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27th Presentation Session for Traffic Accident Investigations, Analysis, and Research

Characteristics of Rear Passenger Injuries in Frontal Collisions (Among Seatbelt Wearers)

- Relationship Between Road Alignments and Most Severely Injured Body Part -

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1. Background and Purpose

Traffic accident fatalities and injuries are trending downwards due to the effects of measures from various perspectives. Among fatalities and injuries, numbers of fatalities and severe injuries suffered by four-wheeled vehicle occupants remain at the same level as that of pedestrians (see Fig. 1) when classified by circumstance.

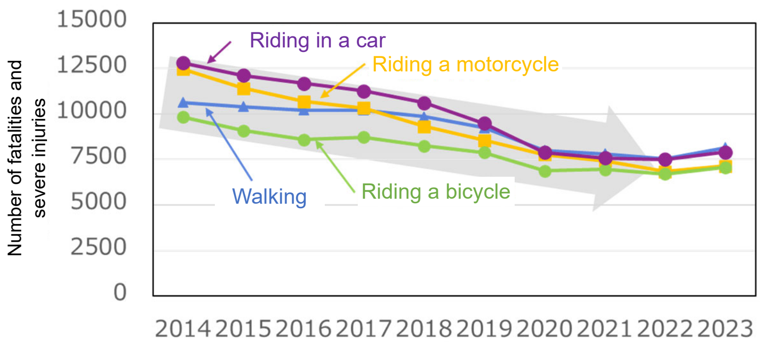

Fig. 1 Trends in fatalities/severe injuries by circumstance

A breakdown of fatalities and severe injuries among four-wheeled vehicle occupants by direction of collision shows that approximately 70% of fatalities and severe injuries occur in frontal collisions (see Fig. 2). Furthermore, when numbers of fatalities and severe injuries in frontal collisions are broken down by seating position, the highest numbers can be seen for driver seat occupants, followed by front passenger seat and rear seat occupants (see Fig. 3). However, as shown in Figure 4, trends for fatalities and severe injuries (with 2014 indexed to 100) reveal that decreases in fatalities and severe injuries among rear seat occupants are smaller than those for driver seat and front passenger seat occupants, with a plateau being seen in recent years.

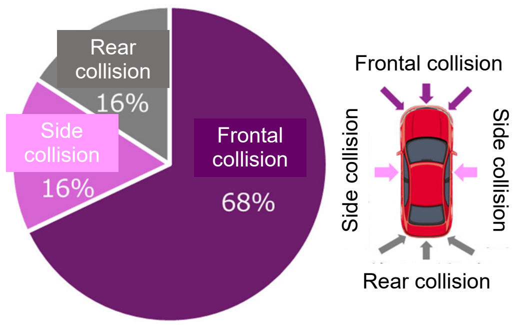

Fig. 2 Fatalities/severe injuries among four-wheeled vehicle occupants by collision direction

This paper investigates and analyzes the characteristics of accidents and resulting injuries sustained by rear seat passengers, in which decreases in the number of fatalities and severe injuries have been the smallest.

