian and bicyclist accounted for 32% of all traffic fatalities, which indicated a high risk of unprotected pedestrians and bicyclists in public transportations in China. Therefore, it is vital to make in depth investigations of the injury risk and mechanisms of such vulnerable road users and to prevent the accidents and injuries.

To date, many studies focusing on the risk of pedestrian injury and fatality in traffic accidents have been carried out in different countries. By analyzing the real-world accident data, the previous studies presented that (1) injury severity among pedestrians strongly depended on the impact speed; (2) the risk of pedestrian injury and fatality can be well-known functions of impact speed and there was a positive relation between them. Typically, the fatality risks have been found in a range of 45-85% at an impact speed of 50 km/h from studies using accident data before 1980 (Yaksich, 1964; Ashton,1980; Anderson et al.,1997), and in a range of 8-34% at the same impact speed from studies using data after 1990 (Hannawald and Kauer,2004; Oh et al., 2008; Cuerden et al.,2007; Rosén and Sander,2009; Kong and Yang, 2010). An overview and the precision of fatality risk curves from the previous study was presented and discussed by Rosén et al. (2011).

As for studies about the safety issue of bicyclists, accident analysis of collisions between vehicles and bicyclists have been carried out in several countries. Rasanen and Summala (1998) investigated vehicle–bicyclist accidents in Finland and reported that neither the bicyclist nor the driver was aware of the risk of a collision in approximately 40% of the cases. Kroon (1990) reported a high frequency of side collisions in vehicle–bicycle accidents in Gothenburg, Sweden. Many studies have shown that bicyclists face high injury risks in accidents with vehicles (Eilert-Petersson and Shelp, 1997; Robinson, 2001; Attewell et al., 2001). Head injuries to bicyclists have been shown to be the main causes of death similar to other road users (Stutts and Hunter, 1999; Ishikawa et al., 1991; Mizuno and Ishikawa, 2001). The location of head impact against the vehicle differed depending on the position of the bicyclist at the time of the collision (Otte, 1980 and 1989; Maki et al., 2003). However, in China, research on bicyclist accidents is still not enough to compare with that of pedestrian and the exposure of bicyclists in public transportation has never been measured quantitatively using real-world accident data.

This study was to measure the risk of pedestrian and bicyclist in urban traffic in China through the analysis of real-world accident data. A selected data set for the study was based on in-depth investigations of real-world traffic accidents collected from Changsha in China. The logistic regression analyses were conducted using the data set to find the risk function for pedestrian and bicyclists casualties related to the vehicle impact speed. Furthermore, the kinematics and the injury mechanisms are investigated for protection of both pedestrian and bicyclist from traffic accidents with the method of accident reconstructions. The knowledge developed from this study would be prerequisite for generating strategies for pedestrians and bicyclists protection from vehicle collisions in China.

2 METHOD AND MATERIAL

2.1 Data and criteria of selection

In current study, accidents that were sampled from an accident database based on the In-depth Investigation of Vehicle Accident in Changsha (IVAC) should follow the sample criteria as follows: (1) the accident was a frontal impact that occurred between 2003 and 2010; (2) the age of bicyclist or pedestrian was above 14; (3) the injury according to Abbreviated Injury Scale (AIS) was 1+; (4) passenger vehicle involved in the accidents; and (5) the vehicle impact speed can be determined. Finally, 338 cases (288 pedestrian cases and 50 bicyclist cases) are selected as a sample from the accident database IVAC. This sampling procedure is intended to provide a sample to represent the whole investigation area. However, due to different reasons (some accidents with minor injuries are resolved on site by consultation between participants and the investigator and traffic policemen do not go to accident scene; some detailed fatality accident information cannot be collected from traffic policemen and person involved accident because these accidents involved allocation of weighty responsibility and huge compensation that belong to secret information in police station), some minor injury cases and fatality cases were not collected and documented. This phenomenon leads to an over-representation of severe accidents. To reduce the influence of this phenomenon, we weight the sample data with Changsha police data. All pedestrian and bicyclist accidents happened from 2003 to 2007 were provided to derive the weighting factors. Table 1 presents the distributions of pedestrian and bicyclist injury severities for Changsha police data and IVAC final sample respectively.

