Real Life Situations for Rear-Seated Occupants in Far-side Impacts

Katarina Bohman, Junaid Shaikh

Abstract

The aim was to describe crash characteristics and injury patterns of MAIS2+ injured, rear seat occupants in far-side impacts.

The study included weighted NASS-CDS cases from 1994–2014, all far-side impacts with the principal directions of force at 8-10, and 2-4 o'clock with far-side, rear-seated, and 3-point belted occupants of all ages with AIS2+ injuries.

For adults, 38% of occupants had at least one injury to the thorax, and approximately every third occupant sustained AIS2+ injuries to the head, upper and/or lower extremities. The main injury sources were the seat back (36%), and seat belt (22%). For children (4-12y), 49% sustained at least one injury to the head, the most commonly injured body region. The struck side interior accounted for 45% of all contact sources, followed by the seat back.

In far-side impacts, a different injury pattern was found for children compared to adults. While children predominately sustained injuries to the head, adult injuries were spread to several body regions. The variation in injury sources indicates that countermeasures should focus on maintaining occupant in position, rather than directing protection systems to impact surfaces. Evaluation of this load case should include measures of lateral excursion as an addition to traditional ATD measures.

Keywords Far-side, Rear seat, Child, Head injury, Chest injury.

INTRODUCTION

Far-side impacts have been identified as an important load case for the front seat occupants, accounting for 43% of all AIS3+ injuries, and 25% of all fatalities in front seat occupants [1-3]. The most commonly injured body region included the head and thorax [4][5], which are associated with contact to the vehicle interior, near-side occupant, and seat belt [1][4][5][6]. Proposed countermeasures have focused on limiting lateral excursion by keeping the occupant restrained using extra belts and by deploying far-side airbags [5][7].

The far-side load case for the rear-seat occupant has not been as extensively explored as for the front seat occupant. Hoffman et al. [8] explored the differences in MAIS3+ injury patterns and crash characteristics of front and rear seat occupants in far-side crashes. It was found that crash characteristics were similar in terms of angled impacts with a frontal component, and with a median delta velocity (DV) of 31 to 40 km/h. Furthermore, the head and chest were the most commonly injured body regions for both front and rear seat occupants. However, the study included 3-pt belted occupants from 6y, and did not distinguish between children and adults. Arbogast et al. [9] showed that children in forward facing child restraint systems (FFCRS) have a greater injury risk on the near-side, compared to the far-side, in side impacts. Maltese et al. [10] showed that the injury risk decreased with a near-side occupant beside the far-seated child occupant (4-15y). Furthermore, the study showed that head was the most commonly injured body region for this load case. Tylko et al. [11] conducted full-vehicle tests and sled tests with 6-year-old child ATDs, showing extensive lateral excursion into the near-side occupant space, regardless of whether the dummy was restrained in a booster cushion or booster seat. Head contact was frequent when the near-side space was occupied by an FFCRS. Furthermore, the study showed that pretensioners reduced lateral head displacement for both booster cushions and booster seats.

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Far-side sled tests of 3-year-old child ATDs restrained in FFCRS showed that head containment was unacceptable, even with large side wings, and that the head rotated out of the side wings, resulting in exposure to the vehicle's interior [12].

The second row in near-side impacts has been rated in both USNCAP and IIHS for many years by using an SID-IIs. There is also ongoing work in new regulatory requirements to improve near-side impact protection for rear-seated children, to be introduced in North America and Europe (FMVSS 213, UN R129). In 2016, EuroNCAP was the first rating program introducing rear-seated occupants at the far-side location to the side impact rating program. The Q6 child dummy, as a far-side occupant, is seated in a booster seat, and shares the second row seat with a Q10 positioned on the near-side seat, behind the driver. The rating evaluates head loading (HIC) and chest acceleration.

However, there is limited accident data published for this load case showing crash characteristics and injury patterns for rear-seated occupants of all ages in far-side impacts. The aim of this study was to describe crash characteristics and injury patterns of AIS2+ injured rear-seat occupants in far-side impacts, to understand if countermeasures are needed to mitigate injuries in this type of impacts.

METHODS

The study included an overview of the frequency of the far-side load case in relation to other load cases. Then the main focus of the study, was a descriptive and detailed field study of rear-seated, far-side occupants.

The study was based on crash data from the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS) collected from 1994 to 2014, including vehicles with the model year 1985 or earlier. The AIS version 98 update was used in this study.

The selection criteria was rear-seated occupants in row 2 and 3, in passenger vehicles, SUVs, and light trucks, including all levels of injuries. Three-point belt restrained occupants, and children in a child restraint system (CRS), including infant seats, a harness child restraint system, and booster seats/cushions, were included. Occupants restrained in a 2-pt belt, an unknown restraint, or unrestrained, were excluded. All injured occupants were included.