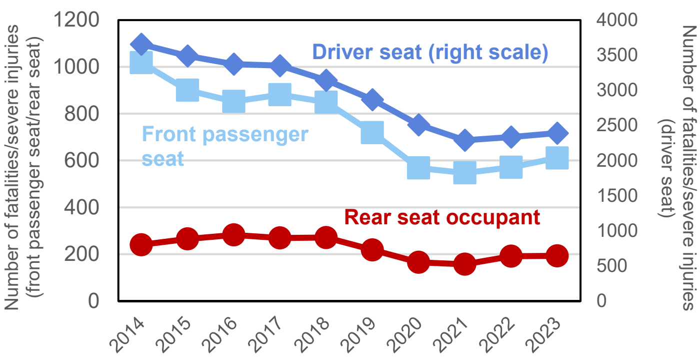

Fig. 3 Trends in numbers of fatalities/severe injuries by seating position

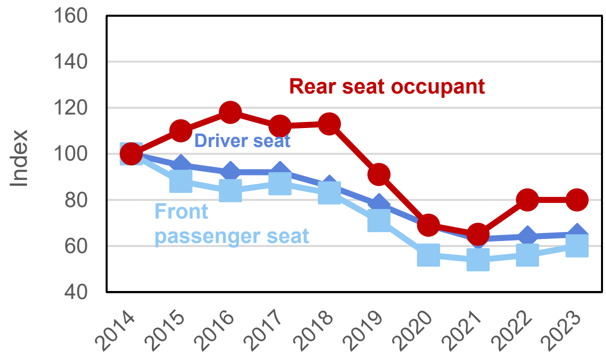

Fig. 4 Trends in fatalities/severe injuries (with 2014 at 100)

2. Types of Accidents Covered in This Paper

The accidents covered in this paper are as follows.

- Accidents involving fatalities or injuries suffered by occupants wearing seatbelts in the rear seats of primary party vehicles between 2012 and 2023
- Accidents involving 10 or more fatalities or injuries found in traffic accident statistical data (macro data) and under conditions created by combining the sub-variables for 8 main variables considered to be related to occupant injuries as shown in Table 1

Table 1. Main variables and sub-variables used in this study

Main variable	Sub variable
Accident type	Single-vehicle accident/Vehicle-vehicle accident
Road alignment	Curve (left and right combined), straight road, area with general traffic
Site of collision on vehicle	Front right (50-58), front center (10-18), front left (80-88)
Primary party	Full-sized passenger car, micro-car
Vehicle type	Sedan, minivan
Pseudo ΔV	20 km/h or less, 21-40 km/h, 41-60 km/h, over 60 km/h
Age	11-20, 21-40, 41-64, 65-74, 75 or over
Gender	Male, female

3. Analysis Methods

The following types of analysis were carried out on accidents identified using the method described in the preceding paragraph.

- Analysis 1: Fatal/severe injury rates were calculated for each main variable and its sub-variables.
- Analysis 2: Factors that contribute to differences in fatal/severe injury rates were analyzed by breaking down characteristic variables from 'Analysis 1' by other sub-variables.
- Analysis 3: Mechanisms were analyzed together with micro data.

4. Analysis Results

4.1 Results of Analysis 1 — Fatality/severe injury rate by main variables and their sub-variables

The following three characteristics were observed when calculating fatality/severe injury rates for each main variable and its sub-variables (see Fig. 5).

- Road alignment: The rate is higher for curves, showing a difference with straight roads.
- Pseudo ΔV/Age: The higher they are, the higher the rates.

Since pseudo ΔV and age are generally considered as being related to energy levels and tolerance values, Analysis 2 was conducted by focusing on road alignment.

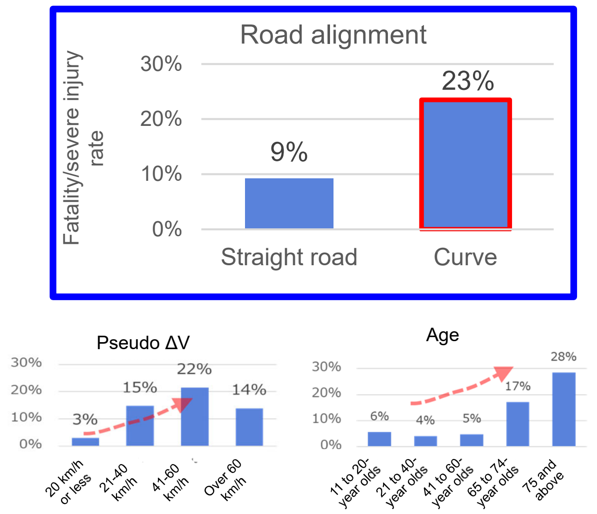

Fig. 5 Results of Analysis 1 - Unique characteristics observed in the fatality/severe injury rates of main variables and their sub-variables

4.2 Results of Analysis 2

4.2.1 Reasons for different rates between curves and straight roads

Due the results of Analysis 1, fatality/severe injury rates were further broken down by the sub-variables of other main variables in order to identify the sub-variables

