

The Effectiveness of Curtain Side Air Bags in Side Impact Crashes

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ABSTRACT

Accident data show that the head and the chest are the most frequently injured body regions in side impact fatal accidents. Curtain side air bag (CSA) and thorax side air bag (SAB) have been installed by manufacturers for the protection devices for these injuries.

In this research, first we studied the recent side impact accident data in Japan and verified that the head and chest continued to be the most frequently injured body regions in fatal accidents.

Second, we studied the occupant seating postures in vehicles on the roads, and found from the vehicle's side view that the head location of 56% of the drivers was in line or overlapped with the vehicle's B-pillar. This observation suggests that in side collisions head injuries may occur frequently due to contacts with the B-pillar.

Third, we conducted a side impact test series for struck vehicles with and without CSA and SAB. The tests were conducted based on the specifications of Regulation ECE/R95 except for the dummy seating position. The dummy seat positions were adjusted such that the dummy head overlapped the B-pillar. The test vehicles were small passenger vehicles and K-cars which are popular in Japan. The K-car is categorized in Japan as a very small size vehicle. It was demonstrated that the CSA and SAB were effective for reducing the number of head and chest injuries in car-to-car crashes. But it was also demonstrated that the effectiveness of CSA and SAB were dependent on the designs.

INTRODUCTION

From the accident data analysis, it was shown that the contacts with the head and chest during side crashes are a major cause of serious injuries and death. In order to prevent the occupant's serious injuries during side impact accident, manufacturers have installed curtain side air bags (CSAs) and thorax side air bags (SABs) as supplemental restraint systems. In general, the CSA protects the occupant from head, face, and neck injuries; and the SAB protects the occupant from thoracic and abdominal injuries.

There are many studies about the effectiveness of the CSA and the SAB. For example, the Insurance Institute for Highway Safety (IIHS) estimates that the side air bags with head protection reduce driver deaths in cars struck on the near side by 37% [1]. Otte et al. conducted research to analyze side impact accident data to confirm the effectiveness of the SAB [2]. The National Agency for Automotive Safety and Victim's Aid (NASVA) conducted pole side impact tests on vehicles with and without CSAs and compared the resulting head injury measures. The National Traffic Safety and Environment Laboratory (NTSEL) reported some pole impact test data with the CSA test cases [3, 4].

But for the case of a side impact accident in which the striking object is a passenger vehicle, the effectiveness of the CSA has not been studied so much. This may be due to the fact that the dummy head injury measures are not so large for the tests based on the ECE/R95 test procedure and the CSAs are not needed. For example, most of the head injury criteria (HIC) data measured in the Japan New Car Assessment Program (J-NCAP) have been less than 500.

In this research project, we hypothesized that the reason why the dummy head injury measures under the ECE/R95 tests were not so large was due to the posture of the dummy. In

almost all cases, the dummy head did not overlap the B-pillar under the ECE/R95 regulation. We conducted research on the side impact accident in Japan and the occupant seating postures in vehicles on the roads, and conducted full car side impact test series. Some of these results already have been published [5]. In this study, first we investigated the recent side impact accident data in Japan by injury levels and confirmed the macro trend. Next, we researched the occupant seating postures in vehicles on the roads and confirmed that 56% of drivers and 78% of passengers were seated such that their head overlapped the B-pillar (from a side view). And from our research sample study, we confirmed that the trend that, when the driver's height was large, the overlap of the head and B-pillar was large. We also found that the individual variability also had a large influence on the position as well as the height. Third, tests were conducted based on the specifications of Regulation ECE/R95 with the exception that the dummy was positioned so as the head would make contact with the B-pillar. To investigate the effectiveness of CSA for head protection in car-to-car crashes, these tests were conducted for struck cars with and without a CSA for two types of vehicles. It was demonstrated that the CSA was effective for reducing the number of head injuries in car-to-car crashes.