Table 1 Distributions of pedestrian and bicyclist injury severities

	Slight	**Severe**	**Fatal**
Changsha (pedestrian accidents, 2003-2007)	68.4%	12.4%	19.2%
Changsha (bicyclist accidents, 2003-2007)	78.5%	11.7%	9.8%
IVAC final sample (pedestrian accidents, 2003-2010)	40.3%	47.2%	12.5%
IVAC final sample (bicyclist accidents, 2003-2010)	82.0%	12.0%	6.0%

From the data in Table 1, the final and normalized weight factors for pedestrian and bicyclist cases in IVAC final sample are straightly derived as follow: Wp_{slight}=1.7, Wp_{severe}=0.26, Wp_{fatal}=1.54, Wb_{slight}=0.96, Wb_{severe}=0.98, and Wb_{fatal}=1.63. A statistic analysis was carried out to measure the fatality and serious injury risk with respect to impact speed based on the weighted sample.

2.2 Statistical analysis

A single logistic regression model of the fatalities or AIS 3+ injuries risks for bicyclist and pedestrian was developed in terms of vehicle impact speed. The corresponding risk function P(v) is

$$P(v) = \frac{1}{1 + \exp(-a - bv)}$$

where v is the impact speed, and the coefficients a and b are estimated using the method of maximum likelihood.

2.3 Accident reconstruction

2.3.1 Examples of accident cases

Accident case 1: a car to pedestrian accident

A 26 years old male adult pedestrian was hit by a Buick car (2006 model) at speed about 60 km/h. The car was driving from east to west and the pedestrian was running to cross the road from south to north. The driver did not notice the pedestrian until the collision happened. The contact dents and cracks were visible on the leading edge of the hood, the hood top and windscreen. The contact dents were identified as the result of the pelvis and upper torso impact, and the cracks on windscreen were due to head impact. The measured wrap distance (WAD) was 2020. The throw distance was about 19 m from initial impact.

The pedestrian was seriously injured on the head/brain, including right temporal epidural hematoma, bilateral intracerebral hemorrhage and scalp hematoma over left forehead. The lower extremity in right side also suffered injuries of tibia fracture, fibula fracture and femur comminuted fracture.

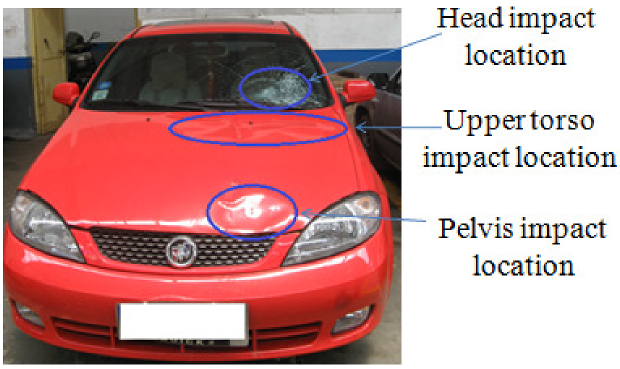

Fig.1. The head impact location on the windscreen of the car in adult pedestrian accident

Accident case 2: a car to bicyclist accident

A 58 years old male bicyclist was hit by a VW Santana car on a straight road. The driver was driving the car from south to north at speed about 40 km/h. A bicyclist suddenly turned left and wants to cross the road from east to north. The driver braked the car, but he could not avoid a stuck to the left side of bicyclist. The brake distance from initial impact was about 7-7.5 m. The throw out distance of bicyclist and bicycle were about 4-4.5 m and 5-6 m. The windscreen was damaged due to the head and upper torso impact (Fig. 2). The measured WAD was 2030 mm.

There were obvious skid marks on scene and the maximal length reached to 8.2m (Fig.1). In addition, the throw out distances of bicyclist and bicycle were around 4m±2m and 5±2m respectively. Figure 2 showed clear first impact point found on the right edge of bonnet and some fragments on the lower windscreen.

The bicyclist sustained cerebral concussion as well as skin and soft tissue contusion on many parts of body.

