Pedestrian Injuries and Vehicles-related Risk Factors in Car-to-pedestrian Frontal Collisions

Jacques Saadé, Sophie Cuny, Maxime Labrousse, Eric Song, Cyril Chauvel, Philippe Chrétien

Abstract Based on a detailed and representative French accident database, this study describes pedestrian injuries and vehicle-related risk factors in collisions between pedestrians and the front-ends of passenger cars. Injuries are described in terms of the body region injured using the Abbreviated Injury Scale (AIS). The influence vehicle-related and accident-related parameters have on the global outcome of the accidents in terms of pedestrian death and pedestrian hospitalisation or death was evaluated using a multivariate logistic regression. Risk factors such as vehicle impact speed, bonnet leading edge height, vehicle model year, impact angle and first impact location on the front-end of the vehicle were investigated. Pedestrian age was also taken into account. The results show that most injuries were sustained by the lower limbs, followed by the head, the thorax and upper limbs. Lower limbs injuries were dominated by the tibia and the fibula, followed by the pelvis and the femur. The logistic regression results show that vehicle impact speed and pedestrian age are both statistically significant and have the most influence on both outcomes, a reminder that active safety systems with the ability to reduce impact speed can have a significant impact on injury reduction.

Keywords Accident database, Car-to-pedestrian accidents, Injury risk curves, Pedestrian injuries, Vehicle-related parameters.

I. INTRODUCTION

Pedestrian road safety remains a key challenge facing worldwide stakeholders. In 2016, pedestrians accounted for 23% of the 1.35 million road fatalities recorded worldwide [1]. Each year, millions of pedestrians are injured and many are disabled for life after being involved in a road accident. In 2016 in Europe (excluding Lithuania and Slovakia), 5,320 pedestrians were killed in road accidents, accounting for 21% of all road fatalities. Between 2007 and 2016, pedestrian fatalities were reduced by 36% while overall road fatalities were reduced by 41% [2]. In mainland France in 2019, 472 pedestrians were killed. This figure is close to that for the year 2010, when 485 pedestrians died on the road. This means that in almost a decade there has been no significant improvement (only 3%), even though the French road death toll was reduced by almost 19% during this same period [3]. Another interesting figure to mention is that 70% of pedestrians are killed in an impact with a passenger vehicle [4].

These figures do not align with European expectations, especially given that various measures were introduced by public and private stakeholders to reduce pedestrian casualties. Two examples of those measures are the European pedestrian safety regulation [5] and the European New Car Assessment Program (Euro NCAP) vulnerable road user protection protocol [6]. Both examples integrate passive and active safety measures by adding vehicle front-end design and active safety systems, such as “brake assist”, “forward collision warning” (FCW) and “autonomous emergency braking” (AEB), to the list of mandatory equipment necessary to obtain type approval or full score at consumer tests. Actual Euro NCAP vehicle front-end design tests use a different surrogate (impactor) for each of the three anatomical regions that are currently included in the test protocol (Headform, Upper Legform and Lower Legform impactors). Some studies suggest that in order to harmonise the tests and to achieve higher biofidelity, the legform tests could be combined into one test by adding a hip model to a modified legform impactor [7], or by adding an upper body mass to the current legform impactor or to a modified version of the current impactor [8-9]. Thus, an update to the legform test protocol seems to be necessary and will be implemented as soon as the criteria for the new impactor are set. The criteria should

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include tolerance measures that represent the limits between a severe and a non-severe injury.

One purpose of this study is to illustrate the most frequent injuries that need to be taken into account when developing new impactors. Another purpose is to investigate accident and vehicle parameters that could influence the outcome of an accident, such as vehicle impact speed, bonnet leading edge height, vehicle model year, impact angle and first impact location on the front-end of the vehicle. The latter parameters are implemented in the test protocols, thus it is important to study the influence of each parameter on the outcome of real-world accidents while controlling for the effects of the remaining parameters. Some accident analysis studies in the literature investigated the influence of different risk factors on the outcome of pedestrian injuries. While some studies [10-12] were oriented towards pedestrian-related and infrastructure-related risk factors, other studies [13-17] investigated some vehicle-related and accident-related parameters. However, none of these studies investigated the influence of all vehicle and accident parameters that are covered in the present study.

II. METHODS

The VOIESUR accident database was used in this study in order to select cases of accidents between passenger cars and pedestrians. VOIESUR is based on the analysis, by accident experts, of more than 8,500 police reports from the year 2011 in France. This includes all reported fatal road accidents for that year and 5% of randomly selected non-fatal injury accidents of the same year. A weighting procedure was also developed so that the database would be representative of all reported injury accidents of the year 2011 in France [18].

The data collection in VOIESUR database was based on the available information in the police reports: photos of the vehicles and of the location after impact, documented two-dimensional (2D) infrastructure map with accident details such like the impact location, pedestrian projection distance, brake marks if any, etc. Witness interview details present in the reports were taken into account on one hand to confirm the police-given information, and on the other hand to complement eventually missing details in the maps. As to the injury information that was gathered, it was only coded when a medical report was available with the police report. Coding of injury information was either achieved or supervised by a medical doctor.