STUDY ON SIDE IMPACT ACCIDENT IN JAPAN

In this study, the accident analyses in Japan were examined based on the Institute for Traffic Accident Research and Data Analysis (ITARDA) global accident data for 3 years (2005-2007). The side impact accident data were filtered to contain only belted occupants and crashes without multiple impacts. [Figure 1](#) shows the percentage of striking vehicles and object types by the injured level (fatal, serious, and minor). The narrow objects (e.g., signals, telephone poles, and road signs) were defined as “poles”. The injury level was defined by the days that the victim visited the hospital. The cases for which the visit to the hospital was over 30 days were defined as “serious” injuries, and the cases where the visits were under 30 days were defined as “minor” injuries. The cases that the occupants died within 24 hours of the accidents were defined as “fatal” accidents. In fatal accidents, 47% of the striking objects were a “passenger vehicle”, 21% were “other object (without pole)”, 19% were “pole,” and 13% were “large vehicle, truck”. In serious injury accidents, 81% of the striking objects were “passenger vehicle”, 10% were “other object (without pole)”, 5% were “large vehicle, truck,” and 4% were “pole”. In minor injury accidents, 97% of the striking objects were “passenger vehicle”, 2% were “other object (without pole)”, 1% were “large vehicle, truck,” and 0.3% were “pole”. The “passenger vehicle” was the largest source of all the accidents though the percentage was relatively smaller in the fatal accidents and larger in the minor accidents. The “Large vehicle, truck”, “pole” and

“other object (without pole)” were large sources in the fatal accidents, but very small in the minor injury accidents.

[Figure 2](#) shows the injured body regions of the occupants by injured level. In the fatal accidents, 43% of the injured body regions were the “head, face” and 28 % were the “thorax, back”. In the serious injury accidents, 32% of the injured body regions were the “thorax, back”, 21% were the “neck”, 19% were the “pelvis, lower extremities,” and 13% were the “head, face”. In minor injury accidents, 69% of the injured body regions were the “neck”. The “head, face” was the largest source in fatal accidents and not a small source in the serious injury accidents. The “thorax, back” was the next largest source in the fatal accidents and the largest source in the serious injury accidents. So, it has been determined that protecting the head and thorax of the occupant is important for reducing the fatal and serious side impact accidents.

[Figure 3](#) shows the injured body regions of the occupants by striking objects in the fatal accidents. [Figure 4](#) shows the injured body regions of the occupants by striking objects in the serious injury accidents. [Figure 5](#) shows the injured body regions of the occupants by striking objects in the minor injury accidents. As for the fatal accidents, when struck by “passenger vehicles”, 36% of the injured body regions were the “thorax, back” and 34% were the “head, face”. When struck by “large vehicles, trucks” 43% of the injured body regions were the “head, face” and 40% were the “thorax, back”. When struck by a “pole”, 60% of the injured body regions were the “head, face” and 13% were the “thorax, back”. When struck by “other object (without pole)”, 50% of the injured body regions were the “head, face” and 15% were the “thorax, back”. In the side impact fatal accidents where the vehicle was struck by another vehicle, the number of occupants injured at the “head, face” and “thorax, back” was similar and larger than that for the other body regions. In the side impact fatal accidents where the vehicle was struck by “other object,” the number of the occupants injured at the “head, face” was larger than all of the other body regions.

As for the serious accidents, when struck by “passenger vehicles”, 33% of the injured body regions were the “thorax, back” and 24% were the “neck”. When struck by “large vehicle, truck”, 47% of the injured body regions were the “thorax, back” and 24% were the “head, face”. When struck by “pole”, 27% of the injured body regions were “pelvis, lower extremities”, 25% were the “head, face” and 22% were the “thorax, back”. When struck by “other object (without pole)”, 27% of the injured body regions were the “pelvis, lower extremities” and 22% were the “thorax, back”. In the side impact serious accident of the vehicle struck by a “passenger vehicle”, the number that occupants injured the “neck” was larger probably because the serious injury had been judged by the days that the victim visited the hospital. And in Japan, generally the neck-injured occupants in a traffic accident visit the hospital for a longer time, even

though the injury may have had an AIS value of 1. In all cases, the percentage of occupants that injured the “thorax, back” was larger than 20%, especially for the case involving being struck by a “large vehicle, truck”, which was 47% and was larger than any other case. In the side impact fatal accidents involving a vehicle being struck by a “large vehicle, truck” and a “pole”, the percentage of occupants that injured the “head, face” was larger than 20% and was larger than that for the other cases. In the side impact fatal accident involving vehicle being struck by objects, the percentage of occupant that injured the “pelvis, lower extremities” was 27% and was largest body injured region for this case.