Fig.2. The head impact location on the windscreen of the car in adult bicyclist accident

2.3.2 Reconstruction models and simulation

From the sample cases above, 24 cases (12 pedestrian cases and 12 bicyclist cases) with detailed information are reconstructed with MADYMO.

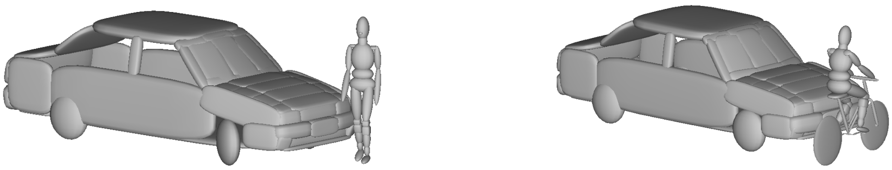

Fig.3. reconstruction models of car-pedestrian (left) and car-bicycle/bicyclist (right)

In the current study, a validated pedestrian model (Yang, 1997; Yang et al., 2000) was employed, from which the computed models were scaled according to the real height and weight of victim in each reconstruction with the "GEBOD" code in MADYMO. The model consists of 52 rigid bodies, with an outer surface described by 24 ellipsoids. This model was efficiently used in previous studies of vehicle-pedestrian and vehicle-bicyclist reconstructions (F. Li and J.K. Yang, 2010; Mo Fuhao et al., 2010).

The mathematical models of vehicle and bicycle were developed based on the drawing of production cars and bicycles involved in the accidents respectively. The stiffness characteristics of the car front were defined based on the Euro-NCAP test results of similar cars (Luis et al., 2007). The relative motion between each part of bicycle was modeled by different types of joint and the contact stiffness properties of the bicycle model were obtained from test results (Tetsuo Maki and Janusz Kajzer, 2001). The initial speed and posture of pedestrians and bicyclists was defined based on the collected accident information. Fig.3 gives an example of car-pedestrian and car-bicycle/bicyclist reconstruction models.

The rest positions of vehicle, pedestrian or bicyclist, and bicycle between simulations and real-world accidents are compared to validate the accident reconstruction.

3 RESULTS

3.1 *Statistical analysis* results

The proportion of pedestrian accidents and bicyclist accidents observed at different impact speed intervals are presented in Fig. 4.

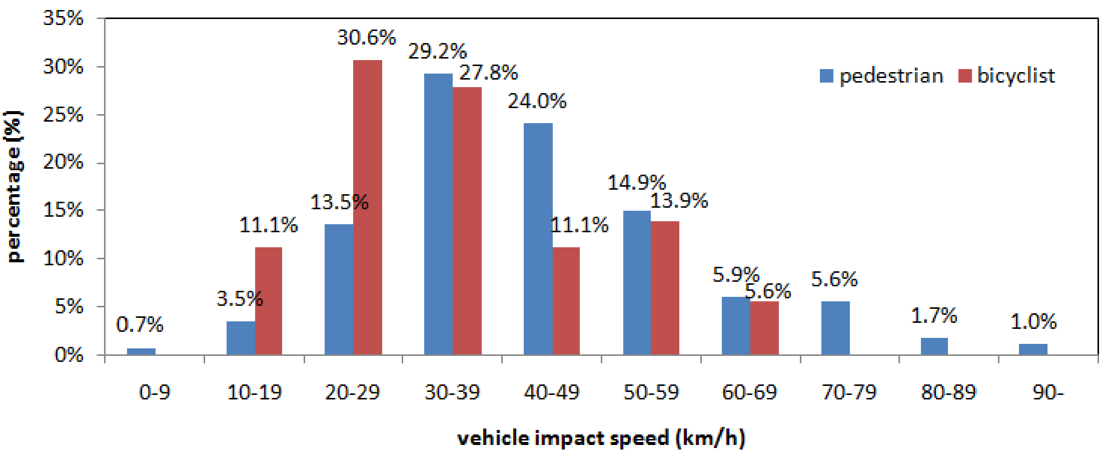

Fig. 4 Distribution of vehicle impact speed for pedestrian and bicyclist cases

From the Figure, it can be seen that approximately 42% of bicycle accidents occurred at the vehicle impact speed below 30 km/h, whereas only 35% of pedestrian accidents happened in this speed range. For bicyclists, only 5.6% of the cases occurred at velocities above 60 km/h, while 14.2% of pedestrian accidents occurred in this range. The average impact speed for pedestrian accidents and bicyclist accidents are 39.5 km/h and 37.5 km/h respectively. These results obviously show that the possibility of collisions occurred at higher impact speeds is larger for pedestrian accidents than for bicyclist accidents.