Data selection

The data selection procedure is described in Fig. 1. From the VOIESUR database, accidents involving pedestrians and the front-end of passenger cars were selected. Then, further selection criteria were added in order to extract the relevant accidents and to eliminate from the sample some accidents in which pedestrian injuries were not caused by collision with the front-end of the passenger car. The selection criteria are as follows: the collision between the pedestrian and the front-end of the passenger car is the first collision of the accident; the car did not run over the pedestrian; and the car did not lose control before the collision. The sample of relevant accidents proved to be the same as that used in [19-20]. Unfortunately, all of the required accident parameters and pedestrian injury information were not available for all relevant accidents, especially those in which only slight injuries were sustained. For this reason, the risk analysis was performed only on those relevant accidents for which all of the accident and vehicle parameters under investigation were available, using a correction factor to compensate for loss of information and to be representative of all relevant accidents. Out of the accidents used for risk analysis, those containing all necessary injury information were used for injury description.

Injury description

Pedestrian injury severity was described using the Abbreviated Injury Scale (AIS) 1998 version [21]. The pedestrian's body was divided into seven anatomical regions based on the AIS standards: head/face, neck, thorax, abdomen, spine, upper extremity, and lower extremity. Only the most severe injury (highest AIS score) within each of these anatomical regions was kept for analysis.

Using the same methodology as for the whole body, the lower extremity region was then investigated in a more detailed manner by dividing it into seven sub-regions: pelvis, femur, knee, tibia, fibula, ankle/foot, and other. Other represents all coded injuries for lower extremities that were not identified in one of the preceding sub-regions, such as skin injuries, for example. The selection criteria for lower extremities were also set such as to restrict injuries included in the analysis to moderate or more severe (AIS2+) and to serious or more severe

(AIS3+). AIS2+ injuries include AIS2, AIS3, AIS4, AIS5, and AIS6 injuries while AIS3+ injuries include AIS3, AIS4, AIS5, and AIS6 injuries. Thus, it is worthy to mention that all AIS3+ injuries would be a part of AIS2+ injuries.

Injury risk analysis

The objective of this part of the study was to evaluate the strength of association between pedestrian injury outcome and predictor variables (risk factors) while controlling for the effects of the remaining variables in the association. Two binary outcomes would be studied: "death/no death" and "hospitalisation or death/no hospitalisation nor death". For this reason, we chose to model our data using a multivariate logistic regression, which is a binary response model widely used in the fields of epidemiology and accident science [10][12][22-23]. Another advantage of the multivariate logistic regression is that it can take into account continuous variables as well as categorical variables. The variables that will be studied simultaneously are: vehicle speed at impact; vehicle bonnet leading edge height (BLEH); vehicle model year; first impact location on the front-end of the vehicle; pedestrian direction just before impact; and pedestrian age. The latter parameter was added as it was assumed to be an important confounding factor that would constitute a bias to this study if not considered in the multivariate analysis. The logistic regression models were developed using R software and the "survey" package [24-25] since the data that are being manipulated were weighted using survey techniques. The results of the regression models were given in terms of adjusted odds ratios (AOR), along with their 95% confidence intervals (CI). The statistical significance of the results was determined using the p-value. In this part of the study, the variables were divided into categories so that the odds of each category would be compared to the reference.

For the next step of the risk analysis, only statistically significant variables were kept. In order to draw injury risk curves, numerical variables were used. Two statistical models derived from the logistic regression were chosen to model the data: the Complementary Log-log (Cloglog) model; and the log-odds or logit model. As to the predictor variables, a combination of different variables is used, depending on which variables would show statistical significance in the first step of the risk analysis. Finally, the various models were evaluated using the Akaike Information Criterion (AIC) and the difference between the real numbers and the recalculated numbers of killed and killed or hospitalised pedestrians using the models as shown in the following equation:

$$\Delta N = |N_{ini} - N_{mod}| \tag{1}$$

where N_{ini} is the number of pedestrians with a certain injury outcome and N_{mod} is the number of pedestrians estimated using the respective model for the same injury outcome.

III. RESULTS

Data selection

Collisions between pedestrians and the front-end of passenger cars represent approximately 6,000 pedestrians (see Fig. 1). The sample of relevant accidents represents 5,163 pedestrians, of whom 195 were fatally injured (death occurring within 30 days of the accident), 1,871 seriously injured (hospitalised more than 24 hours), and 3,097 slightly injured (injury with no hospitalisation or hospitalisation for less than 24 hours). For injury description, the sample containing all injury information includes 1,967 pedestrians (106 fatally injured, 901 seriously injured, and 960 slightly injured). Medical reports were mostly available for seriously injured pedestrian. The lack of information with regards to slightly injured pedestrians is less problematic as the injury description will be for the most severe injuries.

