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The effects of Vehicle Front Design Variables and Impact Speed on Lower Extremity Injury in Pedestrian collisions using In-depth Accident Data

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Abstract:

Background: Lower extremity is the most common injured body region in the pedestrian traffic accidents. And the injuries are mainly caused by the contact force from the car front end structures. Therefore, it is necessary to study the effects of vehicle front design variables on lower extremity injury using real-world accident data.

Objective: This study aimed to identify the correlations of pedestrian AIS2+ lower extremity injury risk with the vehicle front design variables and impact speed by using real-world accident data.

Method and materials: A subsample of 404 pedestrian accident cases with AIS1+ lower extremity injuries was selected from German in-Depth Accident Study (GIDAS) database based on a defined sample criterion to conduct statistical analysis. The main variables related to severity of lower extremity injuries were determined at present study, including vehicle impact speed and vehicle design variables: lower bumper height (LBH), upper bumper height (UBH), bumper leading (BL) and bonnet leading edge height (BLEH). Firstly, analysis of variance (ANOVA) was employed to examine whether the mean values of these variables were statistically significance for pedestrian with or without AIS2+ lower extremity injuries. Furthermore, logistic regression analysis was performed to analyze associations between these predicted variables and risk of the pedestrian with AIS2+ lower extremity injury.

Results: The results revealed that the predicted variables of the impact speed, the LBH and the BLEH were statistically significant for AIS2+ lower extremity injuries. Higher LBH (42.5cm) causing 59.5% probability of AIS2+ lower extremity injury risk, which is about 1.6 times greater than that for lower LBH (20cm) at the impact speed of 40km/h in present study. Involving the BLEH, pedestrian sustain approximately 68% probability of AIS2+ lower extremity injury risk for the 85 cm high, which is about more than 1.5 times as high as the risk for 75 cm high BLEH and 2.5 times higher than that for 65 cm high BLEH at impact speed of 40 km/h.

Conclusions: The higher impact speed, the higher LBH and BLEH correspond to a greater likelihood of suffering an AIS2+ lower extremity injury.

Keywords: AIS2+lower extremity injuries; ANOVA analysis; logistic regression analyses; Vehicle design variables; impact speed

1. Introduction

Statistics analyses of pedestrian traffic accidents indicated that lower extremity was the most frequently injured body region, accounting for 32.8% of all injuries [1]. Although rarely fatal and typically classified as Abbreviated Injury Scale (AIS) 1 to 3, lower extremity injuries often need long term impairment or even disability, causing huge social and economical cost [2].

However, only few studies of real-world pedestrian accident focused on lower extremity injury. Klinich and Schneider used 552 pedestrian impacts from this database to analyze associations of lower extremity AIS2+ injury risk with impact speed, pedestrian age, stature and gender [3]. Matsui study the effects of vehicle bumper height and impact speed velocity on type of lower extremity using 62 pedestrian cases from Pedestrian Crash Data Study (PCDS) database [4]. Following, 312 pedestrian cases from this database were used to investigate the variables affecting the likelihood of pedestrian sustaining severe injuries on the head, torso and lower extremity [5]. The disadvantage of former study was that accident cars involving vans, light truck and passenger cars. But the injury mechanics of lower extremity and the test methods vary with the change of car front structure parameters in pedestrian protection regulation [6, 7].

Therefore a study on pedestrian lower extremity injuries in passenger car collisions was performed by using accident cases from GIDAS database. The objective of this study is to identify the correlations of AIS2+ lower extremity injury risk with impact speed, and vehicle design variables. The knowledge from the study could provide helpful advice for the design of safety countermeasures of pedestrian lower extremity.

2. Data and Methodology

2.1 Data and sampling criteria

The pedestrian accident cases from database of GIDAS were employed in present study. Because the type and severity of lower extremity injuries vary greatly in different types of vehicles [3], only the cases with passenger cars were used in current study.

In order to have an emphasis on the analyses of pedestrian lower extremity injuries in passenger car collisions based on real-world accidents occurred from 2000 to 2012 in Germany, the following sampling criteria on GIDAS database were employed: (1) only cases with lower extremity injuries AIS1+ (2) only bonnet-type front ends of passenger cars; (3) only pedestrians who are taller than 150 cm; (4) the impact speed can be determined, and speed is lower than 80 km/h; (5) collision configurations involving only the 2:00-4:00 o'clock and 8:00-10:00 o'clock clock system (Fig. 1). The final subsample consists of 404 pedestrian accident cases, of which 148 pedestrians sustained AIS2+ lower extremity injuries.