The data was weighted to represent the U.S. population, in both the overview study and the detailed study.

Overview study

For the overview study, the dataset was divided into 4 load cases:

- Frontal – included general deformation (GAD1=F) with a PDOF of 11,12,1.
- Near-Side - included general deformation (GAD1=L and R) with a PDOF of 8-10, 2-4. Occupant positioned on the same side as the side of general deformation.
- Far-Side - included general deformation (GAD1=L and R) with a PDOF of 8-10, 2-4. Occupant positioned on the opposite side as the side of general deformation. Center-seated occupants were not included.
- Rear - included general deformation (GAD1=B) with a PDOF of 5,6,7.
- Other impacts – those not meeting the above inclusion criteria.

Cases in which the target vehicle was bent or shifted in a vertical or lateral direction were also included. In these cases a value of 20, 40, 60 or 80 was added to the direction of force.

Detailed far-side study

The detailed far-side study focused on AIS2+ injured occupants. A far-side impact was defined as having a principal direction of force (PDOF) from 2 to 4 o'clock with a left-side passenger, or from 8 to 10 o'clock with a right-side passenger. Multiple event crashes were included if the far-side impact was the most severe in terms of delta-v (primary CDC). Furthermore, crashes resulting in a rollover event were excluded. Event was defined as a deformation to the vehicle due to an impact with another vehicle or object. It did not include fires or pre-crash manuevers such as braking or steering.

All ages were included and divided into three groups; 0-3y (younger children), 4-12y (older children) and 13 y and older (adults). The younger children's group was most likely to be restrained in a CRS with an internal harness, such as a rear-facing or forward-facing CRS. The older children group were more likely restrained on a booster cushion/booster seat, or directly on the seat bench. The adult group was most likely restrained by the 3-pt belt to the seat bench. Passenger cars, SUVs, and light trucks were included.

RESULTS

Overview

Frontal impacts accounted for the majority of crashes, irrespective of whether all injured, both the MAIS2+ and MAIS3+ levels, were considered, followed by near-side impacts, which increased with the injury severity level. The proportion of crashes for far-side occupants were in the same range as rear-end impacts and other impact directions (see Figure 1).

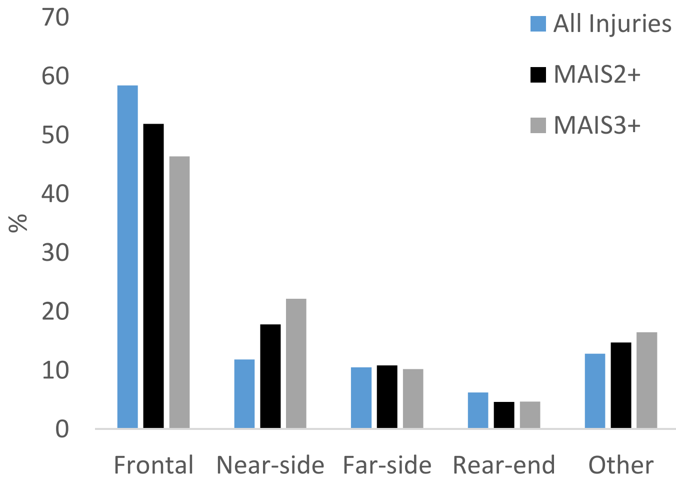


Figure 1 The distribution by impact direction and MAIS level of rear-seated occupants.

Of all side impacts, near-side and far-side, including injuries at all severity levels, far-side accounted for half the side impacts. At an MAIS2+ level, far-side impacts accounted for 34% of all impacts, and at an MAIS3+ level the corresponding figure was 27%.

Given that the occupant had been in a near-side impact, the risk of sustaining an MAIS2+ injury was 17%, which was the highest level compared with other impact directions. The risk of sustaining an injury in a far-side impact was at the same level as frontal and rear-end impacts for both MAIS2+ and MAIS3+ injuries (Figure 2).

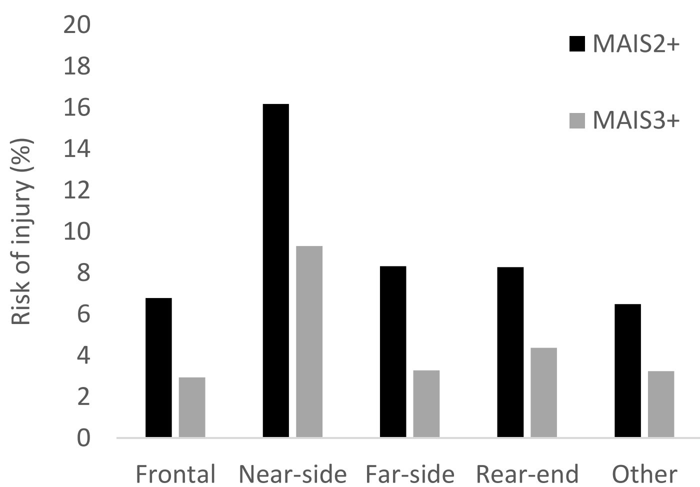


Figure 2. The risk of MAIS2+ and MAIS3+ injured occupants relative to all injured rear-seated occupants by impact direction.