As for the minor accidents of a vehicle being struck by “passenger vehicles”, 70% of the injured body regions were the “neck”. When struck by a “large vehicle, truck”, 48% of the injured body regions were the “neck” and 22% were the “head, face”. When struck by a “pole”, 34% of the injured body regions were the “neck” and 29% were the “head, face”. When struck by an “other object (without pole)”, 44% of the injured body regions were the “neck” and 17% were the “head, face”. In all cases, the percentage of occupants with an injured “neck” was the largest for all of the body regions. In the side impact minor accidents of a vehicle struck by a “large vehicle, truck” and “pole”, the percentage of occupants with an injured “head, face” was larger than 20% and was larger than that for the other cases of being struck by a “passenger vehicle” or “other object.”

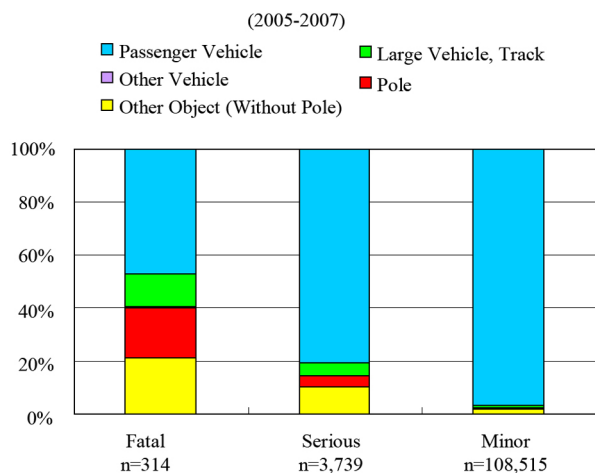


Figure 1. Type of striking vehicle and object involved in side impact accidents (fatal, serious and minor injuries).

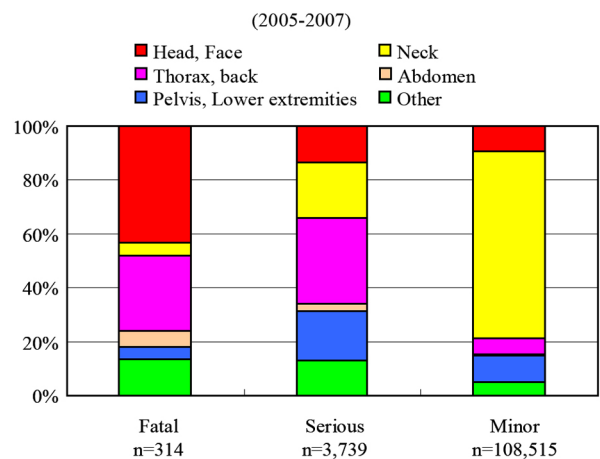


Figure 2. Injured body regions in side impact accidents by injury level

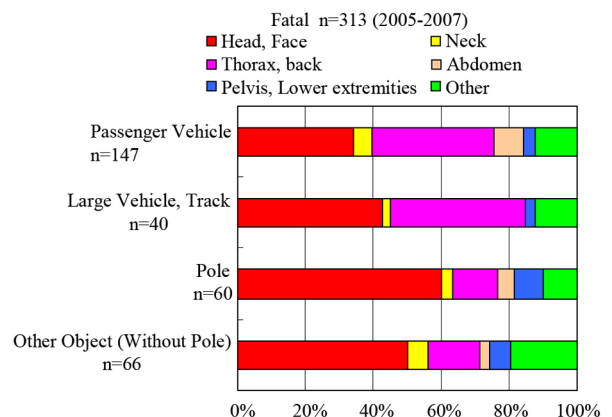


Figure 3. Injured body regions for fatal in side impact accidents by striking object.

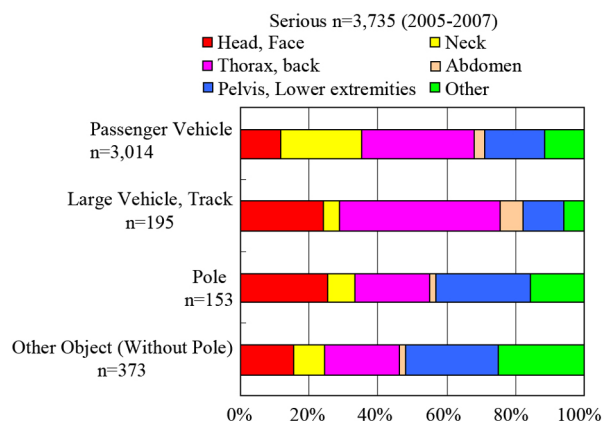


Figure 4. Injured body regions for serious injuries in side impact accidents by striking object.