The number of accidents involved pedestrian and bicyclist, and their AIS 3+ injuries and fatalities rate observed at different impact speed intervals are presented in Table 2 and Table 3. With the weighted final IVAC sample, the logistic regression model of the risk for AIS 3+ injuries and fatalities of pedestrian and bicyclist were developed in terms of vehicle impact speed at the 95% confidence level respectively. The corresponding AIS 3+ injury risk p (v) derived for pedestrian is:

$$P(v) = \frac{1}{1 + \exp(4.8964 - 0.092v)} \quad (1)$$

and derived for bicyclist is:

$$P(v) = \frac{1}{1 + \exp(5.8296 - 0.0933v)} \quad (2)$$

The corresponding fatality risk p (v) derived for pedestrian is:

$$P(v) = \frac{1}{1 + \exp(5.549 - 0.1035v)} \quad (3)$$

and derived for bicyclist is:

$$P(v) = \frac{1}{1 + \exp(8.7026 - 0.1224v)} \quad (4)$$

where v is the impact speed in km/h.

Table 2 Summary of epidemic data for pedestrian and bicyclist AIS 3+ injuries

Impact speed (km/h)	All cases (p)	All cases (b)	AIS 3+ injuries					
			N (p)	%	$Weight_p$%	N (b)	%	$Weight_b$%
0-9	2	0	0	0	0.0	—	—	—
10-19	10	4	4	40.0	9.3	0	0.0	0.0
20-29	39	11	10	47.6	5.0	1	9.1	9.3
30-39	84	13	40	25.6	14.8	1	7.7	7.8
40-49	69	8	47	68.1	41.3	0	0.0	0.0
50-59	43	8	32	74.4	36.8	3	37.5	42.8
60-69	17	4	16	94.1	84.5	2	50.0	57.6
70-79	16	2	15	93.8	90.8	2	100	100
80-89	5	0	5	100	100	—	—	—
90-	3	0	3	100	100	—	—	—

Table 3 Summary of epidemic data for pedestrian and bicyclist fatalities

Impact speed (km/h)	All cases (p)	All cases (b)	Fatalities					
			N (p)	%	N (b)	%	$Weight_{pf}\%$	$Weight_{bf}\%$
0-9	2	0	0	0	—	—	0.0	—
10-19	10	5	0	0	0	0.0	0.0	0.0
20-29	39	10	0	0	0	0.0	0.0	0.0
30-39	84	13	2	2.4	0	0.0	3.5	0.0
40-49	69	8	11	15.9	0	0.0	26.6	0.0
50-59	43	8	2	4.7	1	12.5	10.4	19.4
60-69	17	4	4	23.5	1	25.0	56.1	36.0
70-79	16	2	10	62.5	1	50.0	83.7	62.5
80-89	5	0	4	80.0	—	—	96.0	—
90-	3	0	3	100	—	—	100	—

Remarks: p represents pedestrian and b represents bicyclist.

The curves of AIS 3+ injury risk and fatality risk are generated and provided in Fig. 5.