Crash characteristics and injury patterns in far-side crashes

In total, there were 65 restrained occupants with AIS2+ injuries, representing 3414 occupants when weighted. Of those, 4% were fatally injured. For our purposes only weighted results will be presented, if not otherwise stated.

Women accounted for 55% of cases. The majority (74%) of the occupants were younger than 20 (see Figure 3). The three age groups included; 13% children 0-3y, 39% children 4-12y, and 48 % adults 13y+.

88% of the children 0-3 years old were restrained using CRS systems, and of those, 7% in infant seats, 45% in convertible seats, 19% in toodler seats, and 17% in unknown CRS systems. Eight per cent of the children 4-12 were in a CRS system, and of those, 7% in convertible seats, and 1% in booster seats.

In total, 6% of the vehicles involved in the crashes were equipped with a curtain side airbag, and of those, one-third was deployed.

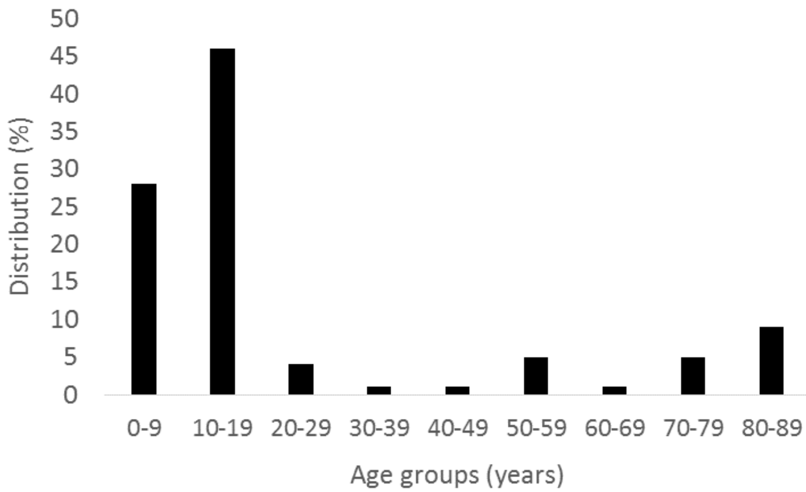


Figure 3 Age distribution of AIS2+ injured.

The majority of impacts (60%) had a delta velocity (DV) of 30 km/h or higher (Figure 4).

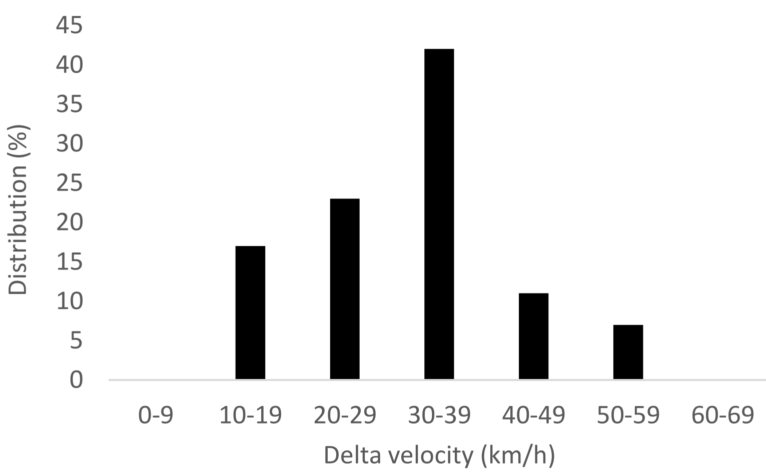


Figure 4. Delta velocity distribution.

Crash characteristics are seen in Table 1. The bullet was most commonly a vehicle of any type in 83% of the crashes. The other bullets accounted for various types of objects. The target vehicle was usually a passenger vehicle (70%). When the bullet was another vehicle, it was more often of a heavier vehicle type than a passenger vehicle.

