A Comparison Study on Head Injury Risk in Pedestrian and Cyclist Accidents

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Abstract: Pedestrian and cyclist are the most vulnerable road users in traffic crash. This paper aims to make a comparison study on head injury risk and kinematics of adult pedestrian and cyclist accidents and to correlate of calculated injury related physical parameters with injuries observed in real-world accidents. A total of 20 passenger-cars to adult pedestrian and cyclist accidents were sampled from GIDAS database, Germany, of which 10 cases were pedestrian accidents and another 10 cases were cyclist accidents. Accidents were reconstructed by using PC-Crash and MADYMO program. The pedestrian and cyclist kinematics and physical injury parameters such as throw out distance, head impact velocity, head contact time, HIC value, 3ms linear head acceleration, maximum angular acceleration and head impact angular were calculated. Relationship curves were obtained based on the calculated parameters and logistic regression model was employed to study brain injury risk in terms of the calculated physical parameters. It is observed that different head injury risks and kinematics are existed between pedestrian and cyclist.
Keywords: Pedestrian and cyclist; Accident reconstruction; Head kinematics and injury; Comparison study

1 Introduction

About 25,000 pedestrians are killed in the traffic accidents each year in China [1]. In the European Union (EU) 7,000 pedestrians are killed each year, 5,000 in the USA, about 3,000 in Japan. Within the EU countries, the relative frequency of the pedestrian fatalities varies remarkably from 14% in Sweden to 32% in UK [2]. In Germany 440,000 road users were injured in 2004, the half of these were aged between 25 to 65 years old, 5800 fatalities could be registered in that year, 14% were pedestrians [3].According to the statistical data of China, of total the traffic fatalities about 60% were motorcyclists, pedestrians and cyclists during the year 2000 to 2005[4]. Compare to developed countries, the safety issue for vulnerable road users (VRUs) seems to be more urgent in the research of vehicle traffic safety in China.

During the last 20 years pedestrian safety has been widely studied and pedestrian protection becomes of increasing concern of the world, especially in the EU. Component subsystem tests for cars proposed by the European Enhanced Vehicle-safety Committee (EEVC/WG10 and WG17) were approved to assess pedestrian protection. Bicycles generally do not have a standardized structure and there is no conformity criterion for the material used, design and construction methods. Hence generic safety standard for bicycle riders have been very difficult to formulate and are not standardized yet. Relationship between variables (impact velocity, points of impact et al.) and cyclist throw distance were investigated previously [5-9]. Furthermore, some statistical and configuration analysis on cyclist accidents in different areas were investigated [10-12].The differences of head injury risks and kinematics between pedestrian and cyclist were not adequately investigated. Suitable protective strategies would be distinct for pedestrian and cyclist because of the different nature of the two kinds of accidents. In-depth accident investigation and accidents reconstruction is regarded as one of the efficient means to understand the head injury mechanisms in pedestrian and cyclist accidents.

This study is based on documented real accident cases of the year 2000 to 2007 in GIDAS (German In-Depth Accident Study) that were collected at the Accident Research Unit at the Medical University Hannover (ARU-MUH). This in-depth-investigation team has been collecting traffic accidents with injured casualties in a statistical random procedure by order of the German Federal Highway Research Institute BAST [13].The vehicle impact velocities considered in this study ranged from 25-50km/h. Each case contained information about the pre-crash, crash, and post-crash events. This information included hospital records and detailed description of damages to the accident vehicles, victims' injuries and the on-site environment collected at the scene.

The objective of this study is to identify the characteristic of head kinematics and injury risks of pedestrian and cyclist in crash based on accidents reconstructions results. The knowledge from this study is a prerequisite for developing guidelines to improve safety of vulnerable road users and with this perhaps the conceptual investigation for regular test procedures of cyclist head protection.

2 Method and Materials

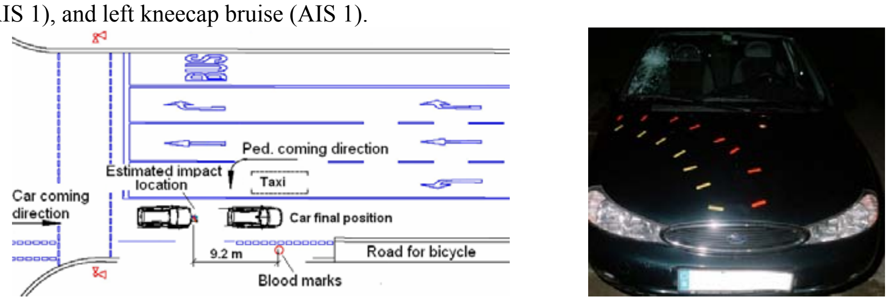
2.1 In-depth investigation and data collection

The first so-called "In-Depth Investigation Teams" were initiated in the 1970s by German automakers. In 1973, the Federal Road Research Institute established and independent team at Medical University of Hannover. Specialist teams go directly to the scene of the accident to collect the necessary information to complete detailed accident reconstructions as well as the medical data about how the involved people were injured and treated. In this way, extensive information about a wide range of fields of research such as " vehicle design for passive and active safety", " biomechanics", "driver behaviors ", "trauma medicine", " rescue services", " road design" and " road conditions" can be collected.

