Accident Analysis and Prevention 37 (2005) 5–17

ACCIDENT ANALYSIS & PREVENTION

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Method to evaluate the effect of safety belt use by rear seat passengers on the injury severity of front seat occupants

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Abstract

Although the effectiveness of seat belts for reducing injury to rear seat passengers in traffic accidents has been well documented, the ratio of rear-seat passengers restrained by seatbelts remains lower than that of drivers or passengers in front seats. If passengers in rear seats do not wear seat belts, they may sustain unexpected injury to themselves when involved in accidents, and also endanger front occupants (drivers or front seat passengers). This paper focuses on the tendency of front seat occupants to sustain severer injuries due to forward movement of passengers in rear seats at the moment of frontal collisions, and evaluates the effectiveness of rear passengers' wearing seat belts in reducing injuries of front seat occupants.

Since the occurrence of occupant injuries depends considerably on the crash severity, we proposed to use pseudo-delta *V* in regression analysis to represent velocity change during a collision when analyzing statistical accident data. As the crash severity can be estimated from pseudo-delta *V*, it becomes possible to make appropriate estimations even when the crash severity differs in data. The binary model derived from the ordered response model was used to evaluate the influence on the injury level based on pseudo-delta *V*, belted or unbelted status, gender and age.

Occupants in cars with a hood in the case of car-to-car frontal collisions were extracted from the statistical data on accidents in Japan. Among 81,817 cars, where at least one passenger was present, a total of 6847 cars in which all passengers sustained injuries and which had at least one rear seat passenger aboard were analyzed. The number of killed or seriously injured drivers is estimated to decrease by around 25% if rear seat occupants come to wear seat belts. Also, the number of killed or seriously injured passengers in front seats is estimated to decrease by 28% if unbelted rear seat occupants come to wear seat belts. Thus, wearing of seat belts by previously unbelted rear seat passengers is considered effective in reducing not only injuries to the rear seat passengers themselves but also injuries to front seat occupants.

Keywords: Seat belt; Rear seat passenger; Delta *V*; Ordered response model; Injury severity

1. Introduction

Cars are equipped with various safety devices to reduce injury to vehicle occupants in traffic accidents. The effectiveness of wearing seat belts is widely known to reduce injury severity to vehicle occupants in accidents, and the effectiveness of seat belt use for rear seat passengers has also been revealed in many studies (Evans, 1988a; Krafft et al., 1990; Padmanaban and Ray, 1992; Huelke and Compton, 1995). However, awareness of the importance of seat belts for rear passengers is low, and according to accident data (ITARDA, 2000), the seat belt use rate of rear seat passengers is only about 20–30%.

Observational research reports in Japan show an average of one front seat passenger per five cars and also an average of one rear seat passenger per five to six cars (NPA and JAF, 2002). Lack of concrete data on rear occupant seating status makes it impossible to give exact figures, but estimates indicate that among vehicles containing passengers, one out of every two to three vehicles contains at least one rear seat passenger. Among vehicles involved in frontal collisions that had at least one rear seat passenger, it is often observed in on-site accident investigations that front seat occupants (drivers or passengers in front seats) suffer severer injuries from unbelted rear seat passengers due to unbelted rear passengers being thrown forward by the impact of frontal collisions, and either pushing the back of a front seat forward or coming into direct contact with front seat occupants (ITARDA, 2000).

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doi:10.1016/j.aap.2004.05.003

Assuming that the number of the seriously injured occupants in front seats increases due to the presence of unbelted rear seat passengers, it can be inferred that wearing seat belts is effective not only in reducing injuries to rear seat passengers themselves but also in reducing injuries to front seat occupants. However, there has been little quantitative research done on the influence of rear seat belt use on injury severity of front occupants.

Analysis of injuries to front seat occupants associated with rear seat occupants should take into account various conditions such as the type of impact, impact severity on the vehicle, occupant restraint system, occupant physical characteristics, gender and age, etc. Detailed accident data on these conditions should be used in analysis. Unfortunately, the Institute for Traffic Accident Research and Data Analysis (ITARDA) had only approximately 2100 detailed accident data as of the end of 2000, which was insufficient for the purpose of such analysis.

Consequently, this report proposes a method employing the Linked Accident Database that combines statistical traffic accident data in Japan with the vehicle registered data, in order to evaluate the effect of rear seat passengers wearing seat belts on the injury severity of front seat occupants in collisions. The Linked Accident Database contains information on all traffic accidents resulting in injury or death (approximately 900,000 per year in Japan), as well as traveling speed, vehicle weight, vehicle type and other data effective in evaluating the injury severity of occupants.

In general, impact severity on the vehicle mainly contributes to the severity of injuries sustained by vehicle occupants in a collision. The delta *V*—or change of velocity during collisions—has generally been used as a gauge of impact severity (Evans, 1994; Buzeman et al., 1998). Velocity after collisions is estimated using such information as skid marks left on the surface of road and the coefficient of friction of the road surface, and impact velocity, which is a vehicle speed at the moment of collision, is estimated according to the principle of conservation of energy or principle of conservation of momentum. Finally, delta *V* is calculated as the difference between the impact velocity and the velocity after collision (Satoh, 1987). The higher the delta *V*, the greater becomes the injury severity of occupants (Joksch, 1993).

