PULSE SHAPES AND INJURY RISKS IN COLLISIONS WITH ROADSIDE OBJECTS:RESULT FROM REAL-LIFE IMPACTS WITH RECORDED CRASH PULSES

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ABSTRACT

The possibility to lower the impact severity in roadside collisions are different compared to car-to-car collisions. This may have implication for the construction of road side objects. The aim of the research was to study pulse shapes and influence on injuries in collisions with roadside objects compared to car-to-car collisions. The results from 119 real-life frontal impacts with recorded crash pulse recorders and the diagnoses from occupant injuries were analysed. It was found that in collisions with roadside objects the meanvalue of the average duration was longer compared to car-to-car collisions and that the average acceleration at the beginning of the crash pulse seems to be lower in road side collisions compared to car-to-car crashes.

A GREAT PROGRESS IN PASSIVE SAFETY development of vehicles has been made in the recent decade. New crash programmes (Griffiths 1994, IIHS 1995, O.Neill 1994) have entailed vehicle manufactures to take more severe crash modes into consideration. The variation of objects and the shape of roadside areas are considerable. Roadside collisions often lead to concentrated loading from irregular-shaped objects,thus causing extensive damage to vehicle and occupants. Collisions with roadside objects account for a large part of fatal and disabling injuries in road traffic accidents. In France, on the road network outside urban areas, about one third of the car fatalities (Henry 1991) occurred in crashes against fixed objects. John (1994) stated according to FARS data, that the fatalities in single car crashes into fixed objects without rollovers make up 49% of all types of single car crashes. Based on statistics, John (1994) also found that the most harmful event were tree impacts. About 21% of fatal roadside impacts occur with other unspecified fixed objects. Impacts with road side objects account for 25% of all occupants in the fatal car crashes in Sweden (Wenäll 1997). To achieve a major reduction in severe and fatal injuries in the road transport system, the vehicle passive safety alone cannot solve the injury outcome from car crashes on and beside the road. Minor effort has been made so far by the road designers to reduce the crash forces on a vehicle in a single run-off road collision. There is a limit to what the vehicle engineers can achieve in safety design with regard to this type of impacts. It is therefore necessary to treat the interaction between the car and the environment as a system where passive safety should be considered for the system as a whole.

Some of the restraint systems in the car are usually adapted to a single crash pulse (Berg 1997) that is common in car-to-car crashes. It takes a certain level of crash severity to activate these systems. It is easier to activate the passive safety systems if the crash severity in the first part of the crash phase is high and has a controlled shape. It should be studied whether the characteristics of the crash pulses in the roadside collisions are different from other types of frontal two-car collisions. If there is a difference in crash pulse characteristics, it may cause difficulties to activate the restraint systems in its present design. The risk of severe multiple collisions is higher in roadside collisions, which may lead to an increasing difficulty to activate the restraint systems.

The aims of this study were to show variations in crash pulse shapes between car-to-car crashes and roadside crashes, and to present a distribution of injuries according to different crash severity in these types of collisions. An additional aim was to explain the necessity to develop the passive safety of the road design and the vehicle as a system and to highlight potential problems of activating supplementary restraint systems in roadside collisions.

MATERIAL/METHODS

Impact severity was measured with a crash recorder, called Crash Pulse Recorder (CPR), which measures the acceleration time history in one direction. The crash pulses have been filtered at approximately 100 Hz. Change of velocity, mean and peak accelerations has been calculated from the crash pulses. The CPR and the analysis of the recordings from the CPR have been described by Aldman et al (1991) and Kullgren et al (1995).

Since 1992, the CPR has been installed in approximately 115.000 vehicles, comprising 4 different car makes and 15 models. The car fleet has been monitored for 7 years and every accident with a repair cost exceeding 7.000 USD has been reported via damage warranty insurance. The accident data collection system has been described by Kamrén et al (1991). When this paper was being compiled, approximately 450 frontal impacts were reported.

1998 there were 4.145.000 vehicles registred in Sweden. The number of fatal accidents 1998 were 540 and the about 100 occupants per year sustain fatal injuries in roadside collisions. Approximately 9000 obstacles per year are strucked by vehicles.