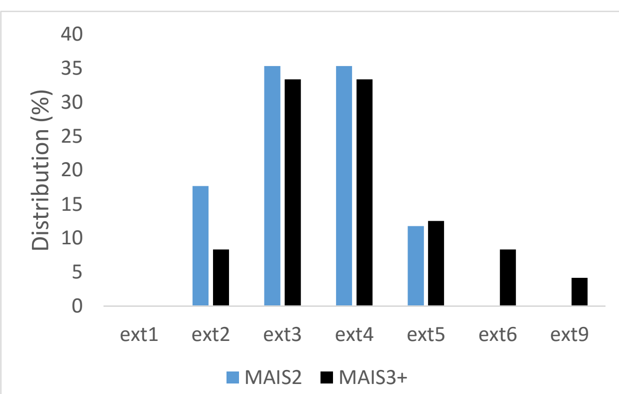
In 55% of cases, intrusion was 15 cm or more on the near-side. The majority of crashes had an angled PDOF of 2 or 10 o'clock (65%).

A crash can be composed of several events. In this dataset, the far-side crash was judged by the NASS-CDS investigator to be the most harmful event of the crash. The far-side crash was the single event in 43% of cases. In the other crashes, there were 2 or more events in each crash.

	Count	%		Count	%
Target vehicle			**Intrusion (cm)**		
Passenger vehicle	2371	69	0-2	809	24
SUV/Van	1035	30	3-7	400	12
Pick up truck	8	0	8-14	320	9
			15-29	557	16
Bullet vehicle/object			30-45	911	27
Vehicle	2836	83	46-60	137	4
Object	578	17	61 +	281	8
Bullet vehicle			**Number of events**		
Passenger vehicle	1063	37	1 event	1444	42
SUV/Van	630	22	2 events	908	27
Pick up truck	654	23	3 events	610	18
Bus	0	0	4 events or more	450	13
Others	489	17			
PDOF					
2&10	2232	65			
3&9	1086	32			
4&8	96	3			

Table 1 Crash characteristics, including distribution of target vehicle type, bullet type, principal direction of force (PDOF), intrusion on the near side occupant space, and number of events.

Crash extent is part of the collision deformation classification (CDC) used in NASS-CDS, revealing information of the maximum penetration into the vehicle. Figure 5 (left) shows the distribution of injury severity by crash extent, and the MAIS2 injuries were more often found in crashes with less deformation compared to MAIS4+ injuries. Figure 5 (right) shows the distribution of the target car model years by crash extent. Both older and newer vehicles were represented in all grades of crash extent, with older vehicles somewhat more frequent in crashes with less deformation compared to newer vehicles.



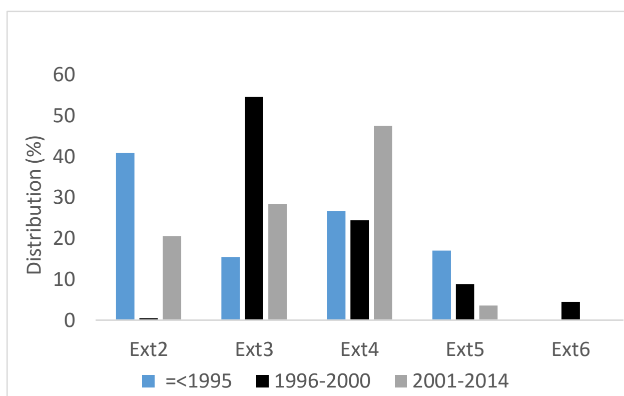


Figure 5 Left) Distribution of MAIS2 and MAIS3+ injured occupants by crash extension. **Right) Distribution of car model year (=<1995, 1996-2000, 2001-2014) by crash extent.**

Figure 6 (left column) shows the percentage of MAIS2+ injured occupants. 39% of the youngest children and 49% of the older children had at least one injury to the head. For adults, 38% of the occupants had at least one injury to the thorax, and about every third occupant sustained an AIS2+ injury to the head, upper and/or lower extremities.