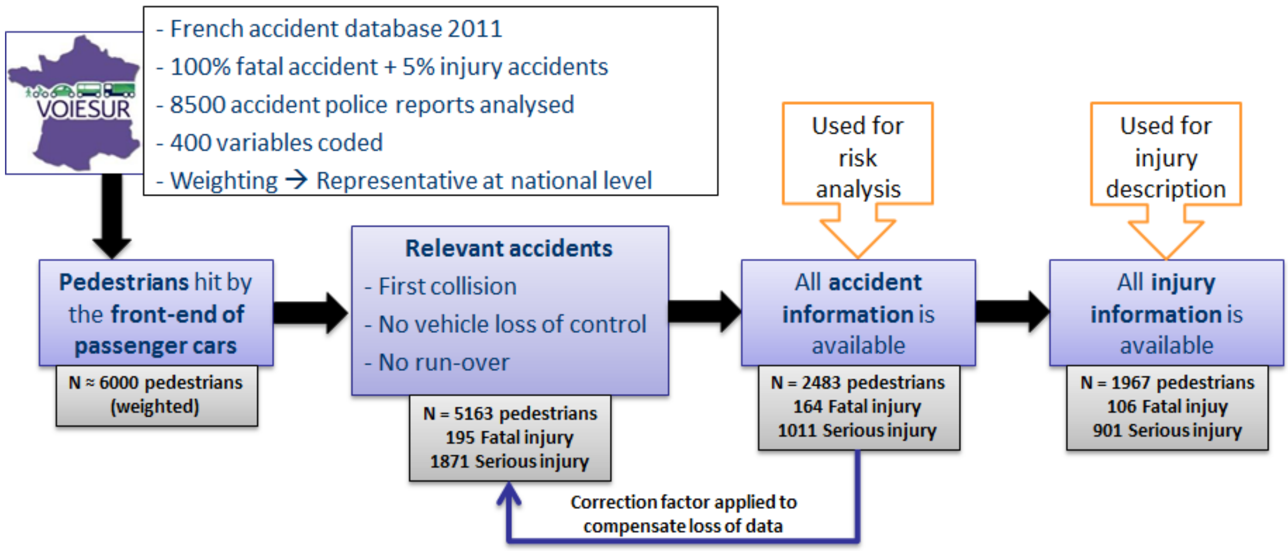


Fig. 1. Accident selection for injury description and risk analysis.

Injury description

For each body region, two dichotomous variables were used (AIS2+ and AIS3+) in order to describe injury severity. This is illustrated in Fig. 2, which shows that most of the AIS2+ and AIS3+ injuries are sustained by the lower extremities, followed by the head and the thorax for AIS3+, and by the head and the upper extremity for AIS2+.

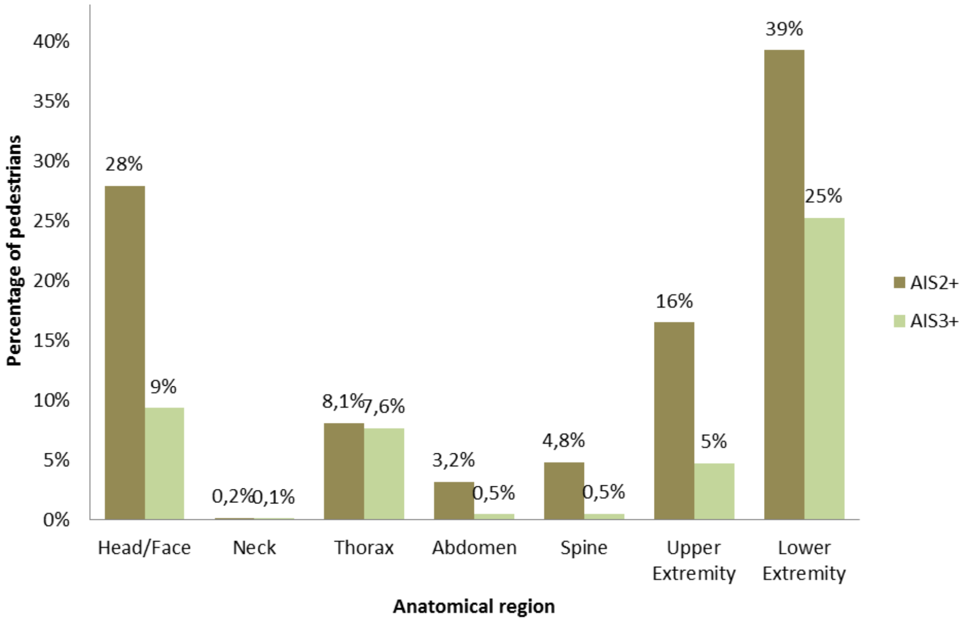


Fig. 2. Percentage of pedestrians with AIS2+ and AIS3+ injuries to designated anatomical regions.

As the lower extremity was the most affected anatomical region, it was investigated in detail by plotting the distribution of AIS2+ and AIS3+ on different sub-regions (see Fig. 3). Lower extremity is also of interest in this study because it is certainly the region that is most frequently first to come into contact with the front-end of the impacting vehicle. Figure 3 shows that lower extremity injuries were dominated by the tibia for AIS3+ and by the fibula for AIS2+, closely followed by the tibia. Pelvic injuries were highly represented in both severity levels, while femur injuries were frequent at AIS3+ level only. It is noteworthy that no AIS3+ injury was sustained by the knee and that only 9.2% of AIS2+ lower limb injuries were attributed to the knee. All of AIS2+ knee injuries were coded as sprain to the knee joint, while no injury to the collateral or cruciate ligaments was coded.