This study includes front seat occupants as shown in Table 1. The roadside impacts and car-to-car collisions had a principal direction of force (PDOF) of ±30° . For the opposite cars in the car-to-car collisions any impact direction was permitted. This study includes injury data from 100 frontal impacts with roadside objects and 165 car-to-car collisions.

Table 1. Case accidents with front seat occupants

Collisions	Driver	Front seat passenger	Number of occupants
Car-car collisions without CPR*	84	5	89
Car-car collisions with CPR*	81	35	116
Total car-car collisions	165	40	205
Roadside collisions without CPR*	62	23	85
Roadside collisions with CPR*	38	10	48
Total roadside collisions	100	33	133

*Crash Pulse Recorder

Aside from the crash recorder information, injury data from the Swedish insurance company Folksam, have been collected and coded according to the 1985 revision of the Abbreviated Injury Scale (Association for the Advancement of Automotive Medicine, 1985). MAIS (maximum AIS) for the injured occupant was used, combined with MAIS for each body region. The body regions used in this study were head/face, neck, arm, leg, pelvis, back, chest and abdomen.

Complementary information was obtained from police reports and questionnaires to the drivers. Belt use has been verified according to interior inspections, and collisions with unrestrained drivers, around 5% in total, were excluded from the study. Multiple impacts with major secondary collision damage and rollovers with more than one turn were excluded from this study. Collisions into large animals were excluded as well.

The impact severity parameters used in the study were change of velocity (delta-v) and mean and peak accelerations. In the distribution of impacts, the data were divided into intervals according to each individual impact severity parameter.

RESULTS

ROADSIDE IMPACTS

In Figure 1 the distribution of 38 roadside collisions is shown according to the different change of velocity intervals based on the results from crash pulse recorders and on different AIS levels. Injuries with maximum AIS for an injured occupant, MAIS, are presented as well. The distribution of crash severity for roadside impacts and car-to-car crashes is almost equal and the mean delta-v is also similar (Table 4). The comparison of Fig.1 and Fig. 2 shows that the percentage of moderate or severe injuries in roadside collisions 8/34 (23%), is smaller than 76% in frontal car-to-car collisions.

Table 2 shows the distribution of injured front seat occupants in roadside impacts according to different AIS levels and body regions. The dominating body areas with moderate or severe injuries sustained in roadside collisions are head, chest and the upper extremities. Head injuries AIS2+ account for 4%, chest injuries AIS2+ 5% and the upper extremities AIS2+ 5%. AIS 1 neck injuries make up 16% of the reported injuries.

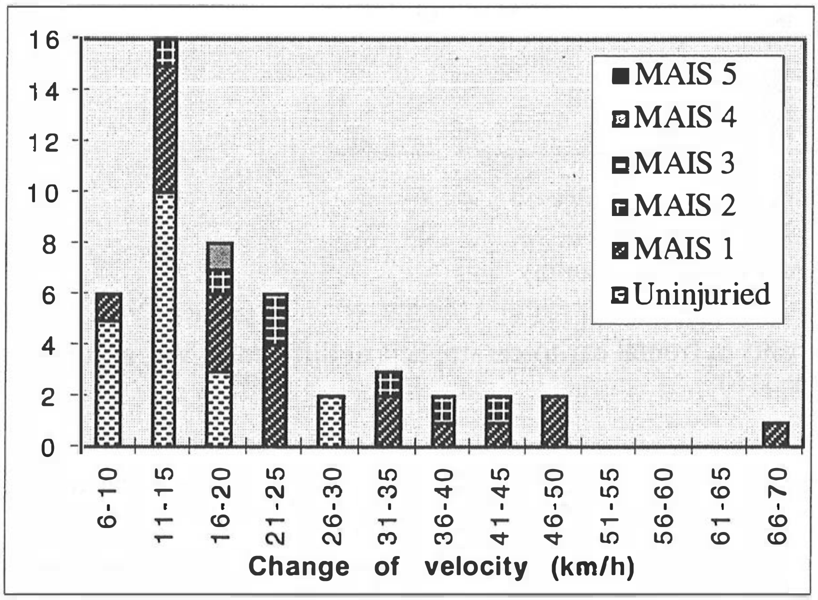

Figure 1. Number of occupants in roadside frontal impacts at different Δ V´s, to different MAIS levels (n=48)

Table 2. Number of driver and front seat passenger injuries at different AIS levels according to different body regions in impacts into roadside objects (n=133).