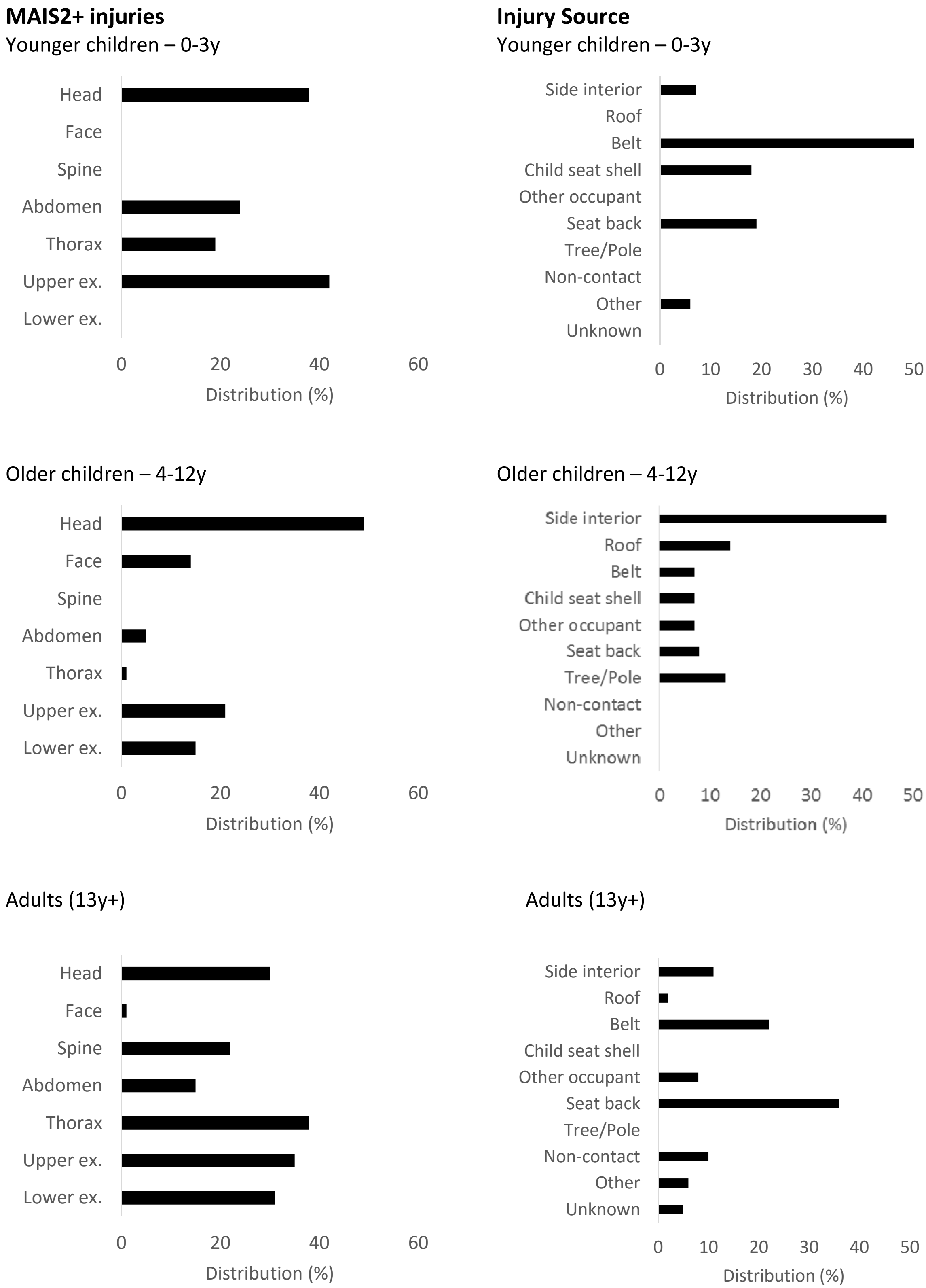


Figure 6 Left column: Percentage of MAIS2+ injuries by body region for different age groups: top graph, younger children 0-3y, middle graph, older children 4-12y, bottom graph, adults 13y+.

Right column: Injury sources for: top graph, younger children 0-3y, middle graph, older children 4-12y, bottom graph, adults 13y+.

The younger children were injured mainly due to contact with the belt/harness (50%), seat back (19%), or the shell of the child restraint (18%). The main injury source for the older children, was the side interior (45%). The most common sources of adult injuries were the seat back (36%), and the seat belt (22%) (Figure 6, right column).

Among children 4-12y, there were one or two near-side occupants beside the far-side occupant in 39% of the crashes. The injury pattern was different, depending on the presence of a near-side occupant. In crashes without a near-side occupant, the far-side occupant sustained head injuries to a greater extent than those with a near-side occupant. Also, injuries to the lower extremities increased with a near-side occupant present (Figure 7, left).

For adults, 41% of the crashes included one or two near-side occupants. For adults, the head injuries increased, while thorax, abdomen and spine injuries decreased if there was a near-side occupant present (Figure 7, right).