Once delta *V* is available, its values are often used directly in regression analysis (Kockelman and Kweon, 2002). Yet, such regression analysis using the delta *V* is valid only in combination with detailed accident data usually collected by a sampling technique such as the National Automotive Sampling System (NASS). Since special technical analyses are required to estimate delta *V*, however, such specific information about impact severity is rarely presented in statistical accident data covering all accidents in a country.

Statistical accident data has been used in the following studies to evaluate the effectiveness of seat belts. Evans (1986) introduced a method known as the “double pair comparison”, which evaluates seat belt effectiveness without directly considering the impact severity. The double pair comparison is a statistical method that, by selecting a “subject” occupant and one “other” occupant and setting two conditions for the “subject” occupant and only one condition for the “other” occupant, analyzes the difference made by double comparison for the “subject” occupant evaluated. This method has been used in many evaluations of injury severity in relation to airbags (Evans, 1991), gender and age (Evans, 1988b), as well as seat belt effectiveness using Fatality Analysis Reporting System (FARS) data, which contains all fatal accidents in the USA. However, problems arise in using the double pair comparison method in cases involving many influencing factors or when the number of data is limited for selecting “other” occupants.

Since traveling speeds are abundantly available in statistical accident data, O’Donnell and Connor (1996) used traveling speed directly as an explanatory variable. Other researchers often categorize the traveling speed in regression analysis to assess the influence on the evaluation index (Barry et al., 1999; Chang and Mannering, 1999; Al-Ghamdi, 2002). In another study, Mercier et al. (1997) examined accidents occurring only on expressways, where the traveling speed can be considered stable, instead of directly taking into account delta *V*.

In the current research, pseudo-delta *V* is proposed for use in regression analysis to represent velocity change during a collision. An equation of pseudo-delta *V* is derived from the principle of conservation of momentum. Values of pseudo-delta *V* calculated from vehicle speeds and weights which are available in the Linked Accident Database have been shown to correlate favorably with delta *V* (Shimamura et al., 2002; Shimamura, 2002).

In Japan, the injury severity of occupants is categorized into four levels: the “killed”, the “seriously injured”, the “slightly injured” and the “non-injured”. With injury severity ranked as qualitative data, the ordered response model is recognized as effective in handling this kind of dependent variable (Nawata, 1997). O’Donnell and Connor (1996) demonstrated the possibility of applying the ordered response model to the evaluation of the injury severity. Shimamura et al. (2001) applied the ordered response model in Japan to the evaluation of airbag systems. Kockelman and Kweon (2002) applied the probit model to the evaluation of the driver injury severity. Based on favorable results from these previous studies, the authors of this paper decided to apply the ordered response model.

Another problem with applying the Linked Accident Database is that the database contains no information about the location (left or right) of rear seat passengers. It is difficult, therefore, to obtain data on vehicles in which rear seat passengers sit on the right or left side (behind the driver or front seat passenger[1]), the position in which front and rear seat occupants most frequently collide in an acci-

[1] It should be noted that vehicles run on the left side of the road in Japan, and that the driver is seated on the right of the vehicle and the front passenger on the left.

dent. However, in the detailed accident investigation data ITARDA has collected, there are some vehicles in which a rear seat passenger on the left impacted the driver even in head-on collisions (ITARDA, 2000). These vehicles usually sustained an oblique impact force, which complicates the occupant's movements during impact, even in head-on collisions. In this paper, the effectiveness of seat belts for rear seat passengers is evaluated by comparing the injury severity of front seat occupants in two vehicles; one of which is a vehicle with belted rear seat passengers, the other a vehicle in which rear seat passengers are not restrained by seat belts.

As reported later in this paper, pseudo-delta *V* proved effective in analyzing 6 years of accident data (1995–2000), as a result of which seatbelt use by rear seat passengers was found effective in reducing the injury severity of front seat occupants in passenger cars with a hood involved in a frontal collision either through a head-on crash or rear-end crash.

2. Methods

2.1. Applicable data on accidents

2.1.1. The Linked Accident Database

For the purpose of timely understanding of accident conditions and degree of damage, statistical accident data in Japan is compiled by National Police Agency (NPA), since all accidents that result in injury or death to at least one person are reported to the police. The data includes such information as type of crash, road conditions, driver characteristics, and the injury status of occupants. In addition, the Ministry of Land, Infrastructure and Transport (MLIT) holds the country's registered vehicle data, which includes such information as manufacturer, the type of motor vehicle, vehicle length, width, and weight, etc. ITARDA owns the Linked Accident Database that combines the statistical accident data provided by NPA with the registered vehicle data provided by MLIT. Essential data available in the Linked Accident Database are briefly as follows.