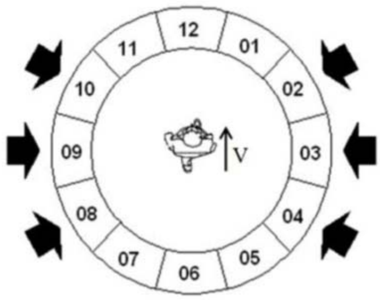

Fig.1. Impact configurations recorded in clock system in GIDAS (black arrows—the vehicular impact direction relative to pedestrian)

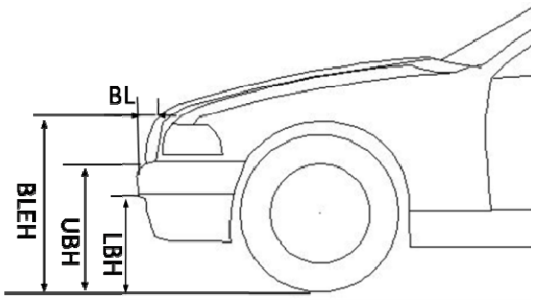

Fig.2. Car front structure parameters related to lower limb injuries
BL=Bumper leading (cm); BLEH=Bonnet leading edge height (cm); UBH=Upper bumper height (cm); LBH=Lower bumper height (cm)

2.2 Variance Analysis

The sample were firstly analyzed by performing variance analysis to determine whether the mean values of impact speed and vehicle variables were statistically different (P=5% significance) for pedestrian with and without AIS2+ lower extremity injuries. Passenger car design variables consist of front upper bumper height (UBH), lower bumper height (LBH), bumper leading (BL) and front bonnet leading edge height (BLEH). All the front structure parameters derived from the real accident cars and measured based on the definition of pedestrian protection regulation [7] and illustrated in Fig. 2.

2.3 Logistic Regression Analysis

Previous study about the selected subsample has proved that the impact speed is predictive parameters to cause lower extremity injuries[8].Therefore, in order to assess the relationships between vehicle design variables and AIS2+ lower extremity injuries at a certain impact speed, other statistical significant variables together with impact speed were tested using multiple logistic regression models. The corresponding AIS2+ lower extremity injury risk P (ν, y) is

$$P(\nu, y) = 1/(1+e^{(\alpha-\beta\nu-\lambda y)}) \qquad (1)$$

where ν is the impact speed, y is the one of the predictive car design parameters. α, β and λ are coefficients to be estimated via the method of maximum likelihood [9].

3. Results

3.1 Variance Analysis results

To better understand the distribution of variables in the selected subsample descriptive statistics were performed. The results are presented in Table 1 and Table 2. The difference of mean and median values of impact speed in two groups are big enough to determine impact speed should be considered as the important variable for AIS2+ lower extremity injuries.

Table 1 Descriptive statistics of vehicle variables for the subsample (N=404)

Variables	Unit	Mean	Median	S.D.	Min	Max
Impact speed	km/h	29.84	30	15.11	3	80
LBH	cm	28.66	26.2	8.00	16.2	48.3
UBH	cm	51.66	51.2	2.78	45.8	62.2
BL	cm	12.09	12	2.76	4.6	22.2
BLEH	cm	73.55	73	3.99	60.5	88.5

Table 2 Descriptive statistics of vehicle variables for the AIS2+ lower extremity injuries (N=148) of subsample

variables	unit	Mean	median	S.D.	Min	Max
Impact speed	km/h	34.32	34	15.92	3	80
LBH	cm	30.3	27	8.49	16.2	48.3
UBH	cm	51.92	51.5	3.13	45.8	62.2
BL	cm	12.32	12	2.59	5	21.7
BLEH	cm	74.27	74	4.39	60.5	88.5

In order to determine whether the selected variables are statistically significant different for pedestrian with AIS2+ lower extremity injuries, variance analysis for these variables were conducted. The results were summarized in Table3. It can be seen that for cases with and without AIS2+ lower extremity injuries, impact speed, lower bumper height and bonnet leading edge height were statistically different at the $p<0.05$ level. The mean values of variables in AIS2+ injury group are greater than those in without AIS2+ injury group.

Table 3 the mean values of variables for cases with and without AIS2+ lower extremity injuries

Variables	AIS2+ lower extremity injuries		
	With(N=148)	Without(N=256)	p-value
Impact speed	**34.32±15.92**	**27.25±14.03**	**0.000**
UBH	51.93±3.14	51.52±2.54	0.152
LBH	**30.30±8.49**	**27.72±7.56**	**0.018**
BL	12.32±2.60	11.96±2.86	0.207
BLEH	**74.27±4.39**	**73.14±3.70**	**0.006**

3.2 Correlations between AIS2+ lower extremity injuries and related vehicle design variables

Variance Analysis results proved that LBH and BLEH are two statistically significant vehicle variables for cases with and without AIS2+ lower extremity injuries. Therefore, In order to identify the associations of design variables LBH and BLEH with AIS2+ lower extremity injury risk, logistic regression analysis was conducted, and the analysis results were shown in Table 4.

Table 4 Results of predictive variables together with impact speed on AIS2+ lower extremity injury risk

Independent Variable	Intercept α	Coefficient β、λ	p-value	Wald chi-square
Impact speed	2.702	0.033	**0.000**	2.049
LBH		0.04	**0.003**	9.586
Impact speed	8.133	0.035	**0.000**	1.591
BLEH		0.088	**0.001**	7.332

The curves of AIS2+ lower extremity injury risk by impact speed together with LBH is presented in Fig. 3. The 50% probability of injury risk is predicted at 56.5 km/h for a 20 cm low LBH and 30 km/h for a 42.5 cm high LBH. If the impact speed is 40 km/h as set in the pedestrian protection regulation [7], pedestrians will suffer approximately 59.5%

and 37.5% probability of AIS2+ lower extremity injury risk for high and low LBH, respectively.