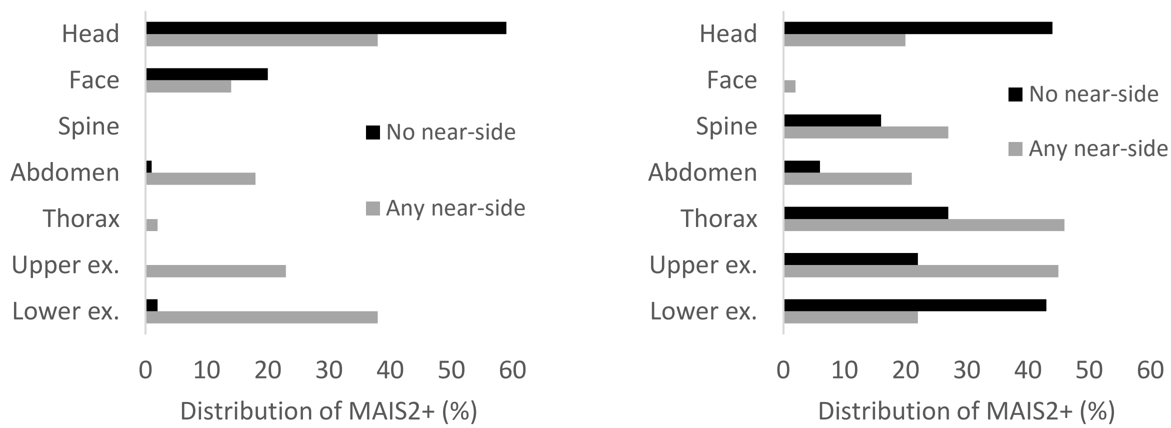


Figure 7 MAIS2+ injury distribution for occupants with and without a near-side occupant: left, 4-12y occupants right, 13y+ occupants.

It was common that a crash included more events than the main crash event (table 1). Figure 8 shows that head injuries were more frequent in crashes with one single event for both children and adults, while upper extremities were more common in crashes with several events. However, the subgroups are small in this dataset and more data is needed to confirm that these trends are significant.

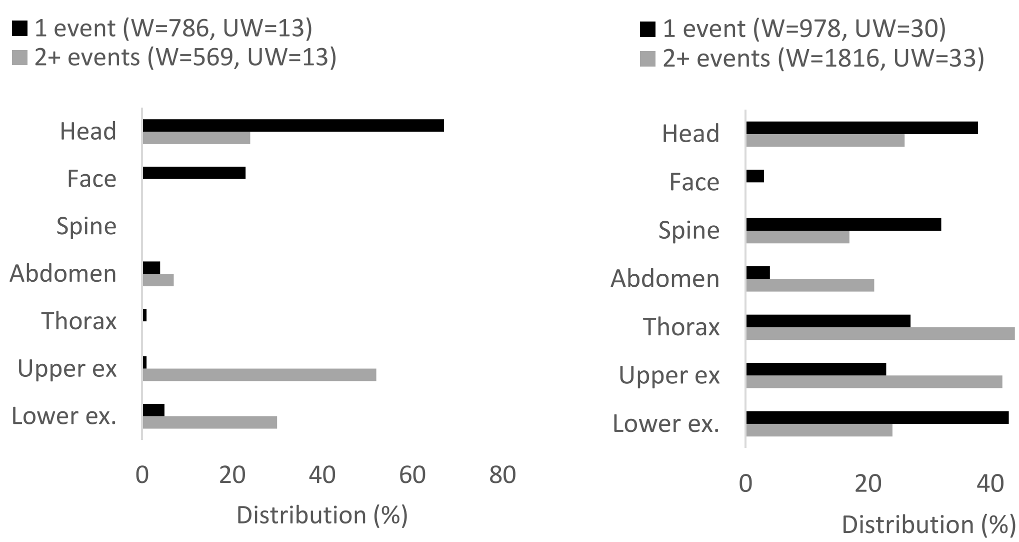


Figure 8 MAIS2+ injury distribution with crashes with only one event and crashes with two or more events for 4-12y occupants (left) and 13y + occupants (right). The number of weighted (W) and unweighted (UW) cases are included in the legends.

DISCUSSION

Far-side crashes have been well studied for the front seat but limited for the rear seat for this load case. This study shows the crash characteristics and injury patterns of rear-seated occupants in far-side crashes, for both children and adults.

Overview

When comparing the frequency of crashes by impact direction, frontal impacts followed by near-side impacts are the most frequent load cases, while far-side impact is the third most common load case. Far-side impacts accounted for 34% of all side impact crashes with MAIS2+ injuries to rear seated occupants, and 27% of all MAIS3+ injuries. This is the same level as for front seat occupants [13]. Hoffman et al. [8] found that the ratio of those MAIS3+ injured relative to MAIS1+ injured occupants, was at the same level for front seated occupants as for rear seated occupants in far-side impacts. The current study shows that the risk of AIS2+ injury, given that the occupant was involved in an impact of a certain direction, were highest in near-side (16%) impacts, followed by far-side (8%), and frontal impacts (7%). Arbogast et al. [9] found similar priorities between impact directions when studying younger children in FFCRS (booster seats excluded). They found that the risk of injury in far-side impacts were 2.1 injured children per 1000 crashes, compared with 8.9 injured children in near-side impacts, and 2.7 injured children in frontal impacts. Hence, far-side impacts are second after frontal, and near-side impacts the third impact direction that needs to be addressed, in order to reduce fatalities and severely injured occupants in the rear seat.