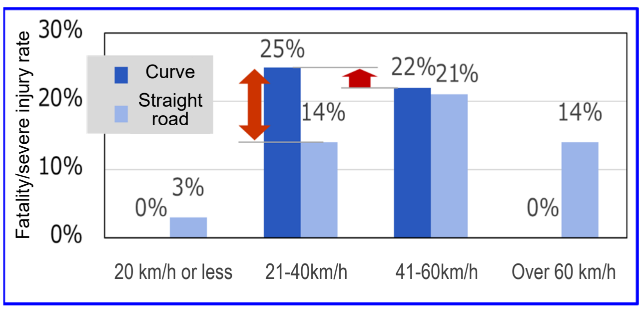

Fig. 6 Results of Analysis 2 (pt. 1): Fatality/severe injury rate by pseudo ΔV

causing differences in rates. As a result, a large difference was seen in the fatality/severe injury rates for curves and straight roads when pseudo ΔV = 21-40 km/h (see Fig. 6).

4.2.2 Characteristics of pseudo ΔV = 21-40 km/h (most severely injured body part)

Further detailed analysis of the pseudo ΔV range of 21-40 km/h revealed a distinct pattern in fatality/severe injury rates when categorized by the most severely injured body part. Specifically, fatalities and severe injuries involving the chest and arms/legs were significantly higher on curves than on straight roads (see Fig. 7).

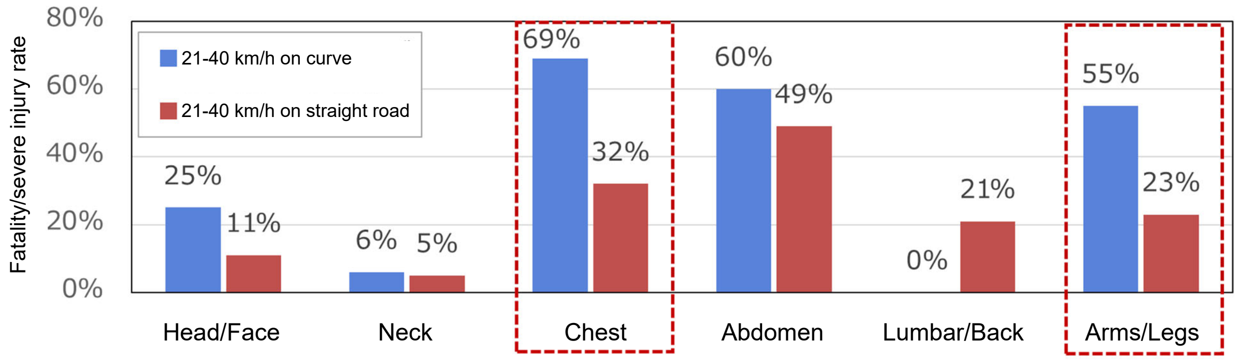

Fig. 7 Results of Analysis 2 (pt. 2): Fatality/severe injury rate by most severely injured body part when pseudo ΔV = 21-40 km/h

4.2.3 Differences in occupant movement between curves and straight roads

Differences in fatality/severe injury rates by injury site between curves and straight roads are thought to be influenced by the different manners in which force is applied in an accident, or in other words, differences in how occupant bodies move in a collision. Based on this assumption, the relationship between the point of impact and most severely injured body part was analyzed. Figure 8 shows spheres of different sizes indicating rates for combinations of most severely injured body part and point of impact during collisions on curves and straight roads.

One characteristic of curves is the larger percentage of chest injuries caused by seatbelts (see (1) in the figure). In addition, the percentage of accidents in which the heads of occupants are impacted by exterior vehicle components such as door windows is higher for curves (see (2) in the figure), suggesting that occupants are subjected to more lateral movement than on straight roads.