Hazard recognition speed is available as data pertaining to vehicle speed. This is the traveling speed at which the driver recognizes a hazard, and is determined by police officers owing to information given by witnesses or from analysis of skid marks.

Each vehicle is assigned a motor vehicle type as a proof of compliance with safety regulations and to maintain uniform safety. The motor vehicle type is entered in the motor vehicle inspection certificate, in addition to vehicle length, width, weight, and other data. All this information is available in the Linked Accident Database. Once the type of motor vehicle is ascertained, the characteristics of the vehicle such as its frontal shape can be determined. Passenger cars are classified as sedan, station wagon, minivan, SUV(RV), etc. according to information on motor vehicle type.

To fulfill one purpose of Japan's statistical accident data, which is a major part of the Linked Accident Database, the total number of car occupants as well as information about the drivers involved in accidents are reported as they relate to the accident's occurrence, although passengers who do not sustain injury are not listed in the report at all. The number of non-injured passengers is simply determined by subtraction of injured passengers from total passengers.

The injury severity in accidents in Japan is graded according the following four categories: (1) the "killed" or persons who die within 24 h after accidents; (2) the "seriously injured" or persons who need medical treatment for 30 days or more after accidents; (3) the "slightly injured" or persons who need medical treatment for less than 30 days after accidents; and (4) the "non-injured" or persons who receive no injury. The days of medical treatment are determined by physicians during medical diagnosis immediately following an accident.

2.1.2. Method of sampling subject vehicles

In order to study the influence on injury severity of front occupants exerted by rear seat passengers, the subject vehicles (referred to hereinafter as the "subject(s)") were sampled from the data according to the following criteria: (1) the subject shall be a sedan or station wagon passenger vehicle in which front seats and rear seats are laid out in two rows; (2) the subject shall be a vehicle involved in a head-on collision, in which the front ends of two vehicles collide, or a rear-end collision, in which the front end of one vehicle collides with the rear end of another. These criteria were required to avoid, as much as possible, cases where spinning movements occurred, since the influence of rear seat passengers on injury to front seat occupants mainly appears in head-on collision cases.

The following vehicles were excluded from this study due to difficulties of evaluation: (1) vehicles in which two or more passengers (in addition to a driver) were found in front seats; (2) vehicles in which passengers were found other than in the front and rear seats; (3) vehicles in which more than four passengers (five occupants) were found; (4) vehicles which were involved in multiple collisions; (5) vehicles involved in accidents in which the hazard recognition speed and/or vehicle weight was unknown, and (6) vehicles involved in expressway accidents.

2.1.3. Detailed conditions to analyze the relation between rear seat passengers and front seat occupants

As the purpose of this research is to evaluate the influence on injury severity of front seat occupants of belted and unbelted rear seat passengers, it is necessary to ascertain the seating positions of all occupants in a vehicle and at least whether the occupants were found in front or rear seats. Because the Linked Accident Database contains no information on non-injured passengers, vehicles in which all passengers sustained either injury or death are extracted from the data in order to ascertain the seating positions of all passengers.

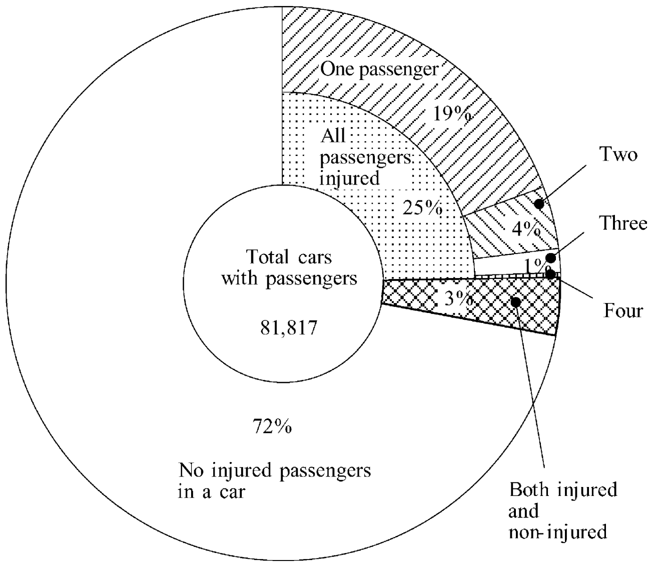

Fig. 1. Percentage of vehicles with injured and non-injured passengers (vehicles having at least one passenger).