Far-side

A different injury pattern was found for children (4-12y) compared to adults. While children predominately suffered head injuries, adult injuries were spread to several body regions including the thorax, head, spine, and upper and lower extremities. Similar findings are found in other impact directions for children and adults. In frontal impacts as well as near-side impacts children are more likely to sustain head injuries, while adults are more likely to sustain an injury to the thorax [14] [15]. Furthermore, studies have shown that injury pattern to the thorax changes with age, due to physical development the chest becomes more fragile with age [16] [17].

Furthermore, there was also a difference in the pattern of injury sources between the two age groups. Side interior accounted for 45% of all injury contacts for children, while adults contacted the seat back (36%) to a much higher degree than the children (8%). Considering that children are shorter and thinner than adults, the shoulder belt might not have restrained the upper torso of the children to the same extent as it did for adults. Tylko et al. [11] found, in vehicle and sled testing in far-side impacts with 6y ATDs as far-side occupants, that the 6y ATDs slid out of the shoulder belt in all tests when seated on a booster without a back, and no activated pretensioner. In the current study, there were few children on booster seats, and furthermore, there were no vehicles with pretensioners for the rear seat. Furthermore, Arbogast et al. [18] showed that children have greater spinal flexibility during the forward excursion in frontal impacts when compared to adults. This has not been explored in far-side impacts.

The seat belt was also an injury source to both adults (22%) and the older children (7%). The seat belt contact was associated with abdominal and thorax injuries. The seat belt may reduce lateral excursion thereby reducing the risk of head contact, especially if remaining on the shoulder [11] [19]. However, it can also induce injuries by loading the abdomen and lower thorax [1]. In the current study, adults sustained injuries more often associated with the seat belt than the children, one possible explanation being that children, due to their small size, may completely roll out of the shoulder belt resulting in limited contact with the shoulder belt to the abdomen and thorax. Such kinematics were found in some tests made by Tylko et al. [11], (see Figure 9).

Figure 9 Q6 ATD in far-side impact [11].

The seat back was the source of injury, especially in adult chest and abdominal injuries. In some crashes, the front seat will move inboards, and possibly rearward, into the rear seat occupant compartment due to deformation on the impacted side, contributing to the risk of contact with the rear seat occupant. Furthermore, the majority of crashes with injured far-side occupants were angled with a frontal component, and it might also have contributed to occupant kinematics in the direction of the seat back. Arbogast et al. [20] explored accident data with children in side impacts, including 7 cases with far-side seated children (1-5y). Their head injuries were associated with impacts along the edges of seat backs and head restraints.

There were very few vehicles equipped with curtain side airbags, therefor it was not possible to draw conclusions for injury protection provided in real life. However, the contact sources referred to as “side interior” included windows, door panels, armrests, b-pillars and window rails, and several of these areas are not generally covered by the inflated chambers of the curtain side airbag. With the typical design of today’s curtain side airbag, it would have limited injury-reducing effect in far-side crashes for rear-seated occupants.

The injury pattern was changed if there was a near-side occupant present beside the far-side occupant. For children, 4-12y, head injuries were reduced, while abdominal and lower extremity injuries increased, when a near-side occupant was present. Maltese et al. [10] showed a reduced risk of injury to the far-side occupant (4-15y) if there was a near-side occupant. If the far-side occupant does not impact the head with the near-side occupant, it could be assumed that the near-side occupant limits lateral excursion and lateral velocity of the far-side occupant, thereby reducing the risk of head injury due to side interior contact. However, in vehicle crash tests [11], head contact was frequently found when there was an FFCRS on the near-side occupant space, but also head contact to the shoulder between the Q6 and the far-side occupant, and a small female ATD on the near-side occupant space. Similar for adults, the current study showed that the presence of a near-side occupant decreased the number of head injuries and injuries to abdomen, spine and upper extremities increased. In the front seat, where predominately adults are seated, contact with the near-side occupant was a frequent injury contact source [4].

The injuries to children in the age range 0-3y were mainly to the head. Injuries in this age range were associated with the CRS, seat back or harness. Studies with sled tests of both a rearward and forward facing CRS [12][21] showed that the head was not contained within the side wings, and lateral excursion may increase the risk of head contact with the side interior and seat back. These studies [12][21] suggest improvements of the CRS attachment to the vehicle, and also proposed to share protection responsibility between the CRS and the vehicle. It should be noted that the current study included only very few cases in this age group, 8 cases representing 443 occupants. Other studies with larger data sets are needed to state injury patterns and sources with greater confidence.