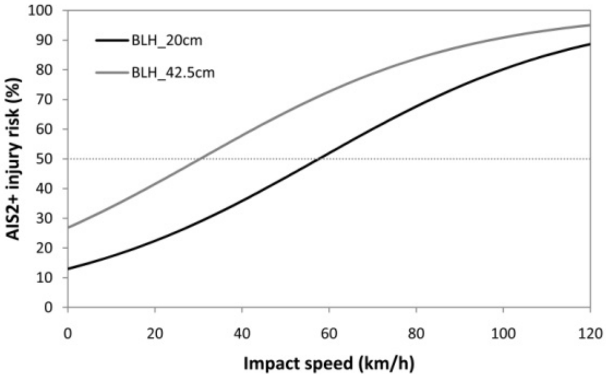

Fig.3. Probability of AIS2+ lower extremity injury risk by impact speed and BLH

As for the BLEH(shown in Fig.4), the 50% probability of AIS2+ lower extremity injury risk corresponds to impact speed of 69 km/h for the 65 cm-high, 44 km/h for the 75cm-high and 18.5km/h for the 85 cm-high. In addition, when the impact speed is 40 km/h, pedestrians sustain approximately 68% probability of AIS2+ lower extremity injury risk for the 85 cm high BLEH, which is about 1.5 times higher than the risk for 75 cm high BLEH and 2.5 times higher than that of 65 cm high BLEH.

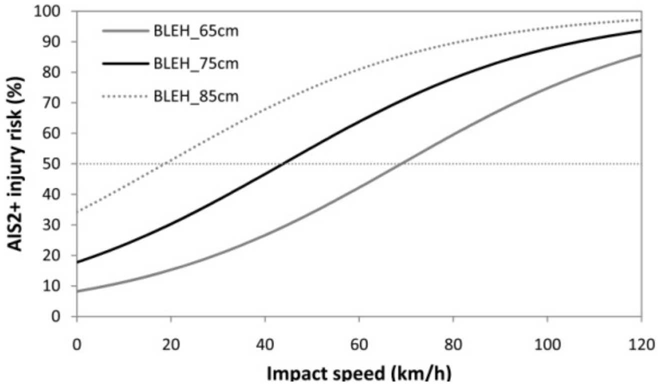

Fig.4. Probability of AIS2+ lower extremity injury risk by impact speed and BLEH

4. Discussions

The results of variables analysis indicated that pedestrians with AIS2+ lower extremity injuries have higher impact speed, higher LBH and higher BLEH than those without these injuries. Higher speed means lower extremity will suffer more impact energy in the collision, thus more severe injury will happen in lower extremity region. Lower LBH means more extensive contact and transfer area between pedestrian lower extremity and car bumper, which will make the tibia bending moment is small[8]. In general, higher BLEH would cause pedestrian thigh or pelvis contact with bonnet edge earlier, so high linear momentum will transfer to the upper leg or pelvis, which will cause severe lower extremity injuries [9, 10]. Similarly, the tendency of impact energy grows up with the increase of BLEH can be found in the pedestrian protection legislation [7].

Only the standard passenger car is used for current study, causing UBH varies very small in the selected cases. This may be the reason that the UBH is not the statistically significant variable. According to current study, the BL is not the statistically significant variable. This result corresponds to the study result of Zhang et al. Commonly considered that longer BL would cause pedestrian thigh or pelvis contact with bonnet edge earlier, leading less thigh or pelvis injuries. And in the pedestrian protection regulation, longer BL corresponds to smaller impact energy of upper legform. However, longer BL may cause more severe lower leg or knee injury. Therefore, the relationships of different patterns of AIS2+ lower extremity injuries with crash and pedestrian variables should be performed in the future work.

Furthermore, Fig 3 and Fig 4 provide some advice for pedestrian lower extremity protection in vehicle design. Lower LBH and BLEH inclined to show good lower extremity protection performance. It can be seen that at the same impact speed, lower LBH and BLEH correspond to lower AIS2+ lower extremity injury risk.

5. Conclusions

Variance analyses indicate that impact speed, LBH and BLEH are statistically significant factors ($p<0.05$) for cases with and without AIS2+ lower extremity injuries. And having higher impact speed, lower bumper height and bonnet leading edge height correspond to a greater likelihood of sustaining an AIS2+ lower extremity injury.

When the impact speed is 40 km/h, higher LBH (42.5cm) causing 59.5% probability of AIS2+ lower extremity injury risk, which is about 1.6 times greater than that for lower LBH (20cm) in present study. Involving the BLEH, pedestrian sustain approximately 68% probability of AIS2+ lower extremity injury risk for the 85 cm high, which is about more than 1.5 times as high as the risk for 75 cm high BLEH and 2.5 times higher than that for 65 cm high BLEH at impact speed of 40 km/h.

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