2.1.4. Subject vehicles

In Japan, of the 931,934 accidents resulting in injury or death reported to the police in 2000, 9066 resulted in fatalities. Since accident data for 1 year alone was considered insufficient for the purpose of this study, the authors used accident data over a 6-year period from 1995 to 2000. The accidents resulting in injury or death in the 6-year accident data 1995–2000 totaled 4,899,447, and the number of casualties resulting in death or serious injury was 520,075. The total number of vehicles subject to the analysis (those that met the sampling conditions) was 530,085. Among these vehicles, 448,268 contained a driver only, the remaining 81,817 vehicles containing a driver and up to four passengers. Among 81,817 vehicles in which there was at least one passenger aboard, the percentage of vehicles in which no passengers were injured was 72% (see Fig. 1 Percentage of vehicle with injured and non-injured passengers). Vehicles with non-injured passengers are difficult to analyze since the seating locations of those passengers are unknown. Fig. 1 shows that 3% of vehicles contained injured and non-injured passengers, although these vehicles too are difficult to use in analysis because of the unknown seating location of non-injured passengers. Vehicles that can be used in the analysis on the relation between rear seat passengers and front seat occupants were those in which all passengers were injured. These amounted to 20,277 vehicles, 25% of the total vehicles where at least one passenger was present.

2.2. Pseudo-delta V

The approach to pseudo-delta *V* and its reliability have already described in detail (Shimamura et al., 2002; Shimamura, 2002) and the authors reintroduce them here. Pseudo-delta *V* is obtained as the velocity change from

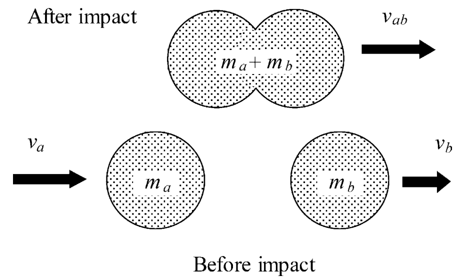

Fig. 2. One-dimensional impact model.

the formula below based on the principle of conservation of momentum according to the following three primary hypotheses: (1) the movement of the vehicle is identified one-dimensionally as shown in Fig. 2; (2) there is a linear correlation between the impact velocity and the hazard recognition speed, and (3) the coefficient of rebound is 0.

$$\text{Pseudo-delta V}_\text{a} = \frac{m_\text{b}}{(m_\text{a} + m_\text{b})} \cdot (v_\text{a} - v_\text{b}) \quad (1)$$

In this formula, m_a and m_b are vehicle masses, and v_a and v_b are the hazard recognition speeds. Hypothesis 1 above is for the most part acceptable for vehicles involved in head-on collisions or rear-end collisions. Hypothesis 3 is also mostly acceptable in cases of high impact velocity (Satoh, 1987). Hypothesis 2 above is acceptable under the following circumstances.

ITARDA has been conducting on-site accident investigations and compiled accident files containing information on hazard recognition speed mainly obtained through interviews with vehicle drivers as well as impact velocity, or delta *V* (true-delta *V*), obtained from engineering data. Accident data files up to the end of 1999 contain 146 cases of vehicles involved in head-on (front-to-front) collisions on regular roads (not expressways). For these vehicles, analysis of the correlation between hazard recognition speed and impact velocity revealed that the impact velocity was approximately 0.84 of the hazard recognition speed as shown in Fig. 3; the coefficient of determination R^2 was 0.517 and a linear relationship could be recognized between hazard recognition speed and impact velocity.

Next, ITARDA studied the correlation between pseudo-delta *V* and true-delta *V*. As there were some vehicles for which the hazard recognition speed or true-delta *V* could not be ascertained, these vehicles were omitted and 40 vehicles were targeted for analysis. In this analysis, assuming that true-delta *V* was approximately 0.70 of the pseudo-delta *V*, a linear relationship could be recognized as shown in Fig. 4. R^2 was 0.552.

Most of the impact velocity analyzed from engineering data was less than the hazard recognition speed. This suggests that vehicle speed decreased due to brake operation owing to the drivers' recognition of hazardous situations. However, at the 60 km/h or lower, there are some vehicles whose impact velocity is 20 km/h higher than the hazard

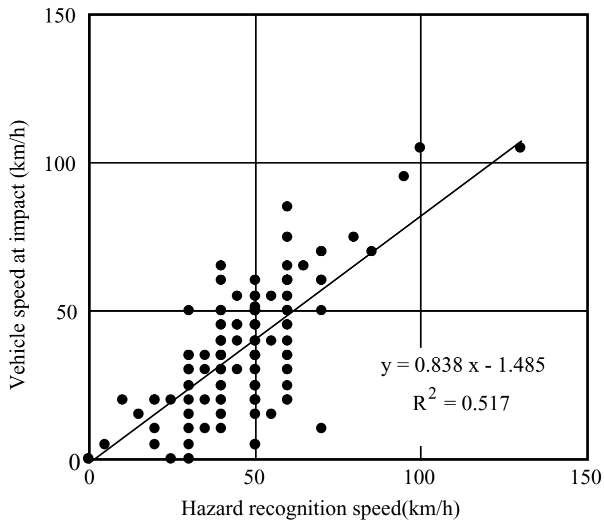

Fig. 3. Correlation between hazard recognition speed and vehicle speed at impact in head-on collisions.

recognition speed. In Japan, the speed limit on regular roads is usually 60 km/h or less. The hazard recognition speed doubtless reflects drivers' alertness against being charged with speed limit violation. However, there were some cases in which drivers did not remember vehicle speed accurately.