Body region	AIS 1	AIS 2	AIS 3	AIS 4
Head	18	3	-	2

Neck	19	-	-	-
Arm	11	6	-	-
Leg	14	1	-	-
Back	14	-	-	-
Chest	22	5	1	-
Abdomen	-	-	-	-
Pelvis	-	-	-	-

CAR-TO-CAR IMPACTS

Figure 2 shows the distribution of 81 car-to-car collisions at different change of velocity according to different MAIS levels. 76% sustained MAIS 2+ injuries in car-to-car collisions. Table 3, showing the distribution of injured front seat occupants in car-to-car collisions according to different AIS levels and body regions, has similar injury distribution as Table 2, but a higher rate of upper extremity AIS 2+ injuries (16%) and neck AIS 1 injuries (23%).

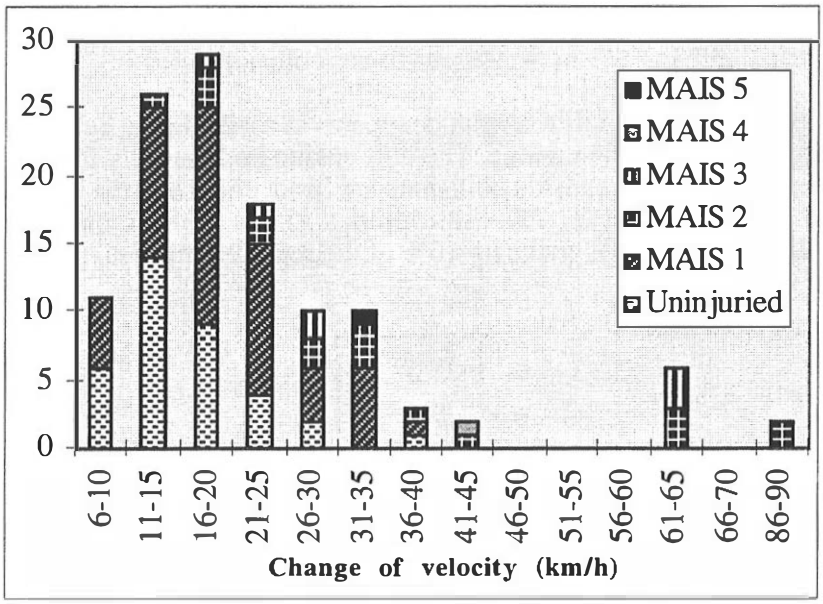

Figure 2. Number of occupants in frontal car-to-car impacts at different Δ V´s, according to different MAIS levels (n=116)

Table 3. Number of driver and front seat passengers at different AIS-level in car-to-car impacts (n=205)

Body region	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5
Head	15	10	-	2	1
Neck	71	1	-	-	-
Arm	37	22	1	-	-
Leg	29	20	5	-	-
Back	32	-	-	-	-
Chest	35	17	4	1	1
Abdomen	1	-	-	1	-
Pelvis	-	1	1	-	-

Table 4 describes the difference between the average of four parameters in roadside and car-to-car collisions. The mean acceleration is 17% higher in car-to-car impacts than for roadside impacts, while the total pulse duration is 6% lower. If the car-to-car accident material is reduced to include only frontal impacts on the opposite vehicle, the average ΔV increases to 30,7 km/h compared to 22,7 km/h. This may explain some difference in injuries in roadside impacts compared to car-to-car collisions. In Figure 3 the mean ΔV values of each pulse are divided in 33 ms intervals and the average of these pulses is expressed in roadside and car-to-car impacts respectively. The mean ΔV is lower in roadside impacts in the first part (0-66 ms) of the crash phase. Figure 4 describes the relative distribution of ΔV in car-to-car impacts and roadside single car crashes during the first 33 ms of the crash phase. Most of the impacts have a severity below ΔV 8 km/h. At the severity above ΔV 8 km/h the share of roadside collisions is 14%, while in car-to-car impacts it is 38%. This means that the roadside collisions appear to have lower severity in the first part of the crash.

Table 5 shows at which crash severity the driver airbags were deployed in roadside collisions compared to car-to-car impacts. Although the number of roadside cases with airbag is small, an indication of the difference in proportion of activated airbags is presented.

