

CAR OR GROUND: WHICH CAUSES MORE PEDESTRIAN INJURIES?

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ABSTRACT

The aim was to study the cause of the injuries of pedestrians when hit in frontal impacts by a vehicle. Depending on the impact speed, the type and severity of the injuries may be due partly to the vehicle and partly to the road/ infrastructure, when falling down. The study took into account the projection distance and the age of pedestrians.

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All the accident cases were reviewed by an expert committee composed by physicians and accident analysis experts. For each wounded pedestrian, the injuries were reviewed in order to determine their causing mechanism taking into account the accident occurrence circumstances, the vehicle deformations and the clues on the road or infrastructure.

The data base was a sample of 100 in-depth investigations and reconstructions of accidents from years 2009 to 2011 involving at least one injured pedestrian hit by a vehicle and continuously collected in a 20 km diameter area in the south of Paris (France).

The accident analysis team was called with the emergency team on field where the data were collected.

In the sample, 89 pedestrians were injured in a frontal impact. For 83 of them, it was possible to evaluate the vehicle speed during the impact. In 12% of the cases the speed exceeded 50 km/h and all the pedestrians were severely injured (MAIS3+: pedestrian with at least one injury scored above AIS3) with a high projection distance. Therefore, we focused on frontal impact with vehicle speed below 50 km/h. In this configuration, considering injuries AIS2+, the head was the most often injured (53%) and then the lower limbs (21%). Among the wounding elements, the ground was incriminated in 27.5% of the cases, then the bonnet (22%), the windshield (17%) and the bumper (15.5%). When the vehicle speed was below 30 km/h, more than half of the injuries AIS2+ observed were caused by an impact with the ground. There was a compounding effect of age.

Though the sample is not representative of all French pedestrian accidents, it allows categorizing these accidents depending on the impact speed. For each speed range, the main causal factor of the injuries was determined.

The vehicle speed was the major factor in the determinism of the injury severity of pedestrians involved in frontal impact, firstly by direct impact secondly by increasing the projection distance and thus the severity of injuries due to ground impact. Primary safety systems should reduce the severity of pedestrian injuries by decreasing the impact speed.

INTRODUCTION

The last WHO report relates that among the 1.24 million deaths on the world's roads, 22% were pedestrians [1]. When focusing on European countries, they are representing 21% of the fatalities [2]. In France, the percent is lower but still high with 15% of the fatalities in 2014 [3]. In this context, a better understanding of the pedestrian injury mechanisms will help to orient the preventive actions. LAB and CEESAR carried out a specific study about this topic using in-depth accident analysis that was part of a larger project called CACIAUP supported by Fondation Sécurité Routière and the French car manufacturers. The aim of CACIAUP was to study three main topics: 1) to improve the in-depth accident analysis in order to specifically adapt them to pedestrian accidents. It means to optimize the alert, the way how data are collected and accident reconstruction techniques. 2) to follow the injured pedestrians until recovery or stabilization of injury sequelae in order to evaluate the efficiency of the Injury Impairment Scale (IIS) for this population of wounded people. 3) to identify main scenarios of accident involving a pedestrian in order to better specify the primary or secondary safety systems.

The paper focus on the evaluation of the type and severity of injuries depending on the impact speed in frontal impacts of pedestrians hit by a vehicle and of the determination of the cause of the injuries (part of the vehicle or road/ infrastructure).

METHOD

Even a large part of the road fatalities are pedestrians, there is a lack of knowledge about the mechanisms of injuries. In fact in accidents involving pedestrians, numerous clues and parameters rapidly disappear from the scene and render difficult the analysis of the accident. That explains the necessity to adapt the current methodology of in-depth accident investigation.

The in-depth accident investigation is a method to collect detailed road accident data. The latter are useful to describe the circumstances leading up to the occurrence of road accidents. Experts collect transient clues concerning many aspects of road environment (infrastructure, traffic, weather, ...), vehicles and road users that may have contributed to the accident. This detailed knowledge allows to understand the determinism of the accident and to reconstruct the accident with the pre and post crash periods by a PC crash simulation. Two ways to collect data are available:

- on-the-spot in real time
- in delayed time: several days after the accidents

In-depth accident investigation is limited to a study zone where the accident analysis team has obtained all the authorizations from different organizations: national commission for computing and liberties, the prosecutor of the district: judicial authority, the police, the emergency services, the medical services, etc.