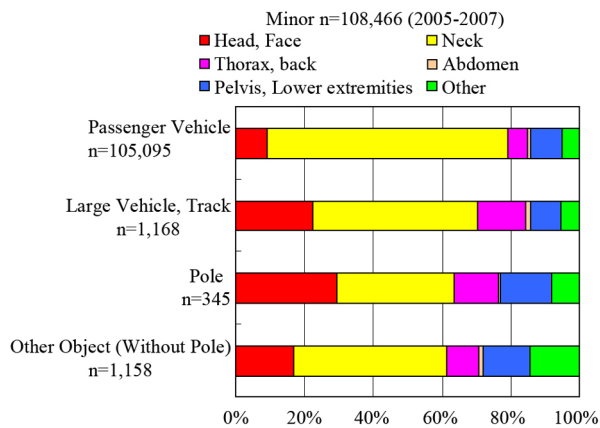


Figure 5. Injured body regions for minor injuries in side impact accidents by striking object.

INVESTIGATION OF RIDING POSTURE POSITION

VIDEO ANALYSIS

The postures of the driver and front passenger in real-world driving conditions were surveyed in order to provide a basis for predicting injuries caused by the car interior in side impact accidents. The pictures of the position of a front seat occupant were recorded by a video camera from a side view of the vehicle, and the occupant head's position was observed. From the accident analyses, the head was determined to be a frequently injured body region in side impact accidents. Therefore, the percentage of occupants whose head location overlapped with the vehicle's B-pillar was examined. By analyzing the results, the conditions for which occupant protection devices effectively work (i.e., the area to be covered by the occupant protection device) also could be estimated.

Side views of vehicles traveling in both directions on a road near an intersection were filmed with a video recorder. Using the side view of the filmed occupants, the percentage of the occupants whose head overlapped with the B-pillar was examined. The head positions of the drivers (right side) and the front passengers (left side) were surveyed. The surveyed vehicles were limited to the passenger cars (sedans, wagons, K-cars and 1BOXs). That is, large vehicles (such as trucks and buses) and 2-door cars were excluded from the survey. In total, 565 cars were surveyed from the driver side and 1,290 cars were surveyed from the front passenger side. However, note that only 165 front passengers were examined since the front passenger seating frequency was observed to be only 13%. [Figure 6](#) shows the criterion used to evaluate whether the head overlapped the B-pillar. Note that, even if only a part of the head overlapped with the B-pillar, it was defined as head/B-pillar overlap. [Figure 7](#) shows the percentage of vehicles that have passengers in the cars in this research. As

already mentioned above, the number of vehicles that contained an occupant seated in the passenger seat was 165 during this research.

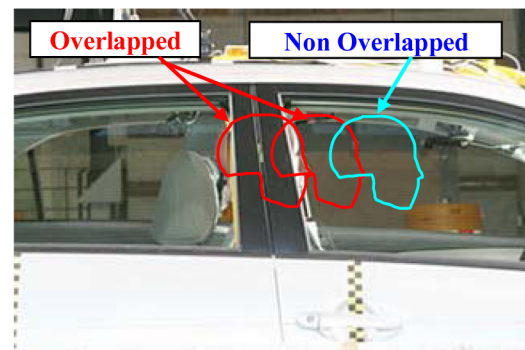


Figure 6. The criterion of judgment for the head overlapping B-pillar.

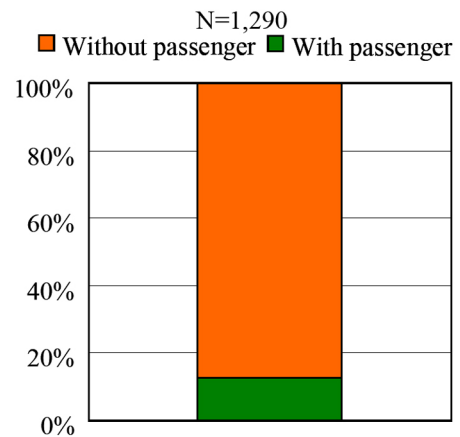


Figure 7. The percentage that there are passengers in the vehicles.