Table 4. Average mean delta-v, average mean acceleration, average peak acceleration and pulse duration for roadside impacts and car-to-car collisions.

	Average delta v (km/h)	Average mean acceleration (g)	Average peak acceleration (g)	Average pulse duration (ms)	Observations n
Roadside impact	22,3	5,4	15,9	108,1	38
Car-car impact	22,7	6,3	18,2	101,6	81

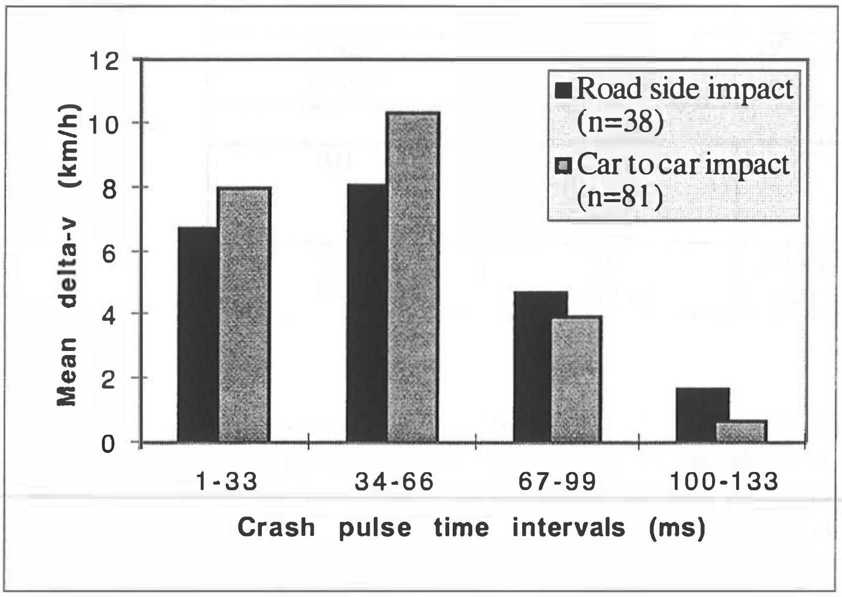

Figure 3. Mean delta-v according to different 33 ms intervals in roadside and car-to-car collisions.

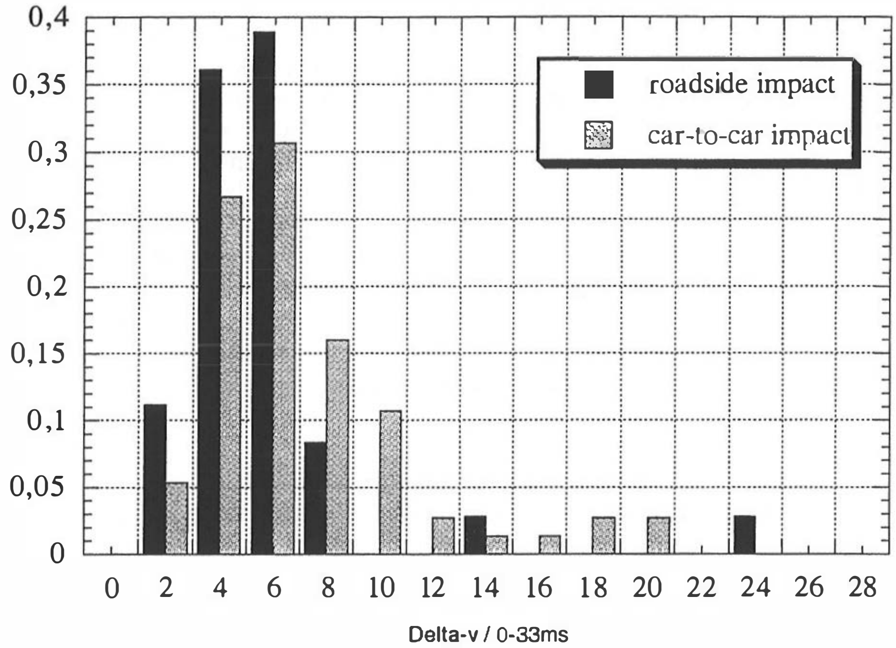

Figure 4. Relative distribution of ΔV during 0 - 33 ms of the crash phase for roadside and car-to-car collisions.