True-delta V was lower than pseudo-delta V. One of the reasons for this difference is that pseudo-delta V is derived from the hazard recognition speed, which is usually greater than the impact velocity. The difference could also be attributed to the influence of the zero coefficient of rebound and one dimensional vehicle movement.

2.3. Ordered response model and logit model

It is assumed that there is a latent factor Y_i^* which is a continuous variable that determines the injury severity Y_i whose number of options is s. In this analysis, it is assumed

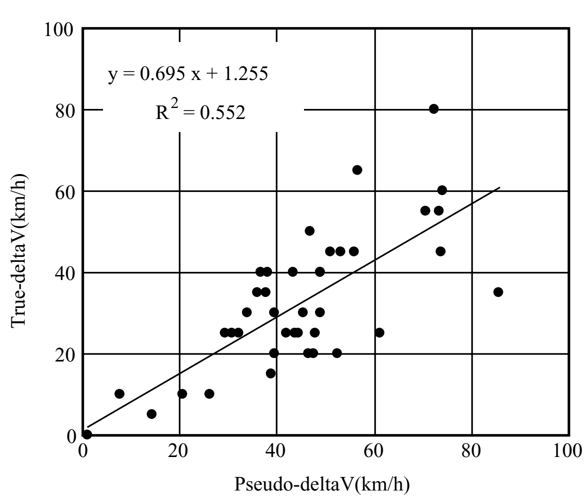

Fig. 4. Correlation between true-delta V and pseudo-delta V in head-on collisions.

that there is a linear relation between the continuous latent factor Y_i^*, which implies the injury severity, and explanatory variables including pseudo-delta V, $X_{k,i}$ ($k = 2, 3, \ldots$) which are considered as independent variables.

$$Y_i^* = z_i + \varepsilon_i \tag{2}$$

$$z_i = \beta_0 + \beta_1 \Delta V_i + \beta_2 X_{2,i} + \cdots + \beta_k X_{k,i} \tag{3}$$

$$Y_i = \begin{cases} 0: \text{ in case of } Y_i^* \leq 0 \\ 1: \text{ in case of } 0 < Y_i^* \leq \alpha_2 \\ 2: \text{ in case of } \alpha_2 < Y_i^* \leq \alpha_3 \\ \ldots \\ s-1: \text{ in case of } \alpha_{s-1} < Y_i^* \end{cases} \tag{4}$$

z_i is a value which can be explained by $\Delta V_i, X_{2,i}, \ldots, X_{k,i}$, etc. ε_i is a residual value. $\alpha_2, \ldots, \alpha_{s-1}$, and $\beta_0, \beta_1, \ldots, \beta_\mathrm{k}$ are constant values. $X_{2,i}, \ldots, X_{k,i}$ are explanatory variables and take either of 0 and 1 if they are dummy variables. The cumulative distribution function F of $-\varepsilon_i$ is assumed to be the logistic distribution given in Eq. (5), which is easy to formulate because no large differences are found even if this cumulative distribution function is chosen in the probit distribution (O'Donnell and Connor, 1996).

$$F = \frac{\mathrm{e}^z}{1 + \mathrm{e}^z} \tag{5}$$

The probability of $Y_i = j$ would be expressed as Eq. (6), and the likelihood function is shown as Eq. (7);

$$P(Y_i = j|z_i) = F(z_i - \alpha_j) - F(z_i - \alpha_{j+1}) \tag{6}$$

$$\begin{aligned} L(\alpha_2, \ldots, \alpha_{s-1}, \beta_0, \ldots, \beta_k) &= \prod_{Y_i=s-1} F(z_i - \alpha_{s-1}) \prod_{Y_i=s-2} (F(z_i - \alpha_{s-2}) \\ &\quad - F(z_i - \alpha_{s-1})) \cdots \prod_{Y_i=0} (1 - F(z_i)) \end{aligned} \tag{7}$$

here, Π represents the product of i where $Y_i = j$; and $\alpha_0 = -\infty$, $\alpha_1 = 0$ and $\alpha_s = +\infty$. Using these formulations, $\alpha_2, \ldots, \alpha_{s-1}$ and $\beta_0, \beta_1, \ldots$ are estimated by the maximum likelihood method (TSP Japan, 2000), and it is possible to evaluate the influence by the explanatory variable to the injury severity.

As described later, however, the number of the killed in this study was few and sometimes zero depending on conditions. In order to avoid loss of stability in calculation and to increase the reliability of the analysis, it was decided to combine the killed and seriously injured as one group and to combine the slightly injured and non-injured as another group. Therefore, rank of injury severity was reduced to 2, and dealt with binary data. In case of binary data, s equals 2 and no consideration is necessary about α. The likelihood function of binary data is shown in Eq. (8).

$$L(\beta_0, \beta_1, \ldots) = \prod_{Y_i=1} F(z_i) \prod_{Y_i=0} (1 - F(z_i)) \tag{8}$$

As this equation is based on the hypothesis of a logistic distribution shown in Eq. (5), the regression method in the latter section is called the logit model simply.