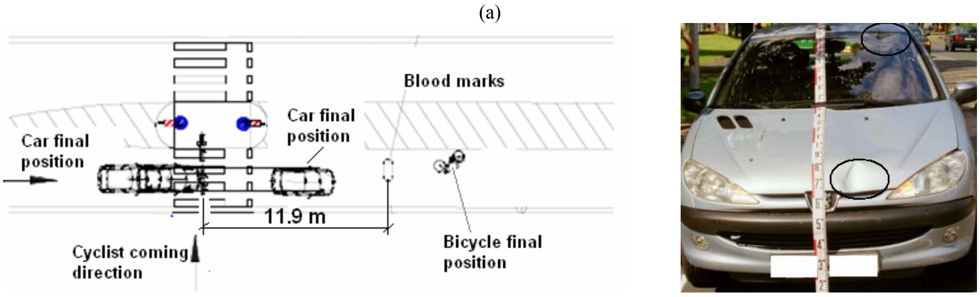
In order to decrease the influence of crash configurations, we have only considered the car-front to pedestrian/ cyclist side impact situation, which is one of the most prevalent crossing path crashes. Fig.1 shows an example of a pedestrian (a) and a cyclist (b) case, which respectively correspond to the case P6 in appendix Table 1 and case C10 in Table 2. All of the contact points to damage car were measure in x, y, z coordinate system.

A male pedestrian was hit by a Ford Mondeo with an estimated impact velocity about 40km/h when he got off the taxi and came across the street. The pedestrian was struck by the centre front of the vehicle, slid to the right along the hood and hit the head on the windshield The victim pedestrian was thrown away about10m and sustained 1 degree brain trauma (AIS 2), deep lacerations to forehead (AIS 1), nose (AIS 1) and right ear (AIS 1), lacerations to the fingers on the left and right hand (AIS1), and ligament rupture to the right knee (AIS 2).

A female cyclist was hit by a Peugeot 206 with an estimated impact velocity about 40km/h when she past the street at the crosswalk. The travelling speed of cyclist was estimated about 5km/h. The car bonnet edge struck the upper leg of the cyclist and the upper edge of windscreen struck the cyclist`s head. Obvious dent on bonnet edge and crack on windscreen were shown in Fig.1 (b). The victim cyclist was thrown away about 12m and sustained 1 degree brain trauma (AIS 2), Nasal bone fracture (AIS2), right and left shoulder bruise (AIS 1), and left kneecap bruise (AIS 1).



(a)



(b)

Fig.1 Sketches of the accident scene and photos of damage to the involved vehicle (a: Pedestrian; b: Cyclist)

2.2 Procedure of Accident reconstruction

Reconstructions in this study included two parts: PC-Crash simulation and MADYMO simulation. Fig.2 shows the schematic illustration of reconstruction combining the two programs. A scaled on-site sketch of the accident scene is important for PC-Crash simulation. Estimated initial impact location, rest positions of accident vehicle and victim, brake traces (if available) and some other marks are involved on the sketch. Vehicle information contains the damages of accident car, type, model and manufacture and so on. Victim information mainly includes the height, weight, year, injury parts and severity. Witness statements may include information about initial stance of victims at the moment of impact; however, not all cases can be witnesses available.

The initial setup of car velocity and dynamics in MADYMO reconstructions was based on the PC-Crash simulation results. The pedestrian orientations and positions in MADYMO simulation are approximated by associating the pedestrian injuries with the car impact points. Parametric studies concerning the velocity of accident car and stance of the pedestrian, pitch angle during the braking were performed in refine iterations to find the best correlations with all indications of in-depth on-site investigations. The final configuration which reproduced the same impact points on the car, the same injuries and throw out distance to the real accident was retained.

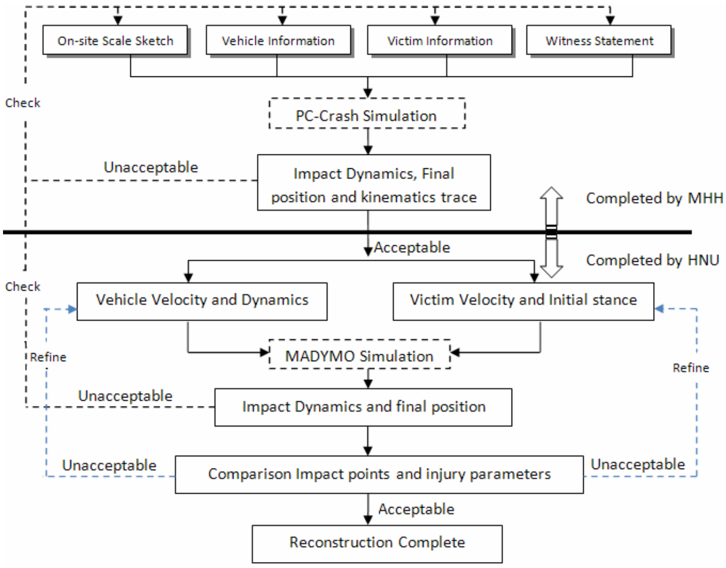


Fig.2 Schematic illustration of accident reconstruction combining PC-Crash and MADYMO

2.3 Vehicle model development

For vehicle-front-end impacting vulnerable road user accidents, there are 10 key parameters for the development of vehicle model (Fig.3). Vehicle models were developed based on the drawing of production cars with the same model and year as the accident car. The stiffness characteristics of the car front were defined based on the Euro-NCAP test results of similar cars [14].