In-depth accident investigation in real time

A key point for the accident analysis experts is to be alerted at the same time as the emergency teams in order to arrive with them on the scene to note and figure out the meaning of the transient clues. Among the latter, were the locations of the involved vehicle and of the pedestrian in CACIAUP study. This point was specifically critical because in these accidents involving a pedestrian the damaged vehicle was often moved and the emergency and medical teams had to move the injured people in order to intervene as quickly as possible.

On the scene, experts collected transient data:

- Collection of the debriefings of the involved people and the potential witnesses,
- Collection of contextual information about infrastructure, weather etc...
- Measures of the deformations of the involved vehicles and transcription of the clues

Though most of the information was collected on the scene, experts tried to keep in contact with the involved people in hospital or at home in order to complete the interview. They were also in contact with the police and hospital services.

This valuable method allows to collect very specific and useful data but has also drawbacks. It needs to be located in a limited geographical zone so that experts have time enough to join the accident location in a minimum time before transient clues disappear. Furthermore it is expensive and time consuming.

In-depth accident investigation in delayed time

In-depth accident investigation was sometimes carried out in delayed time. Experts were kept informed of the accidents involving a pedestrian on the investigation area. They had to collect all the information from the police and the road safety district squadron in order to get the accident location and time, accident configuration, vehicle type, name and address of the involved people. Then the investigation went further by looking for additional data. Experts went to analyze car deformations, infrastructure on the accident location. They also met the pedestrian and the driver involved in the accident in order to determine the accident conditions and the performed maneuvers before and during the accident.

This method was less efficient than the previous one on-the-spot due to the fact that transient clues were sometimes lost. It was still informative and allows to increase the number of observations.

In both cases, a physician was in charge of collecting the medical data and to anonymize them.

CACIAUP sample

The main interest of CACIAUP sample was to have numerous parameters and the reconstruction of the accidents in most of the cases. Though very useful, in-depth accident investigations addressed rather severe accidents and did not allow to gather a representative sample. Nevertheless, when possible, it will be compared to the French national road accident data base (BAAC: Bulletin d'Analyse des Accidents Corporels) collected in 2010.

The data base was a sample of 100 in-depth investigations and reconstructions of accidents from years 2009 to 2011 involving at least one injured pedestrian hit by a vehicle. They were collected in a 20 km diameter area in the south of Paris (France) in the timeframe ranging between 6 a.m. and 9 p.m.. A pedestrian was defined as one person who was on a roadway, a sidewalk, a path contiguous with a traffic way, or on a private property [4]. The road users in roller or in scooter were not considered as pedestrians in the study. Among 100 in-depth investigations, 67 were collected on-the-spot and in real time and 33 were collected a few days after the accidents.

Every accident was described in details using general variables in three areas (vehicle, occupant, and infrastructure). Up to 800 variables usable for future studies were coded for each accident. Medical data of every injured road users has been coded using AIS code revision 98 [5]. The score MAIS (Maximum AIS) was also used. It defined the overall level of severity of the injuries and was obtained by considering the highest level of AIS of a casualty having undergone multiple lesions. All the accident cases were reviewed by an expert committee composed by physicians and accident analysis experts. For each wounded pedestrian, the injuries were reviewed in order to determine their causing mechanism taking into account the accident occurrence circumstances, the vehicle deformations and the clues on the road or infrastructure. The categorization of the wounding elements was facilitated by the accident reconstructions.

GENERAL RESULTS:

General information on CACIAUP sample

Location

Among the 100 accidents, 95 of them were located in an urban area, 4 were on roads outside towns and 1 was on an highway. It is comparable to what was observed in the BAAC: 94% of the accidents involving a pedestrian against a car or a light truck were in urban areas.

Weather and light conditions

81% of the accidents occurred during the day, 4% at dawn or dusk and 15% during night. This differed from the accidents observed in the BAAC with 20% of the accidents during the night. It must be reminded that the timeframe of observation did not include a part of the night (from 9 p.m. to 6 a.m.).

81% of the accidents occurred under normal atmospheric conditions, 10% during rain, 6% under overcast and 3% in bright weather. This was approximately the same in the BAAC.

General information on the injured pedestrians

Description of the population of injured pedestrians

The 100 accidents involved 110 pedestrians including 50 males and 60 females. This corresponded to the percent observed in the BAAC.

The sample was different from the BAAC with regard to age (Figure 1). 17% were children under 11 years (12% in the BAAC) and 13% of the people older than 70 years (19% in the BAAC).