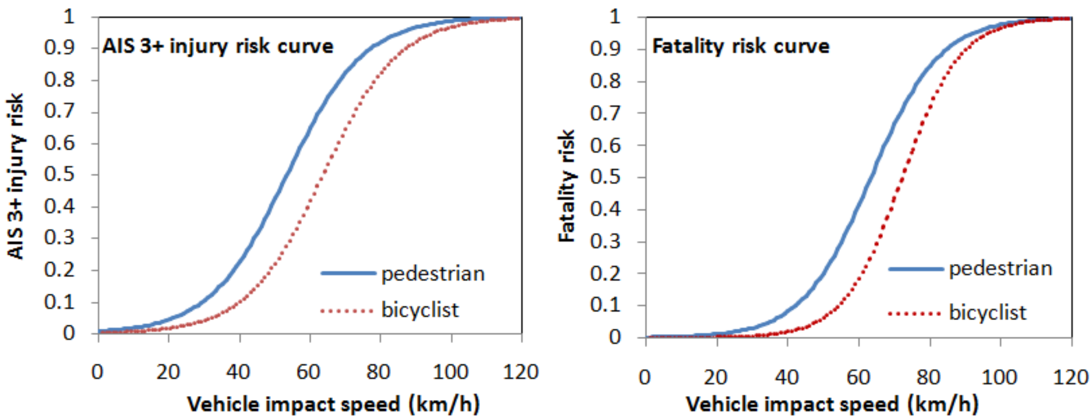

Fig. 5 AIS 3+ injury risk (left) and fatality risk (right) between pedestrians and bicyclists

Based on the functions 1-4, the statistically significant relationship was validated by Chi-Square test. The values are χ^2 = 91.6549, and p < 0.0001 for function 1, χ^2 = 12.1804, and p = 0.0005 for function 2, χ^2 = 91.0629, and p < 0.0001 for function 3 and χ^2 = 9.3893, and p = 0.0022 for function 4. These test results indicated that the impact speed not only has statistically significant relationship with AIS 3+ injury and fatality risk of pedestrian, but also has statistically significant relationship with that of bicyclist.

From the Fig. 5, we can see that both AIS 3+ injury risk and fatality risk of bicyclist are lower than that of pedestrian. Functions 1-2 demonstrate that the risk of AIS 3+ injury is 10.6% at impact speed of 30 km/h, 42.6% at 50 km/h, and 82.4% at 70 km/h for pedestrian, 4.6% at 30 km/h, 23.8% at 50km/h, and 66.8% at 70 km/h for bicyclist. Similarly, Functions 3-4 demonstrate that the risk of fatality is 3.1% at impact speed of 30 km/h, 20.2% at 50 km/h, and 66.7% at 70 km/h for pedestrian, 0.6% at 30 km/h, 7.0% at 50km/h, and 46.5% at 70 km/h for bicyclist.

3.2 Accident reconstruction results

The head impact point of pedestrian and bicyclist could be defined by the wrap-around distance (WAD) along the frontal surface of the car, and the location of head impact point on the vehicle affects the head injuries of pedestrians and bicyclists greatly. Fig. 4 shows the distribution of head impact points on bonnet, windscreen and screen frame. For pedestrians, the head struck on the bonnet, lower part of windscreen or the screen frame, while most of head impact points are on the middle and upper part of windscreen or A-pillar. The average values of WAD for pedestrians and bicyclists are 1819 mm and 1972 mm. Meantime, Fig. 6 also obviously indicates that head collisions with windscreen frame and locations close to the frame are more likely to result in serious injuries (AIS 3+).

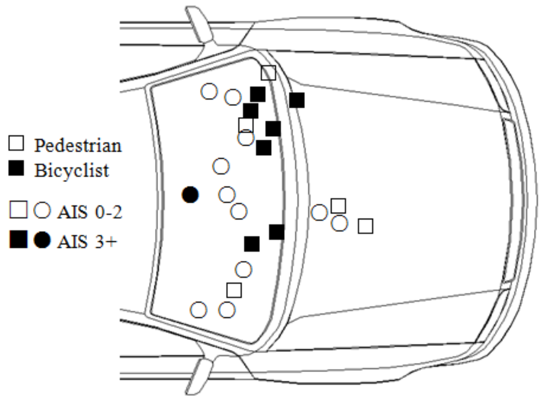

Fig. 6 Distribution of head impact location

The comparison between head relative impact speed and vehicle impact speed of pedestrian and bicyclist is showed in Table 4. For pedestrian cases, the head relative impact speed increases with vehicle impact speed and discrepancy between them is not obvious. However, for bicyclist cases, the trend between head impact speed and the vehicle impact speed is not so obvious as pedestrian cases, and the head relative impact speed is obviously smaller than vehicle impact speed when vehicle impact speed exceeds 30 km/h. The average value of the vehicle impact speed and head relative impact speed are 38.6 km/h and 34.7 km/h for pedestrian cases; while the mean are 33.8 km/h and 25.3 km/h for bicyclist cases.