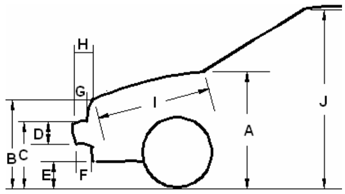
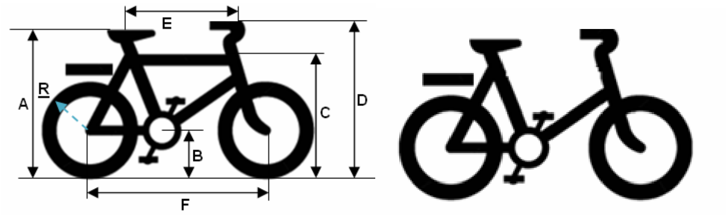


Fig.3 Key front-end parameters of MBS vehicle model development (A: Hood rear-end height; B: Hood front-end height; C: Bumper upper-edge height; D: Bumper width; E: Board lower-edge height; F, G, H: Bumper lead length; I: Bonnet length; J: Windscreen upper-edge height.)

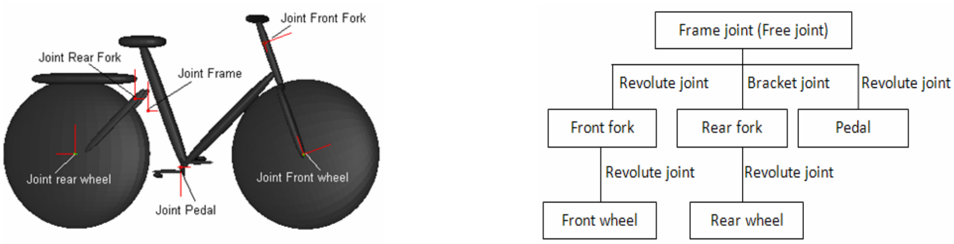
2.4 Bicycle model development

In this study, involved bicycles can be divided into two types: with and without crossbeam (Fig.4a, b). Six key dimensions parameters were defined to model bicycle, which were seat cushion height A, axes height B, crossbeam height C, handlebar height D, wheelbase F and distance of handlebar to seat E (Fig.4a). Bicycles were modeled as a system of rigid bodies linked together with joints. The location of these joints and the joint types determine what kind of relative motions of the linked parts. Because all of other joints were attached to the frame joint, velocities could be load on it to simulate the movement of bicycle. Fig.5 shows the joints distribution and hierarchy. All parts of the bicycle were regarded as rigid body because of the lack of bicycle contact characteristic.



(a) (b)

Fig.4 Bicycle type and key parameters for model development



(a) (b)

Fig.5 Bicycle joints distribution (a) and hierarchy (b)

2.5 Scaling of pedestrian and cyclist models

The standard human model employed in this study was developed by TNO, which has been validated extensively [15-16]. The scaling of human models can be done by using MADYMO/SCALER [17], which generate pedestrian and cyclist models based on the real victim`s height and weight. The advanced no-linear scaling methods enable scaling of all mechanical parameters, including stiffness and damping. Different scaling factors are applied for x, y and z directions. Furthermore, different scaling factors are applied for different body parts. Thus the model geometry can be adapted freely to the desired anthropometric parameters. The methods enable scaling of all mechanical parameters, including geometry, sensor locations, mass and moment inertia, joint characteristics, contact characteristics and so on.

2.6 Contact interactions

Multi-body contact interactions were defined as ‘ellipsoid-ellipsoid’ using the force penetration functions. Different friction coefficients were applied to various contact surfaces according to different weathers and other environment conditions, as well as a small amount of damping (Table 3).

Table 3 Friction coefficient of different contact surfaces

Pedestrian/cyclist-vehicle	Pedestrian/cyclist-ground	Vehicle-ground	Vehicle-bicycle	Cyclist-bicycle
0.3~0.5	0.5~0.7	0.55~0.75	0.3~0.5	0.4~0.5

2.7 Statistical methods

Quadratic polynomial regression model was employed to study the relationship between victim kinematics responses and vehicle impact velocity. A quadratic equation has the form of:

$$y=A+Bx+Cx^2$$

Where A is the y-intercept and B and C are constants. The calculated correlation coefficient R2 was used to describe the strength of the relationship and the regression curves illustrated the relationship.

Logistic regression is a form of regression which is used when the outcome (response) variable is binary and the predictor variables are continuous, categorical, or both. S-shaped regression curves were generated to illustrate the relationship. In this study, the examination of brain injury risks p(x) relative to the calculated injury parameters x was performed with the logistic function:

$$p(x) = 1/\left(1+e^{\alpha-\beta x}\right)$$

Where α is the intercept and β is the regression coefficients of x. Parameters α and β are determined using maximum likelihood method to maximize the function's fit to the data. Goodness-of-fit of the statistical model was examined by means of chi-squared χ^2. The probability value P is associated with χ^2. The relationship between injury and predictor variables is statistically significant when the probability value is at the level of $P \leq 0.05$. When $x = \alpha/\beta$, p(x) has a bending point with a maximum or minimum value for the slope and p(x) = 50% level. So the value of α/β gives the median of the distribution of predicted head injuries over values of x.