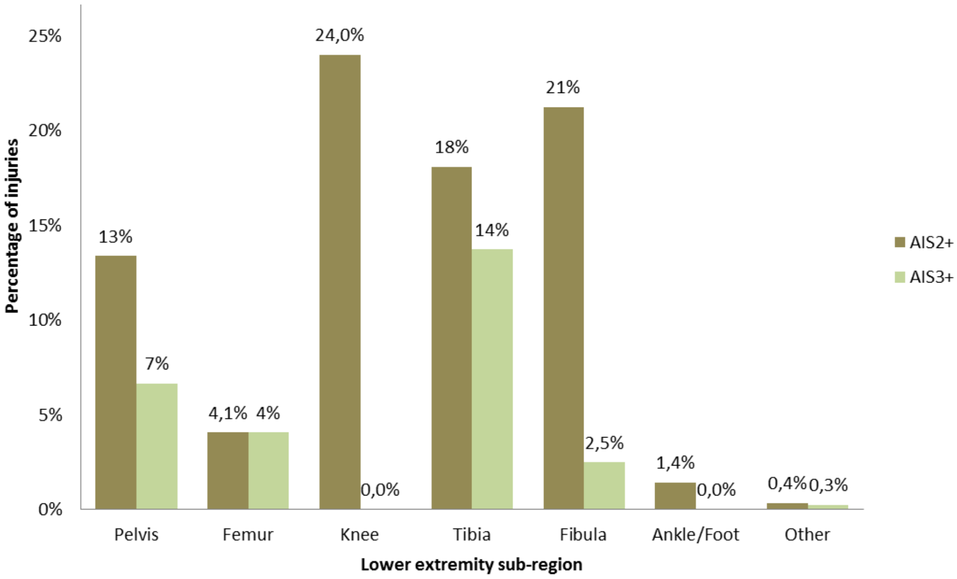


Fig. 3. Distribution of AIS2+ and AIS3+ injuries to designated lower extremity sub-regions.

Injury risk analysis

The results of the multivariate logistic regression are given in Table I along with the distribution of fatally injured pedestrians (K), fatally or seriously injured pedestrians (KSI), and all pedestrians in the sample on the different variable categories in terms of frequency of occurrence (freq.). These categories were determined so that they would be fairly populated and also to represent variations in real life situations. As an example, in some urban areas in France driving speed is limited to 30 km/h, while 50 km/h is the maximum speed authorised in urban areas in general. Thus it is of interest to study the influence of vehicle speed above 30 km/h and above 50 km/h in comparison to speed under 30 km/h.

The first impact point, the Bonnet Leading Edge Height (BLEH), and pedestrian direction were defined and categories were then created as shown in the Appendix: Fig. A1, Fig. A2, and Fig. A3.

The multivariate logistic regression shows statistically significant results for both categories of vehicle impact speed and for both K and KSI outcomes. However, odds ratios were very high for impact speeds greater than 51 km/h, meaning that a high risk of fatal injury and of fatal or serious injury exists for pedestrians hit at speeds in this category. Pedestrians aged 61 years and older were more at risk than younger pedestrians. The results for this age category were statistically significant for both outcomes. Being hit by the right side of the vehicle seems to carry greater risk than being hit by the centre of the vehicle. Being hit by the left side of the vehicle didn't present any significant results when compared to being hit by the centre of the vehicle. Vehicle model year didn't have any significant results, nor did pedestrian direction just before impact. Regarding vehicle design, BLEH ≥ 835 mm was shown to have a significantly higher risk of fatal injuries, while the result for fatal or severe injuries showed to be not significant.

TABLE I

PEDESTRIAN DISTRIBUTION ON THE DIFFERENT VARIABLE CATEGORIES AND LOGISTIC REGRESSION RESULTS FOR BOTH OUTCOMES "DEATH" (K) AND "HOSPITALISATION OR DEATH" (KSI).

Risk factor	Freq. K	Freq. KSI	Freq. All	AOR K	95% CI K	AOR KSI	95% CI KSI
Vehicle impact speed							
0–30 km/h	15%	46%	66%	1 (ref.)		1 (ref.)	
31–50 km/h	34%	31%	24%	**8.35*****	2.91–23.99	**5.30****	1.51–18.64
51+ km/h	51%	23%	10%	**188.54*****	52.13–681.87	**146.03****	7.07–3,014
Pedestrian age							
0–30 years	18%	30%	38%	1 (ref.)		1 (ref.)	

31–60 years	24%	30%	35%	2.1	0.69–6.40	2.03	0.57–7.20
61+ years	58%	40%	27%	**13.13*****	4.52–38.15	**6.50****	1.86–22.65
First impact point							
Ext_dec_left	7%	11%	10%	0.13	0.02–1.12	4.78	0.60–38.05
Dec_left	18%	18%	15%	0.59	0.14–2.54	4.32	0.61–30.45
Centre	28%	18%	25%	1 (ref.)		1 (ref.)	
Dec_right	29%	21%	15%	**3.54***	1.21–10.37	**10.82****	2.07–56.63
Ext_dec_right	14%	15%	10%	2.54	0.84–7.70	**12.08***	1.79–81.38
Unknown	4%	17%	25%	**0.07****	0.01–0.35	1.31	0.25–6.93
Vehicle model year							
Before 1990	9%	6%	6%	1 (ref.)		1 (ref.)	
1990–1994	18%	24%	26%	4.10	0.71–23.75	3.27	0.26–41.04
1995–1999	25%	20%	18%	2.15	0.33–13.92	3.70	0.27–50.97
2000–2004	24%	23%	28%	3.15	0.53–18.57	1.11	0.07–16.72
2005–2011	23%	25%	20%	4.36	0.62–30.59	5.90	0.37–94.14
Unknown	1%	2%	2%	3.59	0.33–38.59	7.08	0.19–262.60
BLEH							
< 835 mm	87%	95%	95%	1 (ref.)		1 (ref.)	
≥ 835 mm	13%	5%	5%	**7.13****	1.63–31.24	2.61	0.32–21.34
Pedestrian direction							
Longitudinal	20%	12%	9%	1 (ref.)		1 (ref.)	
FS	40%	30%	30%	3.07	0.80–11.74	3.43	0.32–36.97
NS	30%	47%	45%	0.62	0.15–2.49	3.48	0.35–34.36
Oblique	10%	11%	16%	3.43	0.76–15.48	2.59	0.18–37.63

* Statistically significant with p-value < 0.05.
** Statistically significant with p-value < 0.01.
*** Statistically significant with p-value < 0.001.