Table 4 Summary of head relative impact speed, vehicle impact speed and WAD

Case number	Impact speed (km/h)	Head relative impact speed (km/h)	WAD (m)	Case number	Impact speed (km/h)	Head relative impact speed (km/h)	WAD (m)
P1	22.3	13.1	1.46	C1	21.6	22.2	1.72
P2	27	24	2.1	C2	24.5	23.3	2.03
P3	28.6	23.6	1.85	C3	26.6	24.6	2.25
P4	30.2	27.9	1.94	C4	30.2	28.4	1.97
P5	31	36	1.92	C5	31	19.8	1.55
P6	33.4	28.3	1.65	C6	32.4	19.4	2.02

P7	34.2	35.3	1.6	C7	35.6	21.5	2.05
P8	40	33	1.75	C8	37.8	33	2.04

Table 4 Summary of head relative impact speed, vehicle impact speed and WAD

Case number	Impact speed (km/h)	Head relative impact speed (km/h)	WAD (m)	Case number	Impact speed (km/h)	Head relative impact speed (km/h)	WAD (m)
P9	43.6	30	1.73	C9	40	34.2	1.87
P10	54.8	54	1.71	C10	40	16.9	1.97
P11	57.6	47.9	2.02	C11	42	30.7	2.04
P12	60	62.9	2.1	C12	44	30.6	1.95

Head impact angle of all pedestrian and bicyclist cases are presented in Fig. 7. It can be seen that the pedestrian head impact angles fluctuate from 42.7°to 77.8°, with the mean value of 61.8°, while that for bicyclists are ranged from 41°to 80°, with the mean value of 60.2°.

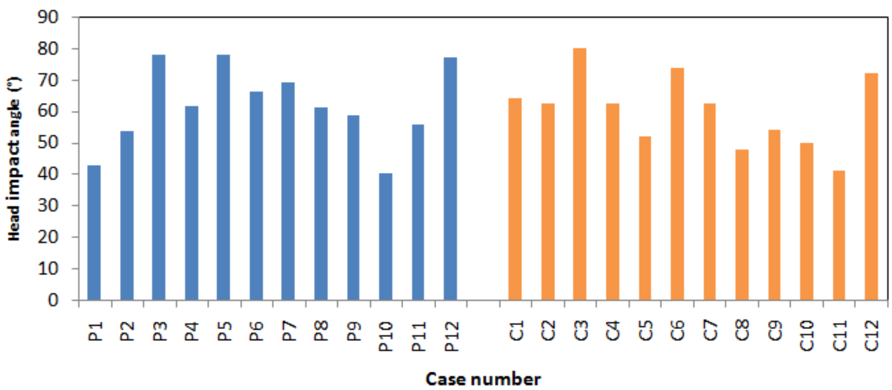

Fig.7. Head impact angle

The head impact time was defined as the time duration during the first contact of human body and head contact with vehicle. Fig. 8 shows that the head impact time for both pedestrian and bicyclist appears to be an inverse proportional to the vehicle impact speed. Strong correlations were found between the head impact time and vehicle impact speed with the calculated correlation coefficients (R2) of 0.824 and 0.868 for pedestrian and bicyclist respectively. The pedestrian head impact time varies from 82 ms to 221 ms while the range for bicyclist is from 130 ms to 255.4 ms. The average head impact time with standard error for pedestrian is 131.3 (±43.8) ms and 181.2 (±37.6) for bicyclist. This means that the head impact time of bicyclist is usually later compared with that of pedestrian in accident under the similar situation.