The spread in injury pattern between children and adults, as well as the large physical spread in contact surfaces, indicate that countermeasures should focus on keeping the occupant in position, rather than directing the protection system to the impacted surfaces. Proposed countermeasures to front-seated occupants in far-side impacts have focused on limiting lateral excursion, keeping the occupant restrained using pretensioners, extra belts, and far-side airbags [5][7]. A similar approach can be used in the rear seat. Furthermore, Arbogast et al. [18] studied human volunteers, adults and children, restrained with pretensioners in low-speed far-side impacts, and concluded that that torso containment within the shoulder belt was improved, and lateral excursion, decreased. Tylko et al. [11] found the highest reduction in lateral excursion of the 6y ATD when restrained by pretensioners and booster seats with ISOFIX, compared to restraint systems without pretensioners.

From 2016, EuroNCAP was the first consumer-rating program including rear-seated far-side occupants. However, in real life, the majority of AIS2+ injured far-side occupants were involved in crashes with a DV higher than 30 km/h, which is higher than a general EuroNCAP AEMDB test. The EuroNCAP AEMDB test was primarily designed to capture crash severity relevant for the near-side occupant in the front seat, who are injured in lower delta velocities [22]. Today, the rating includes HIC and chest acceleration measurements of the Q6 ATD. However, this real-life study shows that lateral excursion can be a relevant measure when evaluating this load case. By limiting lateral excursion, the likelihood of contact with various vehicle interior contact surfaces will be reduced, thereby reducing the risk of injury. Excursion is already used as a measure when evaluating frontal impact performance of child ATDs in EuroNCAP.

In half the cases, the far-side impact was an isolated event, while the other cases included two or more events with the far-side impact as the most harmful. This was similar range, as fond for front seated occupants in far-side crashes [1]. A previous study has shown that multiple impacts may result in increased injury risk or fatality compared to single impacts [23]. Studies of steering maneuvers prior to impact showed they may result in the 3-pt belt sliding off the shoulder, thereby reducing the effect of the seat belt where the maneuver is followed by an impact [24][25]. Gabler et al. [1] found that for front-seated occupants in far-side impacts, there was a higher injury risk in multiple events compared to single event collision. Since it is essential to be well restrained in a far-side impact in order to reduce the risk of impacting the interior surface, impacts with multiple events may require special attention to ensure the occupant stays well restrained during all events.

Limitations

It would be desirable to describe the far-side situation focusing on recent crashes and new vehicles in order to understand the current situation in new vehicles. However, due to the limited number of cases, the dataset included crashes from 1994 and onward. In addition, older vehicle models (1985+) were included. It is likely that there would be less intrusion in newer vehicles due to improved structures in the vehicles. Since children had side interior as the primary injury source, this distribution may have been different if the study included only newer vehicles. Conversely, improved structure may result in increased DV, which has been found in frontal crashes [26][27]. The influence of vehicle compartment improvements could be evaluated for front-seated occupants, for which the data set is much larger than for the rear-seated occupant.

Due to the limited number of cases, all types of near-side occupants (near-side occupant close to the door, center-seated occupant, or with both places occupied) were summarized as “near-side occupants”. The majority of “near-side occupants” were typically occupants sitting by the door, with no center-seated occupant, for both adults and far-side child occupants. In a larger dataset, it would be possible to examine in greater detail possible differences in injury patterns depending on the type of near-side occupant present in the crash.

Unrestrained occupants were not included in this study. It is well known that unrestrained occupants are more frequently injured than restrained occupants, hence, this study focused on analyzing 3-pt seat belt restrained occupants. Nevertheless, it is important to continue the work worldwide to increase seat belt use in the rear seat. Also, in countries with seat belt laws and enforcement, efforts are needed to increase seat belt usage.

Center-seated occupants are also far-side occupants. However, they need to be analyzed separately from far-side occupants sitting in the outboard position, since center-seated occupants are sitting closer to the near-side interior, which may result in different injury patterns. In this data set, there were only 6 center-seated occupants altogether. Due to the small number, they were not included in the study.

CONCLUSIONS

In far-side impacts with rear-seated occupants, a different injury pattern was found for children compared to adults. While children predominately sustained injuries to the head, adult injuries were spread to several body regions including the thorax, head, and upper and lower extremities. The injury sources were spread to numerous vehicle interior surfaces, which indicates that countermeasures should focus on maintaining the occupant in position, rather than directing protection systems to the impacted surfaces.

Evaluation of countermeasures in this load case, should include measures of lateral excursion as an addition to traditional ATD measures in order to limit the kinematics and thereby reduce the risk of contacting the vehicle interior surface.

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