2.4. Patterns of regression analysis

2.4.1. Analysis patterns

To evaluate the effectiveness of belted rear seat passengers in reducing injury severity of front seat occupants, two vehicles are compared: one in which all rear seat passengers wear seat belts, the other in which none of the rear seat passengers wear seat belts (both vehicles have at least one rear seat passenger). Along with this analysis, for reference the authors also analyzed the injury severity of each occupant, including drivers, front seat passengers and rear seat passengers. Using vehicles extracted in Section 2.1, the following five analyses were carried out.

Analysis A (driver with rear seat passenger analysis) dealing with the influence of belted and unbelted rear seat passengers on the injury severity of drivers.

Analysis B (front seat passenger with rear seat passenger analysis) dealing with the influence of belted and unbelted rear seat passenger on the injury severity of front seat passengers.

Analysis C (rear seat passenger analysis) dealing with the effectiveness of seat belts worn by rear seat passengers on condition that there is at least one rear seat passenger in a vehicle.

Analysis D (driver analysis) dealing with the effectiveness of seat belts worn by the driver on condition that there are no passengers in the vehicle.

Analysis E (front seat passenger analysis) dealing with the effectiveness of seat belts worn by front seat passengers on condition that there are a driver and a passenger in the front seats and no other passengers in a vehicle.

As basic conditions had been determined for sampled vehicles and impacted vehicles, the authors decided to choose the following limited number of factors as explanatory variables: pseudo-delta *V*, wearing or non-wearing of seat belt by front seat occupants and rear seat passengers, the number of rear seat passengers, and gender and age groups of drivers and passengers in front seats. The age effect is evaluated by grouping in analysis. Occupant ages were divided into the following four groups: a young group of age 24 or under, elder group of age 65 or over, middle age group between the ages of 25 and 49, and near-elderly group between the ages of 50 and 64. Variables such as gender, age and wearing or non-wearing of seat belt are dummy variables. Male, age 24 or under and belted occupants were chosen as reference.

2.4.2. Subject vehicles or occupants in an analysis pattern

In Analyses A and B, either vehicles in which all rear seat passengers wore seat belts or vehicles in which none of the rear seat passengers wore seat belts are used (see Table 1 for numbers of vehicles according to front and rear seat passengers). Out of a total of 6847 vehicles, the majority of 4846 vehicles had at least one rear seat passenger, and there were even cases of three rear seat passengers in 314 of vehicles sampled. In Analysis B, since the vehicles used must have a front seat passenger, the number of vehicles sampled was 3315 (see Table 1). However, the final number of vehicles for use in Analysis B was 2917, since vehicles with seat belt use unknown passengers or vehicles with passengers below 16 years of age were removed.

Table 1
The number of cars according to front and rear seat passengers (AS represents the number of front seat passengers)

Total occupants	AS	Number of passengers in rear seat			Total
		1	2	3	
2	0	2752	0	0	2762
	1	0	0	0	0
3	0	0	697	0	697
	1	2084	0	0	2084
4	0	0	0	73	73
	1	0	990	0	990
5	0	0	0	0	0
	1	0	0	241	241
Total		4846	1687	314	6847

In Analysis C, injury severity was analyzed individually for rear seat passengers, so whether all rear belts were worn or not is not a required condition. Also, the presence of non-injured passengers (front or rear seat) has only a negligible influence on analysis results. Therefore, a total of 8691 vehicles were extracted in which at least one injured rear seat passenger was present, and a total of 9153 rear seat passengers aged 16 or over of known belted/unbelted status (see Table 2) were used in analysis.

In Analysis D, only drivers were analyzed. To avoid the influence of rear seat passengers, vehicles in which only a driver rode (i.e. one-occupant vehicles), were used as subject vehicles. Although it is possible to also include vehicles in which a front seat passenger rode, such vehicles were disregarded to ensure uniform conditions. Subtraction of drivers of unknown belted/unbelted status brought the total to 446,217 as shown in Table 2.

Analysis E concerns front seat passengers. To avoid the influence of rear seat passengers, vehicles in which a driver and a front seat passenger rode (i.e. two occupant vehicles) were selected as subject vehicles. Although subject vehicles totaled 13,054, exclusion of occupants below 16 years of

Table 2
The number of occupants to be analyzed

	Belted	Unbelted	Total
Passengers in rear seats for Analysis C	1,502	7,651	9,153
Drivers for Analysis D	412,384	33,833	446,217
Passengers in front seats for Analysis E	8,503	3,727	12,230

Table 3
Correlation matrix: data for driver with rear seat passenger analysis (DR means driver and RR rear seat)

	Pseudo-delta *V*	DR unbelted	DR female	DR 25–49 years	DR 50–64 years	DR ≥65 years	RR unbelted	Number of RR occupants
Pseudo-delta *V*	1.000							
DR unbelted	0.191	1.000						
DR female	0.076	−0.010	1.000					
DR 25–49 years	0.000	−0.035	0.158	1.000				
BR 50–64 years	−0.147	−0.107	−0.138	−0.615	1.000			
DR ≥65 years	0.023	−0.042	−0.099	−0.264	−0.197	1.000		
RR unbelted	0.117	0.151	0.012	−0.030	−0.006	0.009	1.000	
Number of RR occupants	0.104	0.046	0.029	0.021	−0.056	0.008	0.076	1.000

age and those with unknown belted/unbelted status reduced the final total to 12,230 (see Table 2).

