### Influence of head impact locations in car-to-pedestrian accidents on pedestrian head injury

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## I. INTRODUCTION

Pedestrian accidents are a particular traffic safety problem in China. In 2013, approximately 26% of all road traffic fatalities in China were pedestrians [1]. China's New Car Assessment Program (NCAP) introduced pedestrian passive safety tests and pedestrian Autonomous Emergency Braking (AEB) tests in its 2018 protocol, which reflects the China NCAP committee's focus on this issue. Head and thorax injuries are the most common injury types in pedestrian accidents [2-3]. In the China NCAP protocol, the head impact test score is based on the head impact criterion (HIC) value, which correlates with pedestrian's head injury severity [4-5]. Generally, higher HIC values occur on rigid parts, such as A-pillar and lower frame of windscreen, while head impacts on pure glass usually show relatively low HIC values [6]. However, a previous study showed severe injuries sustained from head impacts on pure glass in real-life accidents [7]. This paper aims to build and compare injury risk curves for pedestrian head impacts on different vehicle front structures and to resolve conflicting indications from previous studies.

## II. METHODS

# Database and inclusion criteria

Three in-depth accident databases were used to extract field data for this study: the China In-Depth Accident Study (CIDAS, 2011–2016), the Shanghai United Road Traffic Scientific Research Center (SHUFO, 2005–2016), and the German In-Depth Accident Study (GIDAS, 1999–2017). The cases sampled met all of the following criteria: pedestrians with one impact to the front of a passenger car (including sedan, MPV and SUV); pedestrians not run over in the accident; known pedestrian head injury severity; and the availability of a clear investigation photo of passenger car's front. The sample consisted of 141 cases selected from CIDAS, 66 cases from SHUFO and 206 cases from GIDAS.

## Head impact location normalisation

As this study aimed to investigate the influence of head impact locations on the injury outcome, a clear definition of the head impact location was required. This was complicated because the windscreen shape is not a regular geometry, plus the windscreen dimension varies from car to car. We used image processing to project a 22x22 grid chart onto a windscreen (Fig. 1, *left*). By fitting the frame in the outermost cells, we obtained coordinates of head impact locations. In this way, all windscreen shapes were normalised, and the head impact area was divided into three groups – red: A-pillar area; blue: lower frame and Instrument Panel (IP) area; green: pure glass area – as shown in Fig. 1 (*right*).





## Logistic regression

Impact speed and pedestrian age both influence the injury outcome in a car-to-pedestrian accident [8-9]. In order to investigate the effect of head impact location, it is necessary to account for the influence from speed and age.

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Logistic regression can be used to analyse the influence of multiple variables on pedestrian injury risk, using the logistic function for risk estimation:

$$\sigma(t) = \frac{e^t}{e^t + 1} = \frac{1}{1 + e^{-t}}$$

where  $\mathbf{t} = \beta_0 + \beta_1 x_1 + \dots + \beta_n x_n$ .

In this study, the head injury outcome of pedestrians was set as a dependent variable in the regression model, while age, impact speed and head impact location were set as independent variables ( $x_n$ ). Iteratively reweighted least squares (IWLS) were used in the software R as default model fitting method to estimate the coefficients ( $\beta_n$ ).

#### III. INITIAL FINDINGS

### Head impact distribution and head injury severity

A previous study [7] showed severe injury outcomes for pedestrian head impacts on the windscreen. The current study corroborated this. Simple frequency analysis (Fig. 2) shows head impact locations for both Chinese and German data. Many cases had unclear impact locations, hence the large number of "other". Nevertheless the head injury rates on pure glass were not low. Here, MAIS means maximum abbreviated injury scale (AIS) of head injury for each pedestrian, and MAIS3+ means MAIS level higher than or equal to 3.



Fig. 2. Head impact location distribution and head injury severity: (*left*) CIDAS+SHUFO, (*right*) GIDAS.

## Injury risk comparison

The above results should not be interpreted as meaning that head impacts on pure glass are highly dangerous because the effects of impact speed and pedestrian age have not yet been considered. Results accounting for these effects were calculated in four multivariable logistic regression models. Table I shows the GIDAS data for one model for fatal head injuries and one model for fatal or MAIS3+ head injuries. The results include estimated model parameters, standard error of parameters and significance value (p value). Table II shows the same models and parameters from the CIDAS data. Parameters for impact location were relative to head impact on A-pillar. The results imply that for all head impact locations impact speed and pedestrian age were significantly associated with head injury risk (p value < 0.05), and that injury risk increased with impact speed and pedestrian age. However, no general significant effect of head impact location was found.

Regression result of fatal (MAIS3+ or fatal) head injury risk from GIDAS										
Term $(x_n)$	Estimate ( $\beta_n$ )		Std error		P value					
(Intercept)	-5.060	(-4.891)	0.925	(0.838)	<0.001	(<0.001)				
Impact speed	0.064	(0.084)	0.013	(0.014)	<0.001	(<0.001)				
impact.location.Hood	-0.560	(2.235)	1.219	(0.861)	0.646	(0.009)				
impact.location.Lower frame & IP area	-0.829	(-0.367)	0.740	(0.663)	0.263	(0.580)				
impact.location.Other	-0.446	(0.125)	0.564	(0.520)	0.429	(0.810)				
impact.location.Pure glass	-1.868	(-0.200)	0.628	(0.510)	0.003	(0.696)				
Age	0.030	(0.031)	0.009	(0.007)	0.001	(<0.001)				

TABLE I Regression result of fatal (MAIS3+ or fatal) head injury risk from GIDAS

\* Numbers in brackets refer to MAIS3+ or fatal head injury risk model.