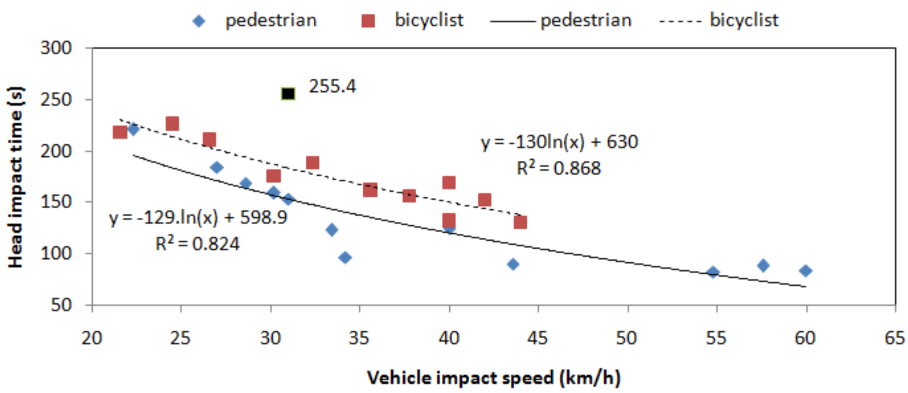

Fig.8. Relation of head impact time to vehicle velocity

The relationship between vehicle impact speed and throw out distance (TOD) for all considered cases are shown in Fig. 9. Generally, the TOD of both pedestrians and bicyclists grows with the increase of vehicle impact speed. A strong correlation between TOD and vehicle impact speed is found for bicyclists with R2 of 0.767. Furthermore, for pedestrian, a statistically significant relationship between is found with R2 of 0.919. Additionally, Fig. 9 also demonstrates that the difference of TOD that observed in pedestrian and bicyclist cases is small at the same vehicle impact speed.

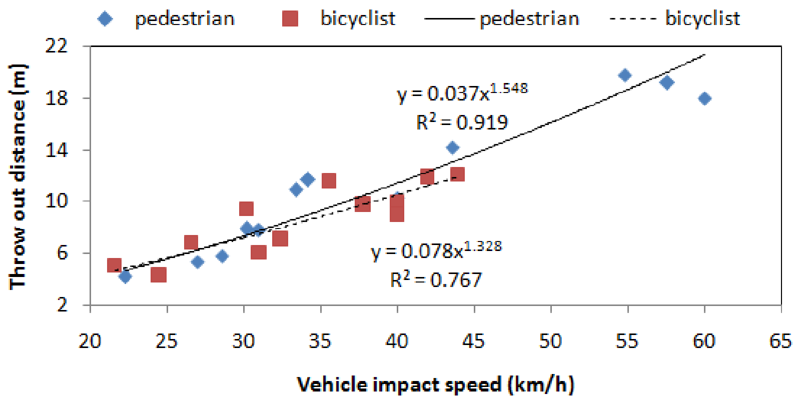

Fig.9. Relationship between throw distance and impact speed

4 DISCUSSION

In the current study, the IVAC final sample was selected from the in-depth investigation database in Changsha. From Table 1, we can see that the proportions of pedestrian slight injury cases and fatal cases in police data from Changsha are 68.4% and 19.2%, which is much higher than that in IVAC final sample. The same phenomenon exists in bicyclist accidents. The potential explanation for this phenomenon is that large number of slight injury cases and fatal cases were not collected and documented in IVAC. Although police data from Changsha was provided to weighting in this study, since some slight injury cases and non-injury cases were not collected and documented into police data, the AIS 3+ injury risk and fatality risk derived from weighted IVAC final sample are still higher than that in realistic.

Fig. 3 shows that pedestrians expose to much higher impact speed environment than bicyclists. The most probable reasons for this phenomenon are as follow: first, it is much easier for drivers to observe bicyclist or bicycle than pedestrian owing to the great apparent area of bicyclist with bicycle, which makes divers take measures in advance to decrease the vehicle travelling speed. Second, bicyclist cannot do anything such as looking down to play phone like pedestrian, which makes them pay more attention to the coming cars than pedestrian in high travelling area. It greatly decreases the incidence of car-bicyclist accidents in high impact speed.

From the results of statistic analysis in current study, the pedestrian fatality risk is 3.1% at impact speed of 30 km/h, 20.2% at 50 km/h, and 66.7% at 70 km/h. Compared these results with the study by Rosén and Sander et al. (2009), the fatality risks derived from IVAC final sample are approximately 2.1, 2.4 and 1.9 times than later at each impact speed. Except the reason mentioned above, another reason is that the emergency and medical care are less developed in China than that developed in Germany.