2.4.3. Correlation matrix

For the multiple regression analysis, the correlation matrix for driver with rear seat passenger analysis is compiled in Table 3. Although there was expected to be a high correlation between belted or unbelted drivers and belted or unbelted rear seat passengers, this correlation coefficient was in fact as low as 0.151. While the correlation coefficient of age groups was as high as 0.615, the other correlation coefficients were relatively low.

3. Results

3.1. Analysis A (driver with rear seat passenger analysis)

In this analysis, the injury severity of drivers was evaluated by comparing two vehicles: one in which all rear seat passengers wear seat belts, the other in which none of rear seat passengers wear seat belts. Table 4 shows the number of belted and unbelted drivers according to injury severity and at the same time in relation to belted and unbelted status of rear seat passengers. In one case, the total number of the killed or seriously injured was only five.

The following explanatory variables were chosen: pseudo-delta *V*, driver gender, age group, belted or unbelted status of drivers, belted or unbelted status of rear seat passengers and the number of rear seat passengers. To evaluate the influence of pseudo-delta *V*, two regression analyses were carried out, one excluding pseudo-delta *V*, the other include pseudo-delta *V*.

Table 4
Injury severity of drivers in relation to belted or unbelted status of rear seat passengers

	RR belted	RR unbelted	Total
DR belted			
Fatal/seriously injured	45	387	432
Slightly/non-injured	1105	4411	5516
Total	1150	4798	5948
DR unbelted			
Fatal/seriously injured	5	224	229
Slightly/non-injured	17	653	670
Total	22	877	899
Total	1172	5675	6847

Table 5
Results of Analysis A: model without pseudo-delta *V*

Parameter	Estimate	S.E.	*t*-statistics	*P*-value
Constant	−3.244	0.193	−16.773	0.000
DR unbelted	1.299	0.097	13.417	0.000
DR female	0.277	0.101	2.735	0.006
DR 25–49 years	−0.387	0.111	−3.489	0.000
DR 50–64 years	−0.470	0.125	−3.751	0.000
DR ≥65 years	0.141	0.164	0.860	0.390
RR unbelted	0.681	0.154	4.422	0.000
Number of RR occupants	0.263	0.069	3.833	0.000

3.1.1. Analysis without pseudo-delta V

The results of the logit model without pseudo-delta *V* are shown in Table 5. The likelihood ratio test was carried out to evaluate the null hypothesis assuming that all estimates are equal to 0. The result of this test *2LL* was 303, and thus statistically significant, because the 5% chi-square of 7 degrees of freedom was 14.067. The fraction of correct prediction was 0.903. The estimates of unbelted drivers or unbelted rear seat passengers were positive and statistically significant. Regarding age groups, estimates for the 25–49 or 50–64 group were negative.

3.1.2. Analysis including pseudo-delta V

The results of the regression analysis including pseudo-delta *V* are shown in Table 6. The fraction of correct pre-

Table 6
Results of Analysis A: model including pseudo-delta *V*

Parameter	Estimate	S.E.	*t*-statistics	*P*-value
Constant	−6.305	0.261	−24.126	0.000
Pseudo-delta *V*	0.062	0.002	26.559	0.000
DR unbelted	1.095	0.112	9.750	0.000
DR female	0.290	0.113	2.563	0.010
DR 25–49 years	0.015	0.130	0.111	0.911
DR 50–64 years	0.187	0.146	1.282	0.200
DR ≥65 years	0.513	0.189	2.707	0.007
RR unbelted	0.443	0.171	2.589	0.010
Number of RR occupants	0.206	0.079	2.613	0.009

diction was 0.914 and the likelihood ratio test *2LL* was 1266. The model was statistically significant because the 5% chi-square of 8 degrees of freedom was 15.507. The estimate of unbelted rear seat passengers or unbelted driver showed a positive value and satisfied the 5% statistical significance. Therefore, the values of both *2LL* and the fraction of correct prediction were larger in the analysis which included pseudo-delta *V* than that without pseudo-delta *V*. Also, considering the age groups of drivers, the both estimates of 25–49 and 50–64 were positive, though no statistical significance was achieved. The estimate for the over 64 group was positive and statistically significant. Furthermore, it was found that the older the age group, the greater the estimate.