For the second part of the injury risk study, the only two parameters that showed robust and significant results (vehicle speed and pedestrian age) were kept for analysis. This will help build injury risk curves for use in studies like [20]. The Complementary Log-log (Cloglog) model and the log-odds or logit model were used as described earlier. As to the predictor variables, a combination of vehicle impact speed and pedestrian age was used (V+A), while another combination was also used (V^2+A) substituting impact speed by impact speed squared as the latter option best matches the energy dissipated during the impact. Impact speed squared also showed better fitting ability with regards to the data used in this study [19] or to similar data [26]. Finally, a set of four models (see Table II) was evaluated using the AIC and the recalculated numbers of fatally injured and fatally or seriously injured pedestrians as shown in equation (1).

TABLE II
PERFORMANCE CRITERIA OF DIFFERENT RISK CURVE MODELS FOR BOTH K AND KSI OUTCOMES

Model	AIC K	ΔN K	AIC KSI	ΔN KSI
Cloglog (V+A)	56.3559	1.1764	293.0908	2.125
Logit (V+A)	56.8511	0	296.0625	0
Cloglog (V^2+A)	55.8829	0.0773	291.2463	3.893
Logit (V^2+A)	56.1882	0	291.7609	0

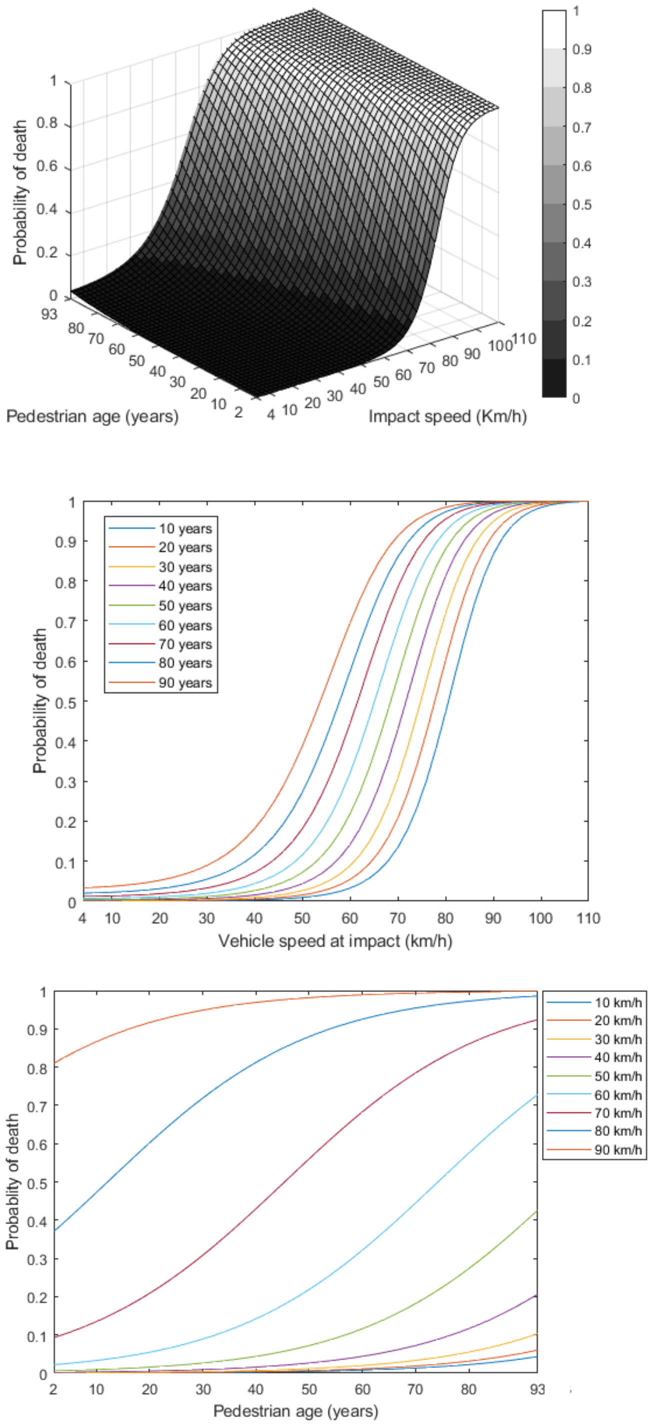
Based on the best combination between the lowest AIC and the lowest ΔN for both K and KSI outcomes, the model that will be kept is Logit (V^2+A).

This helps in deriving the following probabilities of fatal injuries P_K and of fatal or serious injuries P_{KSI} given in equations (2) and (3).

$$P_K = \frac{\exp(-8.0941 + 0.0012 * V^2 + 0.0525 * A)}{1 + \exp(-8.0941 + 0.0012 * V^2 + 0.0525 * A)} \quad (2)$$

$$P_{KSI} = \frac{\exp(-2{,}9893 + 0{,}0013 * V^2 + 0{,}0286 * A)}{1 + \exp(-2{,}9893 + 0{,}0013 * V^2 + 0{,}0286 * A)} \quad (3)$$

Figures 4 and 5 give the three-dimensional and two-dimensional plots for these probabilities.