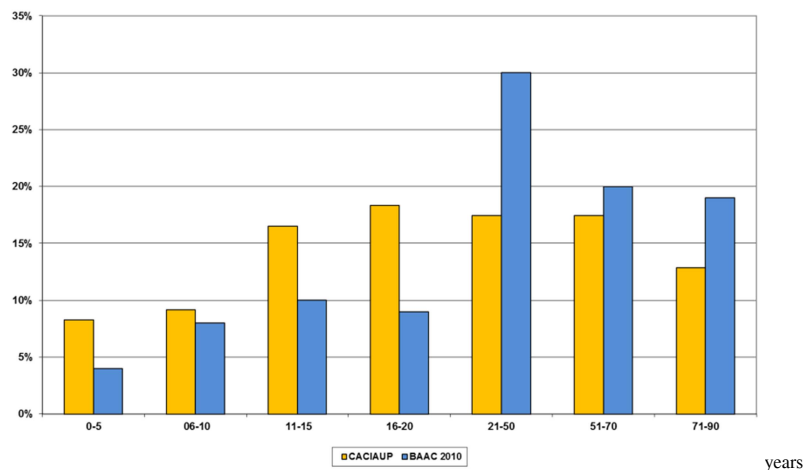


Figure1. Distribution of age (in years) among injured pedestrians in CACIAUP compared to the BAAC

Injury severity

The percent of pedestrians severely injured was similar in CACIAUP and in the BAAC (around 41%). Among them, the part of fatalities was higher in CACIAUP (14,5%) than in the BAAC (3,5%). Thus the CACIAUP sample included cases with a higher level of severity.

Distribution by impact type

The distribution was almost similar in CACIAUP sample and in the BAAC. In the sample, 82% of the vehicles hit the pedestrian by the frontal part, 10% by the rear part and 6% by the side part. Due to the limited size of the sample, further analysis was performed on the frontal impacts only.

RESULTS FOR FRONTAL IMPACT:

Currently, the study focuses on the pedestrians injured in a frontal impact. In the sample, 89 pedestrians were hit by the frontal part of the vehicle. For 83 of them, it was possible to evaluate the vehicle speed during the impact.

Distribution by accidental situations

In-depth accident investigations have shown that the main maneuvers of the pedestrians while hit by the vehicle were the following:

- Road crossing: 56%
- Road crossing at an intersection: 27%
- Walk along the road: 7%
- Other maneuvers: 10%

To sum up, 83% of the accidents occurred while the pedestrian was crossing a road.

Vehicle characteristics

Vehicle front shape

The vehicle front shape is considered as an important factor in the determinism of the pedestrian injuries [6]. It was taken into account. Four vehicle front shapes were observed:

- the wedge shape (2%),
- the box shape (8%),
- the pontoon shape (10%)
- the trapezoidal shape (80%) that was largely the most frequent.

Vehicle speed and projection of the pedestrian

The speed at impact and the projection distance of the pedestrian were two main parameters that were obtained thanks to the in-depth investigations. The projection distance of the pedestrian was correlated to the speed as is shown on figure 2. The higher the speed the longer the projection distance. A few accidents occurred at a speed above 50km/h with a projection distance so high that the severe injuries could be the result of the direct impact of the vehicle and/or of the falling down. So it was decided to focus on the accidents with a speed below 50 km/h.

The mean speed at impact was $32 \text{ km/h} \pm 21.3$.

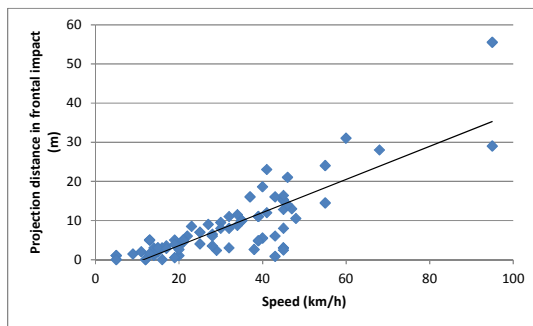


Figure 2. Distribution of the pedestrians according to the speed and the projection distance in frontal impact.

Injuries of the wounded pedestrians

87% of all the injuries , 97% of AIS2+ and 97% of AIS3+ were observed in frontal impacts.

Injuries of the pedestrians for a speed lower than 50 km/h

The sample of pedestrians hit by a vehicle at a speed lower than 50 km/h and for whom all the injuries were known included 71 persons. Thanks to the in-depth investigations, the wounding element was identified for 88% of the injuries. Table 1 describes the wounding elements incriminated to explain the injury AIS2+ of the different body areas.