The current study found that injury and fatality risk of pedestrian and bicyclist have a statistically relationship with vehicle impact speed, which is coinciding with the conclusion of the studies by Maki et al. (2003). Passenger cars pose a higher risk to pedestrians than bicyclists. One reason for this is that the proportion of bicyclist accidents taken place at relative low impact speed is higher than that of pedestrian.

Accident reconstruction results demonstrate that the WAD is influenced by the geometry of vehicle frontal structure, impact speed, pedestrian height, bicycle cushion height and so on. Fig. 4 indicates that head impact locations of bicyclist are relative rearward on the cars compared with that of pedestrian. The discrepancy the mean of WAD between pedestrians and bicyclists is small, and both of them are in the range of 2100 cm, which is the limitation of European regulation for pedestrian protection. Therefore, in pedestrian protection regulations, the division of headform impact location on cars can be adequate for bicyclists.

Fig. 6 presents the fluctuation of head impact angle for pedestrians and bicyclists. The average value of head impact angle of pedestrians (61.8°) is almost the same with that of bicyclists (60.2°). This means that head impact angle in headform impact test for pedestrian protection can be applied to protect bicyclists when we make regulation for bicyclist protection.

For pedestrians, the head relative impact speeds are either higher or lower than the vehicle impact speeds but at a close level. However, for bicyclists, head relative impact speeds fluctuate at different vehicle impact speeds and there is an obvious discrepancy between them that all of the head impact speeds (except C1) are lower than the vehicle impact speeds (see Table 4). The reason to explain it maybe that bicyclist's heads attain a speed at the same direction with vehicle travelling during the sliding procedure on the bonnet due to the friction between bicyclist and vehicle, which reduces the head relative impact speed.

Accidents reconstruction results show that the head impact time of pedestrians and bicyclists decreases with the increase of vehicle impact speed. And the head impact time of bicyclists is usually later compared with that of pedestrian under similar impact condition. This relates to the difference of kinematic response between pedestrians and bicyclists. After the first contact with vehicle, bicyclists spend more time on sliding on the bonnet and the head trajectories of bicyclists are also much longer than that of pedestrians, which makes head of bicyclist take more time than pedestrian's head on the process of moving before contacting with vehicle.

TOD can be used to estimate the impact speed (Otte, 2004), especially the case that there is no clear skid mark on the accident spot. Fig. 9 illustrates that TOD of pedestrian has a stronger correlation with vehicle impact speed than that of bicyclist. The reason for this is that the influence to TOD of bicyclist riding speed is larger than that of pedestrian walking speed. The change of bicyclist riding speed will lead to a large fluctuation of bicyclists' TOD.

5 CONCLUSION

Through statistic analysis and accidents reconstruction for in-depth investigation traffic accidents, injury risk, head impact conditions and kinematics of pedestrians and bicyclists are compared in current study.

Based on in-depth investigation traffic accidents data, AIS 3+ injury risk and fatality risk of pedestrians and bicyclists were indentified quantitatively with logistic regression method. Vehicle impact speed has a significant relationship with AIS 3+ injury risk and fatality risk of bicyclist and pedestrian. The AIS 3+ injury risk and fatality risk of both bicyclist and pedestrian increased with the growth of vehicle impact speed. The AIS 3+ injury risk for pedestrians and bicyclists is 50% at impact speed of 53.2 km/h and 62.5 km/h respectively, while fatality risk for pedestrians and bicyclists is 50% at 63.3 km/h and 71.1 km/h respectively. This can provide theoretical foundation for determining vehicle speed limit in the areas with high frequency of car-pedestrian accidents or car-bicyclists accidents.

Accidents reconstruction results show that the average values of WAD and head impact angle of pedestrians and bicyclists are pretty much the same and the mean of head relative impact speed of pedestrians is larger than that of bicyclists. Therefore, the headform impact test in regulation for pedestrian can be fully applied to bicyclists.

There is a strong correlation between head contact time and vehicle impact speed for both pedestrians and bicyclists. Head impact time of pedestrian is less than that of bicyclists. It can provide background knowledge for determining employing time of devices that are used to protect head of both pedestrian and bicyclist.

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