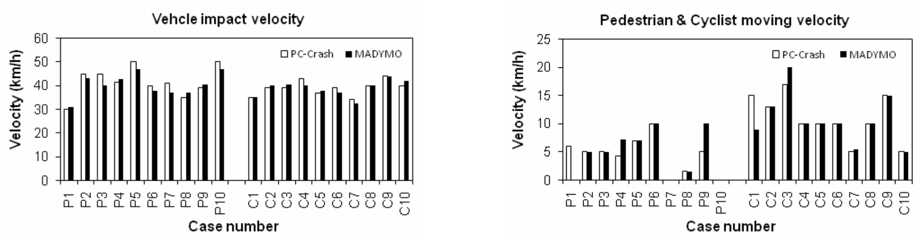
3 RESULTS

Calculated physical parameters of pedestrian and cyclist kinematics response were summarized in appendix Table 4.

3.1 Comparison of PC-Crash and MADYMO simulation results

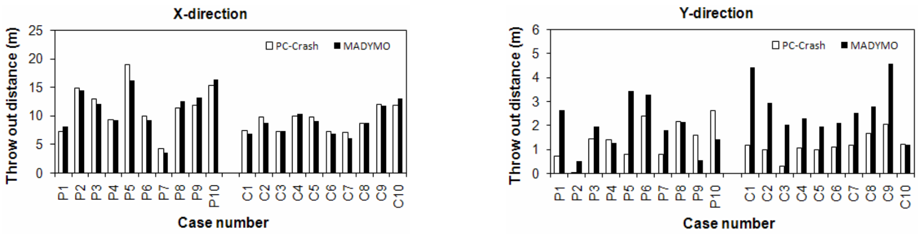
Initial impact conditions of MADYMO simulation were set according to PC-Crash results. However, there could be some adjustments in order to get the best correlations with all indications of in-depth on-site investigations. The results show that vehicle impact velocities were quite close in the two kinds of simulations. Some discrepancies appeared in pedestrian and cyclist velocities (Fig. 6).

In this study, distance between the estimated collision point and the final position of the body is defined as the throw out distance. Fig. 7 shows the throw out distance in X and Y direction, of which X-direction was the car coming direction and Y-direction was the perpendicular direction. The calculated throw out distances were quite consistent in X-direction for both pedestrian and cyclist but not so coincident in Y-direction with the biggest discrepancies of 2.6m and 3.26m for pedestrian and cyclist case respectively.



(a) (b)

Fig.6 Comparison initial impact velocity (a, vehicle impact velocity; b, pedestrian and cyclist moving velocity)



(a) (b)

Fig.7 Comparison of throw out distance (a, In X-direction; b, In Y-direction)

3.2 Relationship between pedestrian and cyclist kinematics response and vehicle impact velocity

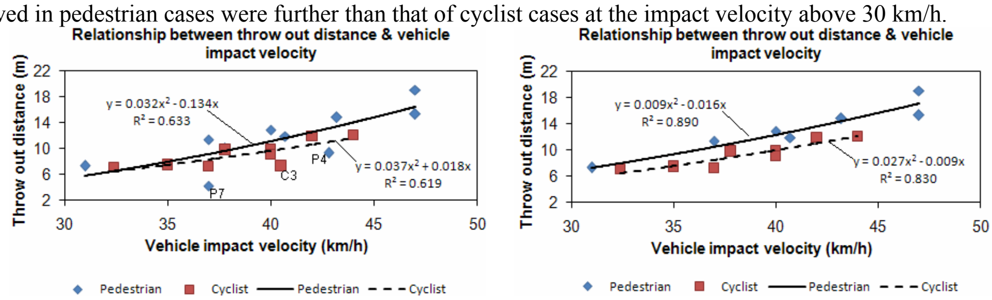
The relationship between victims` kinematics response and vehicle impact velocity was investigated by using quadratic polynomial regression approach. Table 4 summarized the calculated correlation coefficients of each relationship.

Table 4 Summary of correlation coefficients (R^2)

	Correlation coefficients (R^2)	
	Vehicle impact velocity (km/h)	
	Pedestrian	cyclist
Throw out distance in X-direction (m)	0.633	0.619
Throw out distance in X-direction(m) (P4, P7 and C3 excepted)	0.89	0.83
Head impact velocity (km/h)	0.709	-0.51
Head contact time (ms)	0.811	0.762
HIC value	0.501	0.378
3ms linear acceleration (g)	0.24	0.72
Resultant angular velocity (rad/s)	0.57	0.377

3.2.1 Relationship between throw out distance and vehicle impact velocity

The relationship for all of the considered cases is shown in Fig.8 (a).In general, the curves show that increasing vehicle impact velocity resulted in an increase of throw out distance in pedestrian and cyclist accidents. Strong correlations are shown both for pedestrian and cyclist with correlation (R^2) of 0.633 and 0.691 respectively. If we removed cases P4, P7 and C3, which were the pedestrians/cyclist impacted with the lateral side of the car and in extremely offset collisions, much stronger correlations can be found with correlation coefficients of 0.89 and 0.83 for pedestrian and cyclist respectively (Fig. 8 (b)). As shown in Fig.8, throw out distance observed in pedestrian cases were further than that of cyclist cases at the impact velocity above 30 km/h.