	Head	Upper limbs	Lower limbs	Thorax	Abdomen	Spine	Total
Ground	19(15%)	8 (6%)	6 (4.5%)	0 (0%)	1 (1%)	1 (1%)	35(27.5%)
Bonnet	11 (9%)	1 (1%)	6(4.5%)	7(6%)	2 (1.5%)	0 (0%)	27(22%)
Bumper	2 (2%)	0 (0%)	12 (10%)	1(1%)	2 (1.5%)	1 (1%)	18 (15.5%)
Windshield	17(14%)	0 (0%)	0 (0%)	1(1%)	1 (1%)	1 (1%)	20(17%)
Lower windscreen frame	9(7%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	9 (7%)
Pilar	5 (4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5 (4%)
Upper windscreen frame	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Front light	0 (0%)	1 (1%)	1 (1%)	3(2%)	0 (0%)	0 (0%)	5 (4%)
Rear view mirror	3 (2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (2%)
Others	0 (0%)	0 (0%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	1(1%)
Total	66(53%)	10 (8%)	26 (21%)	12(10%)	6 (5%)	3 (3%)	123(100%)

Table 1- Distribution of the injuries AIS2+ per body area and vehicle impact part or ground – Speed ≤ 50 km/h

The head was the most often injured (53%) and then the lower limbs (21%). Among the wounding element, the ground was incriminated in 27.5% of the cases, then the bonnet (22%), the windshield (17%) and the bumper (15.5%).

The severity of the injuries increased with the speed of impact (figure 3). 18% of the injuries were AIS3+.

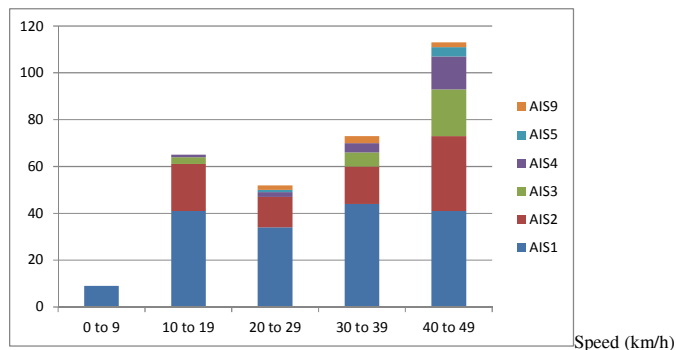


Figure 3. Distribution of AIS according to the speed(km/h) in frontal impact (n=316 injuries).

33% of the pedestrians were severely injured (MAIS3+). Among them, 59% had head injuries AIS3+. In about half the cases, the latter were the consequence of an impact with the windshield probably aggravated by the impact on the ground. 64% of the pedestrians were MAIS2+.

Considering the factor “age of the pedestrian”, 63% of the wounded pedestrians with injuries AIS3+ were older than 51 years. Among them, 54% were older than 71 years.

Injuries of the pedestrians for a speed lower than 30 km/h

When the vehicle speed was below 30 km/h, still 11% of the pedestrians were severely injured (MAIS3+). In most of the cases, these severe injuries were related to the falling down. Considering now the injuries AIS2+ observed when the vehicle speed was below 30 km/h, thanks to the in-depth investigations, the wounding element was identified for 70% of the injuries. More than half of them were caused by an impact with the ground (table 2).

	Head	Upper limbs	Lower limbs	Thorax	Abdomen	Spine	Total
Ground	7(25%)	3 (11%)	4 (14%)	0 (0%)	1 (3.5%)	1 (3.5%)	16(57%)
Bonnet	1 (4%)	0 (0%)	1(3.5%)	0(0%)	0 (0%)	0 (%)	2(7.5%)
Bumper	0 (0%)	0 (0%)	3 (11%)	0(0%)	0 (0%)	1 (3%)	4 (14.5%)
Windshield	4(14%)	0 (0%)	0 (0%)	0(0%)	0 (0%)	0 (0%)	4 (14%)
Lower windscreen frame	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Pilar	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Upper windscreen frame	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Front light	0 (0%)	1 (3.5%)	0 (0%)	0(0%)	0 (0%)	0 (0%)	1 (3.5%)
Rear view mirror	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Others	0 (0%)	0 (0%)	1 (3.5%)	0 (0%)	0 (0%)	0 (0%)	1(3.5%)
Total	12(43%)	4 (14.5%)	9 (32%)	0(0%)	1 (3.5%)	2 (7%)	28(100%)

Table 2- Distribution of the injuries AIS2+ per body area and vehicle impact part or ground – Speed ≤ 30 km/h

The head was the most often injured (43%), then the lower limbs (32%) and the upper limbs (14.5%). Among the wounding element, the ground was incriminated in 57% of the cases, then the bumper (14.5%), the windshield (14%) and the bonnet(7.5%). 64% of the pedestrians were MAIS2+.