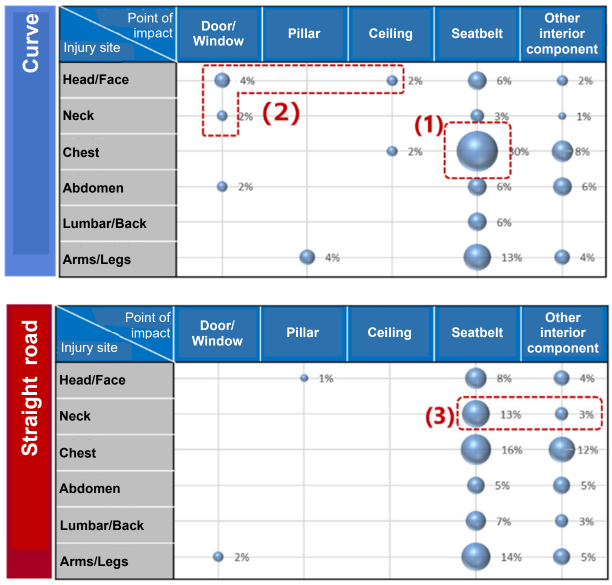

Fig. 8 Percentages of combinations of most severely injured body part and point of impact

However, although one characteristic of straight roads is that no specific combinations of most severely injured body part and point of impact stand out, the percentage of neck injuries is higher than on curves (see (3) in the figure). This increased percentage of neck injuries is thought to be due to occupant chests being restrained, which causes their heads to move further forward in an accident, placing greater stress on the neck.

4.3 Results of Analysis 3 - Injury mechanisms as seen from the micro data

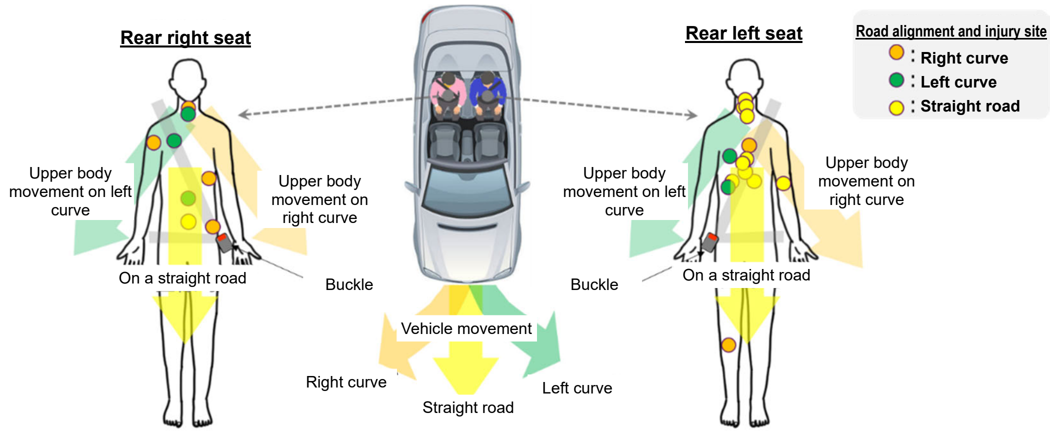

Fig. 9 Results of Analysis 3: Examination results for road alignment and injury site as seen in the micro data

In this analysis, the micro data was used to examine the types of injuries sustained in accidents on both curves and straight roads (see Fig. 9). The figure shows colored circles indicating the locations of injuries sustained by occupants in the left and right rear seats.

Note that orange circles indicate accidents on right curves, while green circles indicate those on left curves and yellow circles those on straight roads.

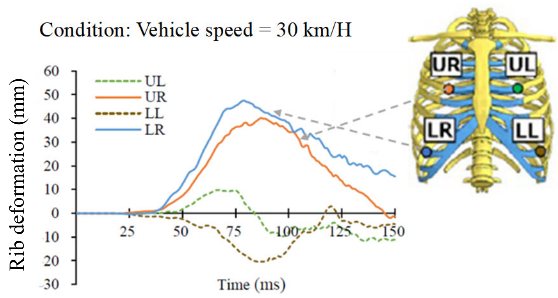

Fig. 10 Rib deformation due to seatbelt load (from Reference 1)

This shows that injuries frequently occur to the center of the body on straight roads, while on curves, injuries are more common on the side of the body where the occupant is restrained by the seatbelt buckle.