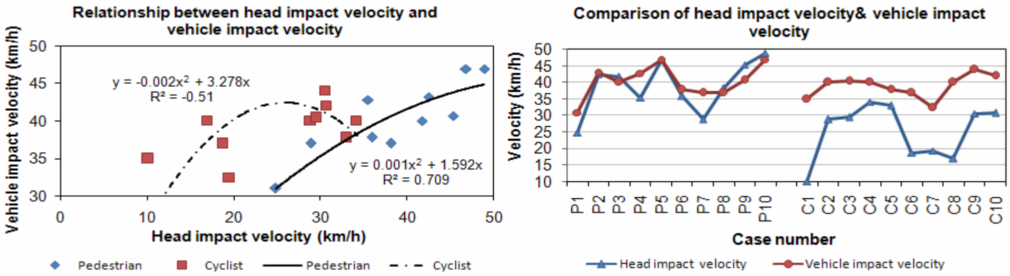


(a) (b)

Fig.8 Relationship between throw out distance and vehicle impact velocity

3.2.2 Relationship between head impact velocity and vehicle impact velocity

The quadratic regression curves and scatter of data points between head impact velocity at the moment of contact with windscreen and vehicle impact velocity are illustrated in Fig.9 (a).As the regression curves show that the pedestrian head impact velocity trend to increase with the vehicle impact velocity and has a strong correlation (R2=0.709). The relationship between cyclist head impact velocity and vehicle impact velocity did not show any correlation with calculated correlation coefficient of -0.51. Fig 9 (b) shows the comparison of head impact velocity and vehicle impact velocity of pedestrian and cyclist accidents. For pedestrian cases, head impact velocities either higher or lower than the vehicle impact velocities but the head impact velocity level is close to the vehicle impact velocity level. For cyclist cases, an obvious discrepancy shows that all of the head impact velocities are lower than the vehicle impact velocities.



(a) (b)

Fig.9 Relationship between head impact velocity and vehicle impact velocity

3.2.3 Relationship between head contact time and vehicle impact velocity

The head contact time was defined as the time during the moment of bumper contacting leg and the moment of head contacting windscreen. Regression curves show that the increase of vehicle impact velocity resulted in the decrease of head contact time for both pedestrians and cyclists. As show in Fig.10, strong correlations were found between head contact time and vehicle impact velocity with calculated correlation coefficients of 0.811 and 0.762 for pedestrian and cyclist respectively. Additionally the contact time for pedestrian accidents ranges from 100ms to175ms and 130ms to190ms for cyclist accidents.

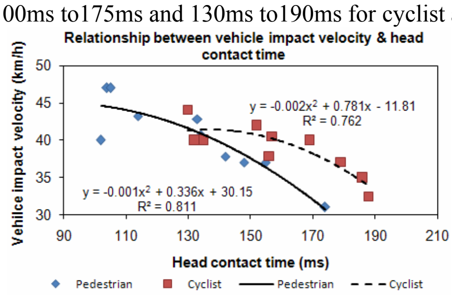
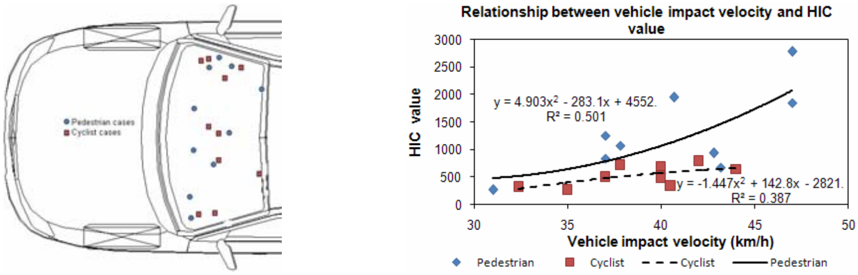


Fig.10 Relationship between vehicle head impact velocity and head contact time

3.2.4 Relationship between HIC value and vehicle impact

The location of head impact points on windscreen affects the head injuries of pedestrian and cyclist significantly. Fig.11 (a) shows the scatter points of head impact points on windscreen. The frequency of point distribution in close areas of windscreen is almost the same for the studied pedestrian and cyclist accidents. In general, regression curves show that increasing vehicle impact velocity leads an increase of HIC value for both pedestrian and cyclist. A higher R2 was found between HIC value and vehicle impact velocity in pedestrian accidents than cyclist accidents, which is 0.501 and 0.387 respectively. Furthermore, estimated regression curve of pedestrian cases lies above that of the cyclist`s. In other words, pedestrians could suffer a higher HIC value than cyclists under the same vehicle impact condition.