Considering the factor “age of the pedestrian”, 30% of the wounded pedestrians with injuries AIS2+ were older than 51 years. Among them, 75% were older than 71 years.

DISCUSSION

Though CACIAUP sample was not representative of the population of pedestrians injured on the French roads, the in-depth investigations were useful to study the determinism of the injuries. For each injury, the causing mechanisms were discussed among the accident experts and the physicians in order to take into account the entire course of the accident and not only the direct impact by the vehicle. The share of all the information about the accidents and their reconstructions enabled to perform this complex task. The final positions of both the vehicle and the pedestrian were so important for an accurate analysis, that the project had asked to the police to mark these positions when they arrived on the spot. Thus, it was possible to obtain the projection distance for the in-depth investigations either in real time or in delayed time. The results showed that the impact speed and the projection distance were correlated although there was a high variation among the different cases. Sometimes, pedestrians hit different obstacles in the infrastructure which reduced the projection distance but often led to severe injuries. The regression curve shows that the higher the speed the longer the projection distance. For speed close to 50 km/h, it could reach more that 20 m. Such distances imply a high risk of injuries during the falling down or at least a risk to worsen the initial injuries due to the direct car impacts.

Most of the CACIAUP results were in accordance with previous studies. The role of the vehicle speed has already been described. Rosen and Sander (2009) have shown a strong relation between the fatality risk and the car impact speed [7]. The circumstances of the accident have been described with a large majority of pedestrians crossing roadway [8] as was found in CACIAUP. However, previous studies found that pedestrians were coded to be not as frequently and severely injured by the ground during vehicle-to-pedestrian crashes [4].

Looking at the two tables describing the distribution of the injuries AIS2+ per body areas and per wounding impact elements, more than a quarter of the injuries were due to ground/infrastructure impacts for speeds below 50 km/h, and more than half of the injuries were due to ground/infrastructure impacts for speeds below 30 km/h. In many studies, these injuries were often underestimated or all injuries were often related by excess to the direct car impacts. The high percent of injuries aggravated or due to the falling down imply that they have to be taken into account. Secondary safety systems have no efficiency on these injuries. They have a limited efficiency on the occurrence of lesions: 1) concerning those related to the direct vehicle impact, secondary safety systems could not impede the abnormal movements of body segments with each other, 2) during the impact, the kinematic energy related to the velocity is transmitted to the pedestrian that is projected to a more or less longer distance. The projection distance increases rapidly with the speed and these systems have no protective effects on the lesions provoked by the falling out. Given the important role of the speed on both direct injuries and secondary injuries due to the falling down or the impact against infrastructure, the priority is to reduce the impact speed. Several solutions could be proposed. First of all, as it is a problem of interaction among the different road users, each of them have rules to respect in order to avoid dangerous conflicts. Especially in urban areas, speed limits help the drivers to adapt their speed to the context of the road and the presence of pedestrians. Primary safety systems could also help the drivers when there is a failure of perception or attention. The advanced emergency braking systems (AEBS) could be very relevant because they avoid contact with the pedestrian or reduce the impact speed if they can not prevent contact. In the latter cases, the resulting reduction of the impact speed decreases the severity of the injuries due to direct vehicle contact and also decreases those due to the falling down because the projection distance is reduced. At low speed, it could be vital for elderly people to avoid the contact as they can be seriously injured only by falling from their height without any injuries due to the vehicle. In CACIAUP, this point especially affects the population of pedestrians over 71.

CONCLUSION

The vehicle speed was the major factor in the determinism of the injury severity of pedestrians involved in frontal impact, firstly by direct impact secondly by increasing the projection distance and thus the severity of injuries due to secondary impacts. CACIAUP results have showed a high number of the injuries due to the ground impact or aggravated by the falling down. Secondary safety has limited effects to protect the pedestrians due to the fact that it does not limit or impede the projection of the pedestrian when hit. Primary safety systems should more efficiently reduce the severity of pedestrian injuries by decreasing the impact speed. In that way, they decrease the energy of the direct impact and the projection distance and thus the severity of the injuries due to all the wounding elements in secondary impacts.

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