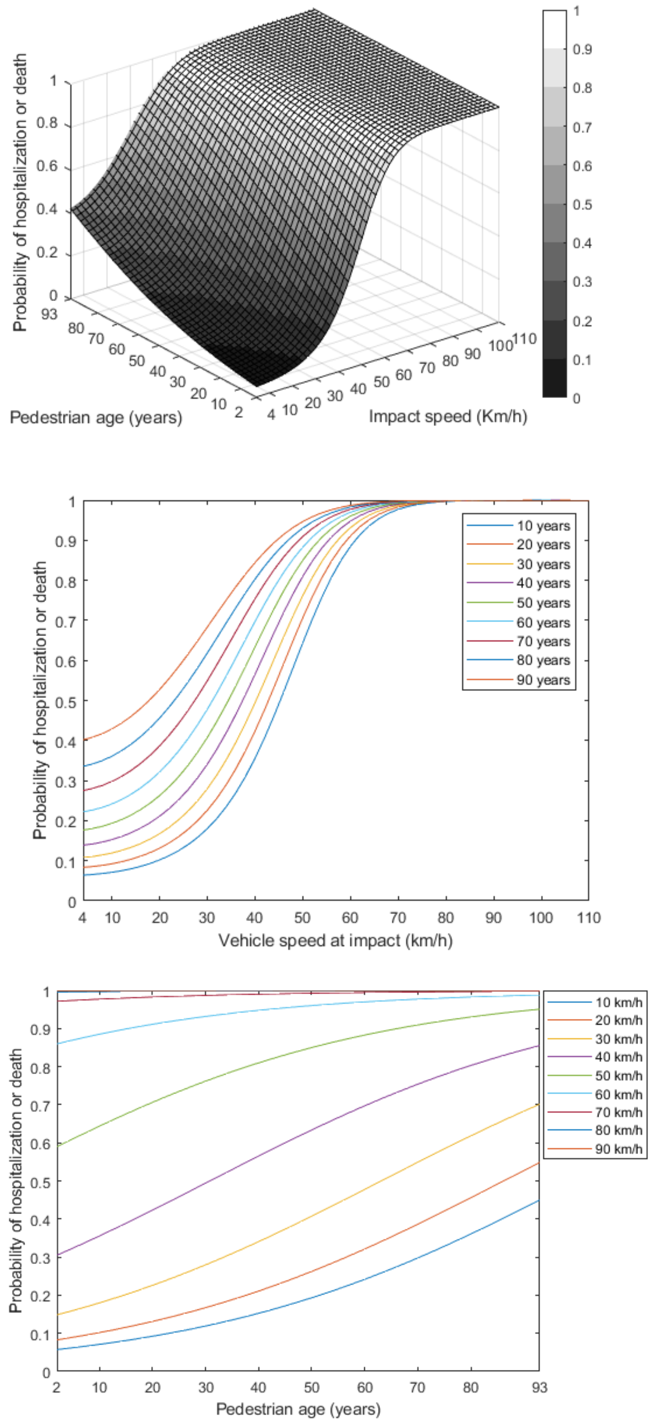


Fig. 4. Upper figure: three-dimensional plot of the probability of death according to vehicle impact speed and pedestrian age. Middle figure: injury risk curves illustrating the probability of pedestrian death as a function of vehicle impact speed and for pedestrians of various ages. Lower figure: injury risk curves

Fig. 5. Upper figure: three-dimensional plot of the probability of hospitalisation or death according to vehicle impact speed and pedestrian age. Middle figure: injury risk curves illustrating the probability of hospitalisation or death as a function of vehicle impact speed and for pedestrians of various ages.

illustrating the probability of pedestrian death as a function of pedestrian age for various impact speeds.

Lower figure: injury risk curves illustrating the probability of hospitalisation or death as a function of pedestrian age for various impact speeds.

IV. Discussion

As the latest studies show, leg impactors and virtual leg models are still under development and have yet to be validated. Different teams have been studying the subject in order to provide precise parameters and a scientific framework for the development of impactors and tests. Likewise, this study provides inputs for designing tests for pedestrian-passenger car collisions, based on events that occur in real-world accidents.

The majority of AIS2+ and AIS3+ injuries were sustained by the lower extremities, followed by the head. Most lower limbs injuries are sustained by the tibia, fibula and pelvis for AIS2+ injuries and by the tibia, pelvis and femur for AIS3+, while there are relatively few injuries of the knee and its ligaments. If this should be confirmed by data from other countries, then it may not be necessary to impose stringent requirements for the knee injury criteria, which will avoid over-engineering vehicles. It would confirm that work should instead focus on biofidelity towards the tibia, fibula, pelvis and femur.

According to the results of the logistic regression analysis, pedestrians are more likely to be killed and killed or seriously injured in a collision that occurs first on the right side of the vehicle, compared to the centre of the vehicle. The results for the left side are not significant. It is therefore not possible to deduce whether the sides of the vehicle pose more or less injury risk for pedestrians than the vehicle centre since, in general, the front-ends of vehicles are designed symmetrically and therefore provide relatively the same type of protection to pedestrians struck by one side or another. It is important to note that this parameter represents the first point of impact on the vehicle. The pedestrian could thus be in contact with different areas of the front of the vehicle (bonnet, windshield, pillar, etc.) and be projected against elements of the infrastructure. Secondary pedestrian impacts, occurring after projection against the infrastructure, were not taken into account due to the lack of systematic information in the database. This might constitute a bias for this study, especially for the results concerning the impact point on the vehicle, since an impact on the right side of the vehicle's front-end could project the pedestrian towards other areas of the infrastructure than a collision that happens first on the centre or on the left side of the vehicle's front-end. Some studies in the literature highlight the effect of secondary impacts on the outcome of accidents [17][27-28]. It seems that secondary impacts could account for 17–66% of injuries sustained by pedestrians. The variation depends mostly on the databases and the samples considered.