(a) (b)

Fig.11 Head impact points (a) and relationship between HIC value and vehicle impact velocity

3.2.5 Relationship between 3ms contiguous linear acceleration and vehicle impact velocity

As show in Fig.12, a strong correlation (R^2=0.72) was appeared between 3ms contiguous linear acceleration and vehicle impact velocity for cyclist cases, while a much weaker correlation coefficient 0.24 was found for pedestrian cases. From the scatter of data points, a phenomenon could be found that higher 3ms contiguous head linear acceleration could be resulted in pedestrian than cyclist under the same vehicle impact condition, which was similar to the relationship between the HIC value and vehicle impact velocity.

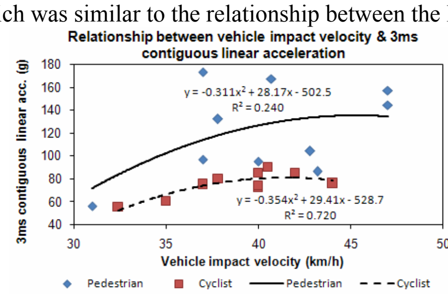
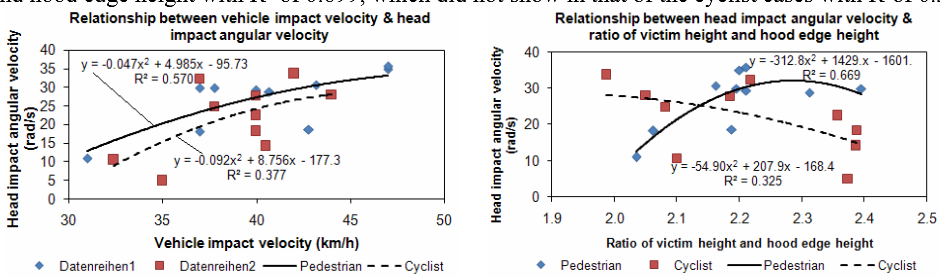


Fig.12 Relationship between 3ms contiguous linear acceleration and vehicle impact velocity

3.2.6 Relationship between head impact angular velocity and vehicle impact velocity

From the trendlines shown in Fig.13 (a), pedestrian cases (R^2=0.57) had a stronger correlation between head impact angular velocity and vehicle impact velocity than cyclist cases (R^2=0.377). In general, head impact angular velocity increased by the increase of vehicle impact velocity. For pedestrian cases, a significant correlation was found between head impact angular velocity and ratio of victim height and hood edge height with R^2 of 0.699, which did not show in that of the cyclist cases with $R^2$of 0.325 (Fig. 16b).



(a) (b)

Fig.13 Relationship between impact angular velocity and vehicle impact velocity (a) and ratio of victim height and hood edge height (b)

3.3 Head impact angle distribution

As shown in Fig.14, head impact angles fluctuate from case to case for both pedestrian and cyclist cases. Except the extremely offset impact case P4, the head impact angle of pedestrian fluctuated from 47 degrees to 64 degrees. The extent of cyclist head impact angle fluctuated more irregularly with the range form 30 degrees to 74 degrees.

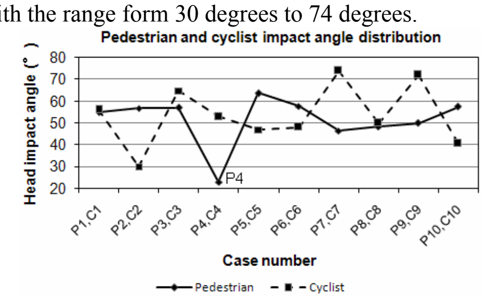


Fig.14 Head impact angle distribution

3.4 Correlation of head injury risk and calculated physical parameters

In this study, a logistic regression analysis was conducted to identify the correlations of head injury risks and calculated physical parameters. The predictor variables investigated were: vehicle impact velocity, head impact velocity, HIC value, 3 ms contiguous linear acceleration, and maximum head angular acceleration. In Table 5, the values of α, β, χ^2, p and α/β were listed. The logistic regression plots for observed injury outcomes and predictor variables are presented from Fig.15 (a) to Fig.15 (d).

Fig.15 (a) shows the correlation between AIS 2+ head injury risk and vehicle impact velocity, which corresponds to the p values of 0.0948 that greater than the significant probability value of 0.05. As shown in Fig.15 (a), the head impact velocity is more significant to predict AIS 2+ head injuries than vehicle impact velocity with p value of 0.0083. Additionally, 50% probability to cause AIS 2+ head injuries correspond to 42 km/h and 36 km/h for vehicle impact velocity and head impact velocity respectively.

The correlations between HIC value, 3ms contiguous linear acceleration, and resultant head angular acceleration and AIS 1+ head injury risks are illustrated in Fig 15 (b), (c) and (d) with calculated p value 0.003, 0.0427 and 0.0436 respectively, which are all lower than 0.05. The predicted values of 50% probability to cause AIS 1+ head injuries are 487, 68g and 12000rad/s^2 respectively.