Regression result of fatal (MAIS3+ or fatal) head injury risk from CIDAS+SHUFO										
Term (x <sub>n</sub> )	Estimate ( $\beta_n$ )		Std error		P value					
(Intercept)	-7.134	(-3.895)	1.159	(0.975)	<0.001	(<0.001)				
Impact speed	0.087	(0.079)	0.013	(0.013)	<0.001	(<0.001)				
impact.location.Hood	0.410	(0.489)	0.759	(0.870)	0.589	(0.574)				
impact.location.Lower frame & IP area	-0.316	(-0.446)	0.647	(0.693)	0.625	(0.520)				
impact.location.Other	-0.705	(-1.878)	0.597	(0.608)	0.238	(0.002)				
impact.location.Pure glass	-0.404	(-0.821)	0.647	(0.690)	0.533	(0.234)				
Age	0.055	(0.039)	0.012	(0.011)	<0.001	(<0.001)				

TABLE II Regression result of fatal (MAIS3+ or fatal) head injury risk from CIDAS+SHUFO

\* Numbers in brackets refer to MAIS3+ or fatal head injury risk model.

Illustrative risk curves with confidence intervals were computed for pedestrians with the average age of the sample (45 yo) and with impact speed varying from 0 to 100 km/h, separated by different head impact locations, which are indicated by colour (Figs 3 and 4). Confidence intervals depict the area in which the risk curve lies with 95% probability. Both the fatal risk curve (Fig. 3) and the "MAIS3+ or fatal" risk curve (Fig. 4) show little difference between curves and overlapping confidence intervals. The curve for impact on pure glass even shows relatively low risk. Furthermore, alongside head impact on A-pillar, head impact on hood also shows high injury risk.



Fig. 4. MAIS3+ or fatal head injury risk curve: (*left*) CIDAS+SHUFO, (*right*) GIDAS.

#### **IV. DISCUSSION**

In the field accident data, many severe and fatal cases were identified in which a pedestrian's head impacted on pure glass area. However, multivariate logistic regression models show no evidence for a significant effect of the head impact location on the pedestrian's head injury outcome. By trend, head impact on pure glass area even showed lower injury risk compared with impacts on other locations, which means injury risk seems lower although without statistical significance. The conflicting information from simple frequency analysis can be explained by the fact that the confounding influence from impact speed and pedestrian age was not included.

The major limitation of this study is the small sample size. Both CIDAS and GIDAS data provided only *c*. 200 cases for this study. Furthermore, GIDAS lacked fatal cases, which led to high variance in regression results. As a result of the small sample size (20 cases in CIDAS, 11 in GIDAS), it is not possible to conclude with certainty that

there is a high risk associated with head impact on hood. Another reason for the high injury risk of hood impacts is that, in contrast to impact locations on the windscreen, it is difficult to find clear evidence for such impacts. Slight impacts on the hood are easily missed and therefore wrongly attributed, which in turn influences the injury risk calculations for the remaining coded hood impacts.

It should be noted that there was no weighting involved in this study. Accordingly, the results reflect only the situation within the sample data and do not reflect the national situation. Comparison between Chinese and German national situations was not available.

Impact speed of passenger car, age of pedestrian and head impact location were selected as risk predictors for the current study. Although a recent paper [10] found ground impact is one of main injury sources in pedestrian accidents, we did not include ground impact as one of risk predictors, because of the difficulties and uncertainties of identifying ground impact as injury source. Vehicle shape was found to influence injury outcome [11]. However, we believe by modelling impact location directly, we have a stronger link between impact location and head injury than modelling vehicle shape would yield.

The results of this study show that the strategy of current pedestrian protection to cover head impact locations on the A-pillar, lower frame and hood is reasonable as these areas showed high risk for head injuries. It should also be noted, however, that impacts on different areas did not lead to significantly lower risk. Even in cases without obvious head impact location, the head injury risk was still high, especially from the GIDAS data. This could be due to the limited sample size, as mentioned above, but could also be due to secondary pedestrian head impacts against road surfaces. The possibility of secondary head impacts on road surfaces is largely unaffected by the primary impact location, and secondary impacts to road surfaces can also lead to severe head injury. For such cases, current pedestrian passive safety protection is not sufficient to prevent injuries. Active safety systems, on the other hand, could potentially help to prevent car-to-pedestrian accidents altogether.

#### V. REFERENCES

[1] WHO, Global status report on road safety, 2015.

[2] Mizuno, Y., ESV, 2005.

[3] Rikard, F. et al., Accid. Anal. Prev., 2010.

- [4] Mervyn, E. et al., Traf. Inj. Prev., 2015.
- [5] Hertz, E., AAAM, 1993.
- [6] MacLaughlin, T. et al., SAE, 1993.
- [7] Chengkai, D. et al., IRCOBI, 2016.
- [8] Harruff, R. et al., Accid. Anal. Prev., 1998.
- [9] Anderson, R. et al., Accid. Anal. Prev., 1997.
- [10] Shi, S. et al., Accid. Anal. Prev., 2017.
- [11] Martin J. et al., Ann Adv Automot Med., 2011.