Pedestrian direction before impact had no statistically significant effect on the overall outcome of the accident. The results for this parameter could also be biased by the fact that secondary impacts were not taken into account and by the fact that this parameter is, to some degree, correlated to the impact point on the vehicle's front-end. However, the present study shows that the vast majority of accidents happen with pedestrians coming from the sides (45% of NS and 30% of FS). This partially explains the development of surrogates and impactors that represent a crossing pedestrian hit at a perpendicular angle. On the other hand, given the uncertainty on the angles deduced from police reports, the categories of angles were slightly widened (20° for FS and NS), making it impossible to study the influence of a small angular variation on the severity of the injury. It is generally admitted that a small angle would allow the rotation of the tibia/fibula and the femur according to the degrees-of-freedom allowed by the functional anatomy of the knee, thus reducing the strain suffered during an impact by all the lower extremity sub-regions.

Passenger cars with higher bonnet pose a greater risk of fatal injuries. The confidence interval of the AOR is quite large, while the influence of bonnet height on the risk of hospitalisation or death is not statistically significant. However, the results confirm other studies [13][17] showing that higher vehicles are less protective for pedestrians compared to lower BLEH vehicles.

Pedestrian age is a risk factor that does not depend on the vehicle characteristics but that was nonetheless taken into account in this study so as not to constitute a bias for the results. It is also an interesting factor to study since the average and median age in developed societies is constantly increasing. Indeed, the study shows that it has a statistically significant influence on the results for the age category "61+". Risk curves considering age could be correlated with biomechanical tests in order to develop test methods specific to the majority of people in the targeted country or region.

The vehicle speed at impact is the risk factor that has the greatest influence on the results, since all the speed categories are statistically significant with very high odds ratios, especially for speeds exceeding 50 km/h in comparison with those less than 30 km/h. This factor does not depend on the design of the vehicle from the point of view of passive safety but could be accounted for by the AEB-pedestrian active safety system. For this reason, it will be necessary to evaluate the speeds of the residual accidents after application of AEB-pedestrian systems. For example, one study [29] recommends a speed reduction of around 34% during pedestrian impactor tests with vehicles equipped with pedestrian AEB in order to cover the same population covered by the vehicle test without the AEB-pedestrian.

Finally, the multivariate logistic regression enabled the determination of the most influential parameters on the outcome of the accidents. This enabled the modelling of the risk of death and the risk of hospitalisation or death using only a bivariate logistic regression with vehicle impact speed squared and pedestrian age as variables. When compared to the previous model, using only speed as a predictor variable [19], the actual risk curves seem to better fit the data according to the AIC and to the recalculated population criteria. This would probably help in adding precision to the AEB-pedestrian model results illustrated in the previous study [20].

V. Conclusions

To the authors' knowledge, this is the first study giving the combined influence of all the above-mentioned vehicle parameters on the outcome of pedestrian accidents.

Vehicle impact speed was proven to be the most influential parameter on pedestrian injury outcome, reminding us that active safety systems with the ability to reduce impact speed will not only avoid many accidents but will also reduce the severity of injuries, when the accident could not be avoided.

However, for accidents that cannot be addressed by active safety measures, it is essential that vehicle parameters be further investigated in controlled environments, as is done in impact biomechanics, where pedestrian secondary impacts could be eliminated or accounted for. The bonnet height effect has already been studied [30], but the impact speeds of the residual accidents after application of AEB-pedestrian have to be analysed, and then fine-tuning of other parameters, such as impact angle, will be necessary.

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VII. APPENDIX

When coding first impact point for each accident, coders were asked to suppose that the vehicle front-end was divided into 19 categories, from -0.9 to 0.9, and to situate the impact point in these categories. For the purposes of this study, however, those precise categories were grouped into larger ones that could better reflect the stiffness of vehicle front-end (see Fig. A1).

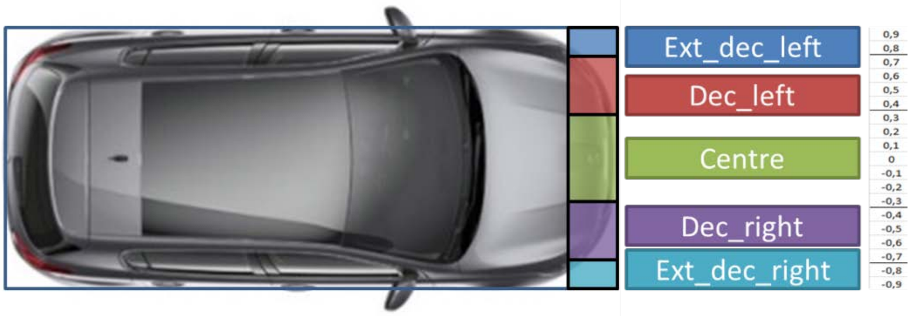

Fig. A1. Definition of the first impact point on the vehicle and its associated categories.

As to the Bonnet Leading Edge height (BLEH), the measurement was taken as described in Fig. A2. Supposing that a print of the vehicle profile was available, a line was drawn tangent to the vehicle front-end and inclined by 50° from the vertical line. The intersection between this line and the vehicle front-end is called the bonnet leading edge reference line. The height of this reference line or its distance from the ground is called the BLEH.