Table 5 Logistic regression coefficients and statistics for probability of head brain injury

Predictor variables	α	β	χ^2	p	α/β
Vehicle impact velocity (km/h)	8.7315	0.2085	2.7902	0.0948	42
Head impact velocity (km/h)	5.6225	0.1555	6.9670	0.0083	36
HIC value	3.3121	0.0068	8.8009	0.003	487
3ms linear acceleration (g)	2.7535	0.0408	4.1086	0.0427	68
Resultant angular acceleration (rad/s2)	2.4086	0.0002	4.0708	0.0436	12000

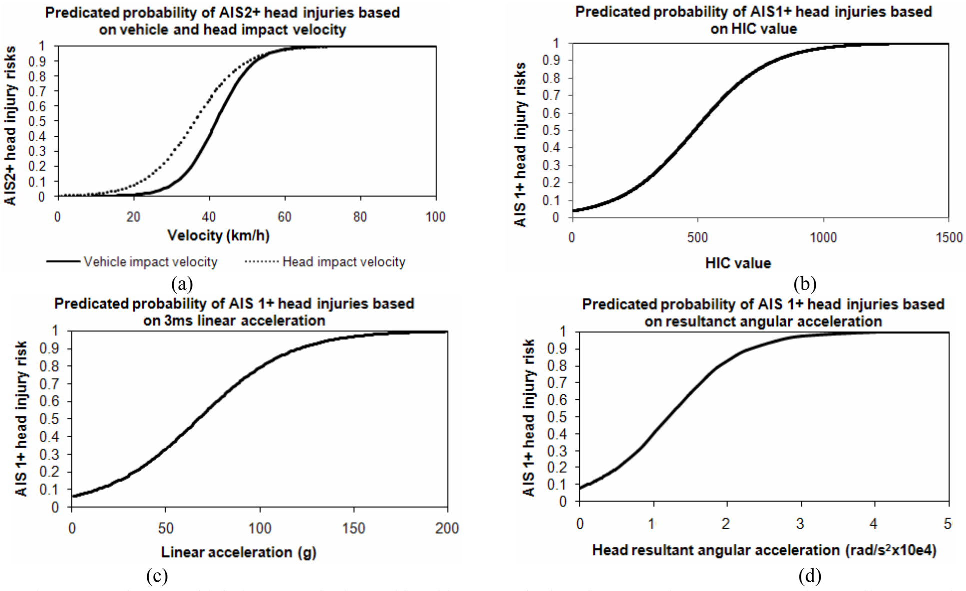


Fig.15 Logistic regression curves for (a) vehicle impact velocity and head impact velocity; (b) HIC value; (c) 3ms contiguous linear acceleration; (d) resultant angular acceleration

4 Discussion

A total of 20 real world pedestrian and cyclist accidents from GIDAS database were reconstructed using PC-Crash and MADYMO programs. It could be observed that in general, the kinematics of pedestrian and cyclist in PC-Crash and MADYMO program were similar and corresponded well with crash scene data in terms of impact location, throw out distance and resting location. By investigating the relationship between vehicle impact velocity and throw out distance, head impact velocity, head contact time, HIC value, 3ms linear acceleration, resultant angular acceleration, and angular velocity with quadratic regression model, it can be found that there are lots of differences in head kinematics between pedestrian and cyclist, especially in throw out distance, head impact velocity, contact time, HIC value, 3ms linear acceleration and impact angle. That means different suitable protective measures should be taken to gain effective protections for pedestrian and cyclist. Furthermore, test regulations should take consider of the nature of accidents for both pedestrian and cyclist protection. Previous correlative studies have been done for pedestrian accidents [18-21], which the homologous results were shown with little difference in the strength of correlation that could be caused by the different ranges of vehicle impact velocity.

Logistical regression approach was employed to relate vehicle and head impact velocity to AIS 2+head injury risks, and HIC value, 3ms contiguous linear acceleration and resultant angular acceleration to AIS 1+ head injury risks. The vehicle impact velocity and head impact velocity that could be result in a probability of 50% AIS 2+head injury are different for pedestrian and cyclist, especially for cyclist the head impact velocity could be always lower than the vehicle impact velocity. The regulatory limit of HIC value 1000 is widely accepted as the head injury criterion, which represented a 16% risk of life-threatening brain injury [22]. According to Zhang [23], the mean HIC value, resultant linear acceleration and the peak resultant rotational acceleration for minor injury cases was 351 (±169), 103 (±30) g and 7,354 (±2,897) rad/s2 respectively. In the present study, the predicted HIC value, 3ms linear acceleration and resultant angular acceleration for 50% probability of AIS 1+ head injury risks are 487, 68g and 12000rad/s2 respectively, which are comparable to previous studies.

However, some limits of this study must be underlined:

- Estimating vehicle impact velocities by skid marks and throw out distance could be somewhat different from the real accident.

Initial postures that significantly affect kinematics responses of pedestrian and cyclist are usually obtained by inquiring the accident witness or deducing the presumable positions at the moment of impact using human body injuries, which objectively have deviations from the real condition.

- Vehicle model in PC-Crash and MADYMO simulation, even though very similar to the accident car, are approximation of real vehicles. Additionally, the stiffness properties of each part of simulation car model come from the similar car impactor test. The total bicycle models were regard as a rigid body because of the absence of stiffness properties.
- Pedestrian models were scaled from a standard adult pedestrian model base on GEBOD program, the characteristics of joints and stature could cause some difference, especially the validity of using pedestrian models as cyclist model need some detailed evaluations.
- The circumstance parameters such as contact friction coefficients between each contact surface, were set according to experienced value, this could be different from the real accidents.
- The results got from regression methods were base on the vehicle impact velocities that ranged from 30km/h to 50km/h, which were the traveling velocities in urban city.
- The accident configurations in current study only focus on the side of pedestrian and cyclist impacted with car front.