[Figure 8](#) shows the percentages of head/B-pillar overlap for the driver and front passenger. Fifty-six percent of drivers and 78% of front passengers were determined to have head/B-pillar overlap. The percentage of front passengers was large probably because front passengers have the freedom to change their seat positions, whereas the driver must adjust the seat to accommodate reaching the steering wheel and floor pedals in order to drive the vehicle.

Based on the survey, it was found that 56% of the driver heads overlapped the B-pillar. Accordingly, it is predicted that the head is likely to contact the B-pillar during side crashes, and thereby lead to head injuries.

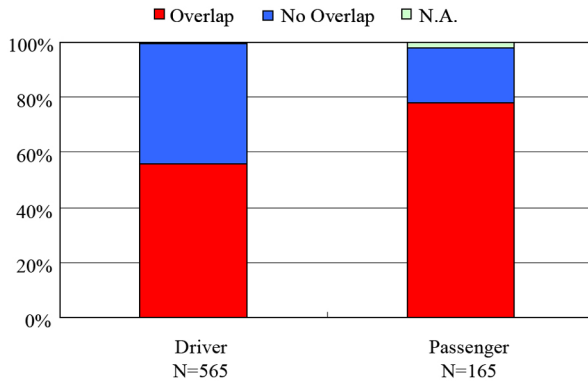


Figure 8. Seat location for the head and B-pillar overlapped.



Figure 9. The vehicle and the camera position in this study.



Figure 10. The sample picture in this study.

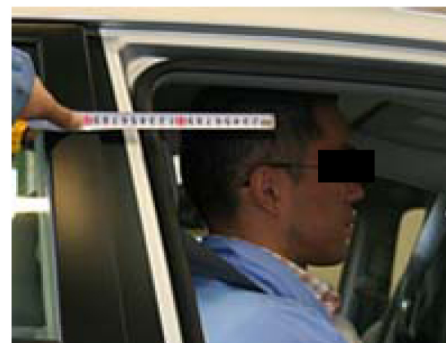


Figure 11. The measurement of the distance from B-pillar to the head.

SAMPLE ANALYSIS

A more detailed study about the postures of the driver was conducted. Pictures of the position of a front seat occupant were recorded with a vehicle that was the same as that tested. The examinees seated on the vehicle were members of the NTSEL staff. The pictures of the position of a driver were recorded by a camera from a side view of the vehicle. The distance from the B-pillar to the individual's head was measured. Also the height and sex of the examinees were recorded. The number of examinees was 38, with the number of males being 30 and the number of females being 8. [Figure 9](#) shows the vehicle and the camera position used in this study. [Figure 10](#) shows the situation of this study. [Figure 11](#) shows the measurements of the distance from the B-pillar to the head. The distance was measured from the center of the ear to the front edge of the B-pillar.

[Figure 12](#) shows the heights of the examinees. The average height of the examinees was 169 cm, with that of the males being 172 cm and that of the female being 157 cm. In this study, the height of the 50th percentile Japanese male was 170 cm and that of the 50th percentile Japanese female was 158cm.

[Figure 13](#) shows the definition of the measurements of the head position in this research. L is defined as the horizontal distance from the center of the ear hole to the front edge of the B-pillar. H is defined as the vertical distance from the Seat Reference Point (SRP) to the center of the ear hole. The zero point of L is defined to be the front edge of the B-pillar, and the positive direction is defined as the direction heading from the rear of the vehicle to the front of the vehicle. So when the parameter L was large, the distance from the B-pillar to the head was large. And when the parameter L was negative, the B-pillar and the ear hole were overlapped. The zero point of H is the SRP, and the positive direction is in the seat bottom to the roof direction of the vehicle.

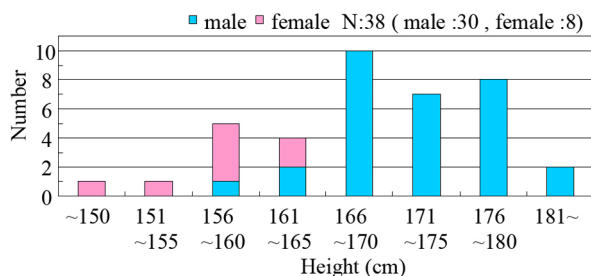


Figure 12. The height of the examinees by the sex.