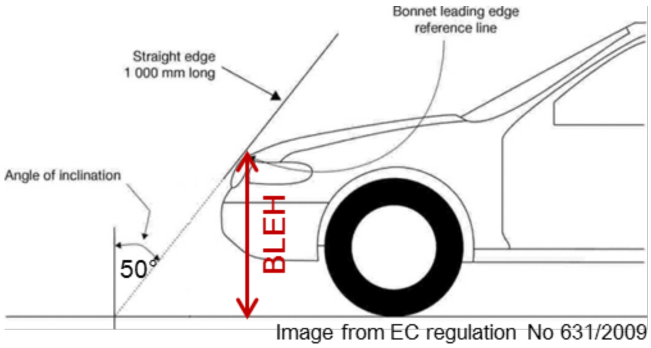

Fig. A2. Illustration of Bonnet Leading Edge Height measurement method.

Pedestrian direction before impact was coded according the categories shown in Fig. A3. The categories were then grouped into more populated ones. Thus “F” and “R” were merged into “Longitudinal, “FFS”, “RFS”, “RNS”, and “FNS” into “Oblique”. Figure A3 also illustrates how impact angles can be deduced from pedestrian direction and vice-versa. There is a need for caution, however, as these are two different definitions. In fact, pedestrians can change direction abruptly, in just a few fractions of seconds before impact. This fact is not included in our accident reconstruction.

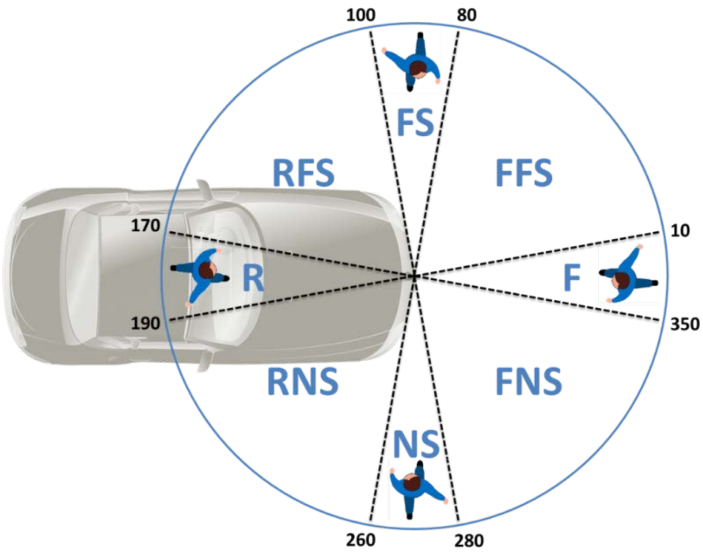

Fig. A3. Illustration of pedestrian direction before impact while the vehicle is positioned at the moment of impact.

Erratum

Pedestrian Injuries and Vehicles-related Risk Factors in Car-to-pedestrian Frontal Collisions

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During the revision procedure of the paper, Fig. 3 was changed by error when trying to change only the names of the lower extremity sub-region. This error concerns only the figure and do not have any consequence on the text in the article. Please consider that the figure illustrated below replaces Fig.3 in the article.

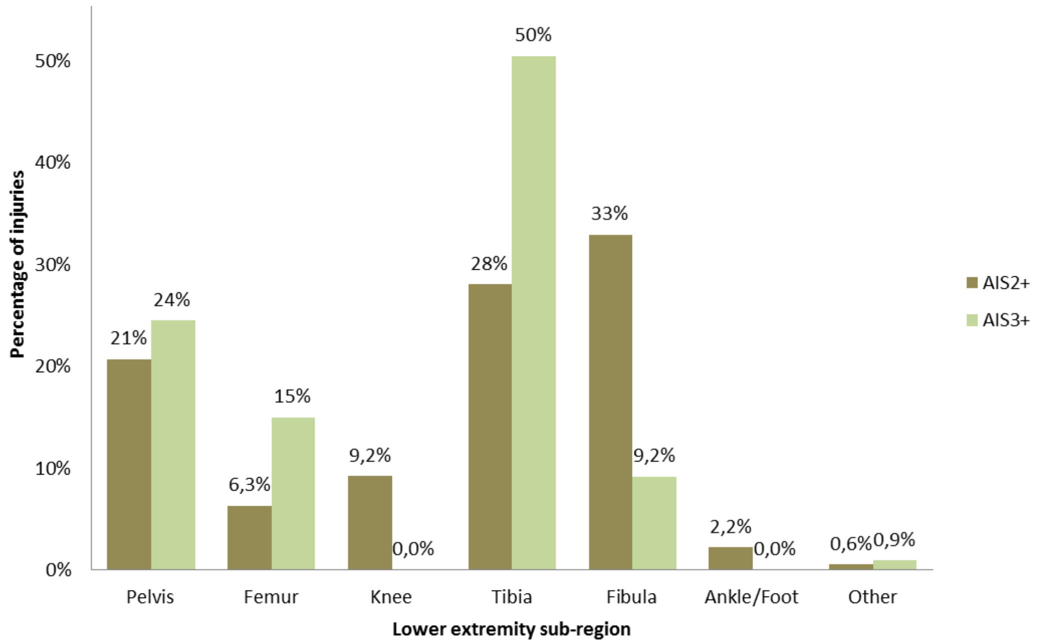

Fig. 3. Distribution of AIS2+ and AIS3+ injuries to designated lower extremity sub-regions.