The purpose of this study has been to present a comparison of the head kinematics in pedestrian and cyclist accident using multi-body models and attempt to correlate head injury severity with calculated physical parameters. Pedestrian and cyclist are the most vulnerable road users in traffic collision. Accident reconstruction based on in-depth accident investigation provides an efficient method in view of understanding the head impact injury mechanics. Undoubtedly, much more should be done. For example, the crash configuration of offsetting impact such as P4, P7 and C3 in this study account for a lot of the whole vulnerable road users' accidents that have a quite different kinematics and injury mechanics, on which special investigations should be done if possible.

5 Conclusion

Comparisons of calculated physical parameters of pedestrian and cyclist including throw out distance, head impact velocity, head impact time, HIC value, 3ms linear contiguous acceleration, maximum angular velocity and resultant angular acceleration show that differences exist in pedestrian and cyclist head kinematics during the collisions because of different natures of the two kinds of accident. Different suitable protective measures should be taken to gain effective protections for pedestrian and cyclist. Test regulations should take consider of the nature of accidents for both pedestrian and cyclist protection.

Vehicle impact velocity and head impact velocity that could result in a probability of 50% AIS 2+head injury are 42 km/h and 36 km/h. Critical values of HIC value, 3ms linear acceleration and resultant angular acceleration for predicting AIS 1+ head injuries are 487, 68g and 12000rad/s2 respectively

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Appendix

Table 1 Summary of Pedestrian Information

Case NO.	Model	Age	Height (cm)	Weight (kg)	Direction	Speed (km/h)	Initial stance	MAIS head
P1	Opel,ASTRA	57	175	80	3 oclock	31	Fast walking	0
P2	VW,Golf4	63	173	68	9 oclock	43.2	Fast walking	0
P3	FIAT,FIORION	55	168	54	8 oclock	40	Fast walking	0
P4	VW,GLOF4	68	175	85	3 oclock	42.8	Fast walking	2
P5	Mercedes,E220	35	176	76	3 oclock	47	run	2
P6	Ford ,Mondeo	18	182	72	9 oclock	37.8	Fast walking	2
P7	BMW,3ER	37	165	66	3 oclock	37	Normal walk	2
P8	Opel,CORSA	57	180	77	2 oclock	37	Normal walk	3
P9	Peugeot,307	32	185	80	9 oclock	40.7	Normal walk	3
P10	Opel,ASTRA	66	168	55	9 oclock	47	Fast walking	4

Table 3 Summary of Cyclist Information

Case NO.	Model	Age	Height (cm)	Weight (Kg)	Direction	Speed(km/h)		MAIS head
						Vehicle	Cyclist	
C1	VW,Golf v1.9	67	178	78	9 oclock	35	9	0
C2	Renault,CLIO	14	165	51	2 oclock	40	13	0
C3	MAZDA,626	44	179	74	2 oclock	40.5	20	0
C4	Opel,ASTRA	11	153	54	9 oclock	40	10	1
C5	Opel,ASTRA	56	152	54	10 oclock	37.8	10	1
C6	FIAT,PUNTO	36	173	110	9 oclock	37	10	1
C7	VW,PASSAT	47	168	50	9 oclock	32.4	5.4	1
C8	Ford,KA	14	160	45	2 oclock	40	10	1
C9	AUDI,A3	28	164	57	4 oclock	44	15	1
C10	Peugeot,206	57	159	88	9 oclock	42	5	2

Table 4 Summary of calculated physical parameters

Case Number	Throw out distance(m)	Head impact velocity (km/h)	Head contact time (ms)	HIC value	3ms linear acceleration (g)	Maximum angular acceleration (rad/s2)	Resultant angular velocity (rad/s)
P1	7.3	24.8	174	268	56	4761	11.03
P2	14.8	42.5	114	675.8	86	10236	30.6
P3	12.9	41.8	102	557	95	15822	29.27
P4	9.3	35.5	133	938	104	14647	18.7
P5	19	46.8	104	2779	157	17260	34.9
P6	10	36.0	142	1072	132	15020	29.8
P7	4.3	28.9	155	835	97	17533	18.2
P8	11.4	38.2	148	1254	173	14907	29.9
P9	11.9	45.4	134	1948	167	22545	28.8
P10	15.3	49.0	105	1854	144	26403	35.7
C1	7.5	10.1	186	269	60	3445	4.96
C2	9.7	28.8	135	529	72	6118	22.49
C3	7.3	29.5	157	341	90	17042	14.25
C4	9.9	34.2	132	692	74	13406	27.7
C5	9.8	33.0	156	720	80	12902	24.8
C6	7.2	18.7	179	502	75	18602	32.3
C7	7.11	19.4	188	321	55	21163	10.6
C8	9.01	16.9	169	482	85	8619	18.3
C9	12.1	30.6	130	635	76	4669	28
C10	11.9	30.7	152	792	85	7811	33.7