The factors behind injuries being sustained on the side of the body where the seatbelt buckle is located on curves were examined by referencing literature on chest deformation caused by seatbelts. According to Reference 1, under conditions involving a straight-moving vehicle colliding at a speed of 30 km/h, the seatbelt causes the ribs to bend more towards the inside of the vehicle, with the lower ribs experiencing the greatest amount of deformation (see Fig. 10).

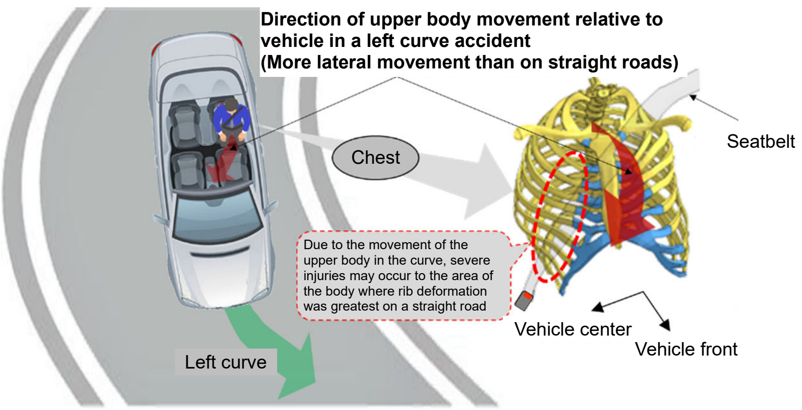

Fig. 11 Assumed movement of occupant in left rear seat during an accident on a left curve

This should be considered in conjunction with the results obtained thus far. Assuming an accident on a left curve involving an occupant in the rear left seat (see Fig. 11), the occupant's upper body would be subjected to more lateral displacement on a curve than would occur on a straight road. This type of accident would cause the occupant's body to lean towards the side of the seatbelt buckle, which contrasts with accidents on straight roads where chest deformation is the greatest.

In this event, load distribution around the seatbelt buckle is higher than when on a straight road, while rib deformation near the buckle is also increased, indicating that larger curves may result in more severe injuries.

5. Summary

The following observations were made while examining the characteristics of injuries suffered by rear seat occupants in the types of accidents analyzed in this study.

5.1 Characteristics observed in the macro data

- Fatality and severe injury rates differ between curves and straight roads. (Fatality and severe injury rates are higher on curves than on straight roads.)
- One characteristic of accidents on curves is that they have a higher fatality/severe injury rate than those on straight roads when pseudo ΔV is in the 21-40 km/h range and when the chest in the most severely injured body part.

5.2 Mechanism of chest injuries in accidents on curves

- Analysis performed on the relationship between the point of impact and most severely injured body part showed that accidents on curves were more likely to result in significant upper body movement in the lateral direction.
- In the micro data, numerous accidents on curves were seen in which lateral shifting caused occupants to be injured in areas in center of their bodies restrained by the seatbelt.
- One possible reason why accidents on curves have higher fatality/severe injury rates for chest injuries than for those on straight roads is that the upper bodies of occupants are tilted more diagonally, which increases the amount of load distributed to the seat belt near the buckle and can possibly result in greater rib deformation on the buckle side.

5.3 Possible measures for reducing injuries to rear seat passengers in accidents on curves

- Seatbelt restraining force should be optimized.
- It may be effective to use seatbelt components such as shoulder straps and buckles that follow the lateral movement of the upper body to evenly distribute load across the entire chest.

[References/Sources]

1) Xu Lei, Yuhei Aoshima, Daichi Korenaga, Koji Mizuno, 2021, “Evaluation of Rib Deformation of THOR Dummy in Seat Belt Loadings”, Journal of the Society of Automotive Engineers of Japan, Vol. 52, P486-491

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