Table 5. Number of cases with airbags deployed according to two crash modes and different ΔV intervals.

		Δ V	
		0-15 km/h	0-25 km/h
Number of car-to-car collisions with driver airbags	N_1	15	30
Deployed airbags n_1	n_1/N_1 (%)	8/15 (53%)	18/30 (60%)
Number of roadside impacts with driver airbags	N_2	8	10
Deployed airbags n_2	n_2/N_2 (%)	1/8 (12%)	2/10 (20%)

Discussion

The amount of knowledge that can be obtained from crash pulse recorders is substantial, although some of the actual results still cannot be generalized to the whole accident population. A relatively limited number of car makes and models with a variety of safety options, such as airbags and seatbelt pretensioners, were included in this research project. The number of impacts at high impact severities was relatively low. Influence of age and gender distributions among the car occupants were not considered.

A relatively limited number of roadside collisions have been analysed, especially with CPR measurement available, which makes it difficult to draw any conclusions regarding the occupant injuries.

In a study by O'Neill (1994) the share of MAIS 2+ injuries in single car crashes was 39% compared to 8/34 (23%) in the present study. An explanation may be the different inclusion criteria i.e. other impact directions and rollovers were excluded in this study, which leads to fewer MAIS 2+ injuries than in single car crashes altogether. From Figure 1 and 2 the rate of moderate or severe injuries, MAIS 2+ is 23% in roadside collisions in this study, compared to 76% in car-to-car collisions. Aside from the reason given above, another explanation may be that there is a higher severity in car-to-car collisions. This may also explain the difference between the result found by (Henry 1991, John 1994, Wenäll 1997) and the results found in this study regarding the amount of severity in car-to-car collisions compared to roadside impacts. In this study 28% sustained AIS 2+ injuries in car-to-car collisions compared to 14% AIS 2+ injuries in roadside impacts. The number of MAIS 2+ injuries in this study is only eight in road side collisions. Further studies have to be undertaken when more data have been collected.

If the car-to-car collision data are reduced to impacts with PDOF of ±30° both for case vehicle and opposite vehicle, the mean delta-v should be 30,7 km/h compared to 22,7 km/h (Table 4). This may explain explain some differencies in injuries in roadside impacts compared to car-to-car collisions. In this study the roadside collisions with other principal direction of forces than ±30° were excluded. A large part of severe injuries occures in side impacts which may reduce the number of severe injuries for roadside collisions in the example.

The total duration of the crash pulse is on the average of 6% longer in the roadside impact. This means that at the same crash severity the average pulse shape is smoother in roadside collisions than in car-to-car collisions. If the collisions with impacts to trees and poles are studied, the duration of the crash pulse is a few per cent shorter than in car-to-car collisions. The result shows the complexity of the roadside impact. Impacts with a smooth crash pulse with a long duration may cause problems for the restraint system to be activated on time or not at all. The risk of multiple impacts may also be higher in roadside collisions which creates problems for restraint systems to protect the occupants throughout the whole crash and also avoiding injuries due to out-of-position.

The first part of the collision is important for accurate deployment of restraint systems. If the first part, 0-33 ms and 33-66 ms, of the crash pulses is studied, it is evident that the mean value of delta-v is lower in roadside impacts than in car-to-car impacts. This presents a potential risk for the vehicle supplementary restraint systems to activate at the wrong time or not at all. If the first 33 ms of the average crash pulse is studied more in detail, we may see that the dominating crash severity in roadside impacts is below 8 km/h ΔV. Above a ΔV of 9 km/h, car-to-car impacts are dominating, which means that the risk, that the sensor systems in roadside collisions do not reach trigger level or are activated too late, is high. Table 5 indicates that these occasions in roadside collisions have a lower rate of deployed airbags. It may be caused by the lower forces at the beginning of the crash. In the studied impact sample the impact severity was in average relatively low, meaning that i.e. airbags should not deploy, even if there would have been higher severity in the beginning.

CONCLUSIONS

• The average acceleration at the beginning of the crash pulse seems to be lower in roadside collisions, compared to car-to-car collisions. This may affect the possibility to correctly activate restraint systems in impacts.

• It is essential that vehicle crashworthiness is evaluated in road environment, up to now this has not been done systematically.

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