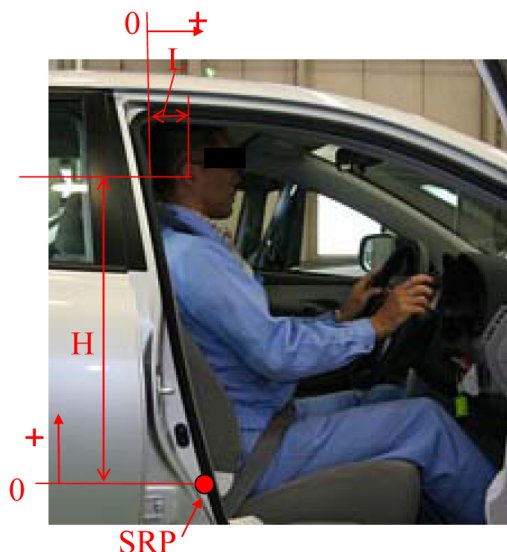


Figure 13. The definition of the measurements.

Figure 14 shows the head positions of the examinees by the height in this research. The 50th percentile of the Japanese head length from the forehead to the rear of the head is about 180 mm. If the center of the ear hole assumed as the center of the head, an L measurement smaller than 90 mm indicates that the head and B-pillar were overlapped. The yellow area of Figure 14 depicts the measurements in which the L measurements are smaller than 90 mm. The number of measurements in the yellow area was 26 and represented 68% of the examinees. From the picture, the number overlapped the head and B-pillar was 30 and near to the number from the judgment from Figure 14. It seemed to be a tendency that, when the height was large, the L was small and the distance from B-pillar to the center of the head was small. But, there were some cases that, even though the height was large, the L was large. For example, the maximum L of the height in the range “151~155” was larger than the minimum L of the height in the range of “171~175”. This was most likely due to that the individual variability was larger than the influence of the height.

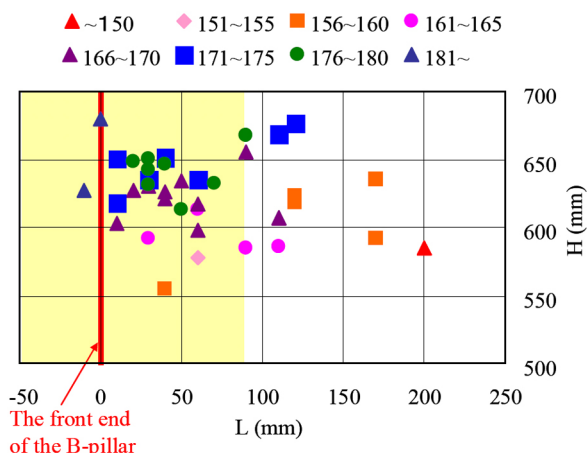


Figure 14. The head positions of the research by the height.

FULL-SCALE SIDE IMPACT TEST

TEST METHOD

In order to understand the effectiveness of the CSA, a series of crash tests were carried out using two types of vehicles as a struck vehicle. Vehicle 1 was a sedan type small passenger vehicle that is popular in Japan. Vehicle 2 was a K-car that is categorized in Japan as a very small size vehicle. Vehicle 2 also is a popular K-car in Japan. Figure 15 shows Vehicle 1 and Figure 16 shows Vehicle 2. Table 1 presents the test vehicles' specifications. The Vehicle 1 was 220 mm larger in width and 310 kg heavier in curb weight than Vehicle 2. Tests were conducted based on the specifications of Regulation ECE/R95 other than the aspect for the positioning of the dummy as previously stated. The dummy position was defined that the dummy head overlapped the B-pillar. Figure 17 shows the ECE/R95 mobile deformable barrier (MDB) used in this test series. Figures 18 and 19 show the dummy postures in the Vehicle 1 and 2 before the tests. As shown, it is seen that the dummy head and B-pillar overlapped.

Figure 20 and Table 2 show the test configuration of Vehicle 1. Figure 21 and Table 3 show the test configuration of Vehicle 2. For these tests, ES-2 dummies were seated in the front driver seats of the struck vehicle. In addition, a front facing child restraint system (CRS) was installed in the rear right seat (near side) and a Q3s dummy was placed in the CRS in all tests. Additionally, in Test 2, a rear facing CRS was installed in the rear left seat and a CRABI 6-month dummy was placed in the CRS. In this study, the injury measures and kinematic behavior of the ES-2 dummies in the front seats of the struck vehicles are compared.