3.1.3. Estimate of vehicles with killed or seriously injured drivers

Based on data shown in Table 6, the reduction of vehicles with killed or seriously injured drivers was estimated as follows. As the latent factor was obtained from Eq. (3), the two values of the latent factor were calculated for each observed data by replacing the value of β representing belted or unbelted status. The first one used the estimated β itself, which represented unbelted status, and the other used 0, which represented belted status, because the belted or unbelted status was the dummy variable. Based on the later latent factors, the probability that drivers are killed or seriously injured could be calculated for vehicles with belted rear seat passengers. By multiplying the obtained probability by the number of vehicles with unbelted rear seat passengers, we assessed the number of vehicles with killed and seriously injured drivers in cases where unbelted rear seat passengers come to wear seat belts. The comparison of distribution of vehicles with killed or seriously injured drivers in the current case where rear seat passengers are unbelted on one hand, with distribution of killed or seriously injured drivers in cases of unbelted rear seat passengers who come to wear seat belts on the other, is shown in Fig. 5. The number of vehicles with killed or seriously injured drivers in the current situation was 636, and this number would decrease to 476 if unbelted rear seat passengers become belted. Therefore, the number of vehicles with killed or seriously injured drivers is expected to decrease by 25%.

3.2. Analysis B (front seat passenger with rear seat passenger analysis)

In this analysis, the injury severity of front seat passengers was evaluated. Unlike Analysis A, this analysis covers all injuries and fatalities, not only of rear seat passengers but of front seat passenger too. Table 7 shows the number of belted and unbelted passengers according to injury severity. The following explanatory variables were used: pseudo-delta *V*, gender of front seat passengers, age group, belted or unbelted status of front seat passengers, belted or unbelted status of rear seat passengers and the number of rear seat passengers.

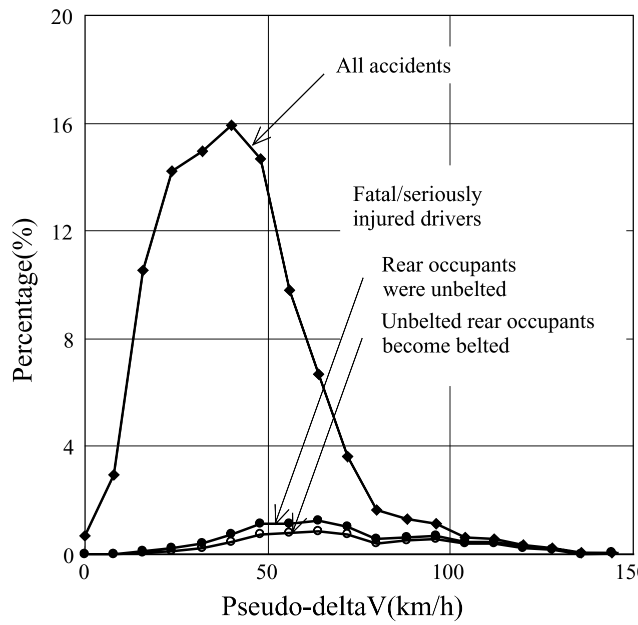

Fig. 5. Comparison between estimated distribution of killed/seriously injured drivers with unbelted rear seat passengers and predicted distribution when unbelted rear seat passengers become belted (percentage calculated by total number of drivers).

The results of the logit model analysis are shown in Table 8. The *2LL* was 400 and the fraction of correct prediction was 0.872. The estimate of unbelted rear seat passengers was 0.455, thus a positive value, and the 5% statistical significance was satisfied.

The number of vehicles with killed or seriously injured front seat passengers was evaluated in the same manner as in Analysis A. There were 368 vehicles with killed or seriously injured front seat passengers in vehicles in which rear seat passengers were unbelted. This number is estimated to decrease to 264 once all unbelted rear seat passengers become belted. The number of vehicles with killed and seriously injured passengers is estimated to decrease by 28%.

Table 7
Injury severity of front seat passengers in relation to belted or unbelted status of rear seat passengers

	RR belted	RR unbelted	Total
AS belted			
Fatal/seriously injured	30	205	235
Slightly injured	402	1402	1804
Total	432	1607	2039
AS unbelted			
Fatal/seriously injured	1	151	152
Slightly injured	13	713	726
Total	14	864	878
Total	446	2471	2917

Table 8
Results of Analysis B (front seat passenger with rear seat passenger analysis)

Parameter	Estimate	S.E.	*t*-statistics	*P*-value
Constant	−5.599	0.326	−17.153	0.000
Pseudo-delta *V*	0.046	0.003	16.787	0.000
AS unbelted	0.514	0.132	3.903	0.000
AS female	0.226	0.124	1.828	0.067
AS 25–49 years	0.518	0.161	3.218	0.001
AS 50–64 years	0.873	0.180	4.862	0.000
AS ≥65 years	1.432	0.193	7.428	0.000
RR unbelted	0.455	0.214	2.127	0.033
Number of RR occupants	0.050	0.095	0.525	0.599

3.3. Analysis C (rear seat passenger analysis)

An analysis was carried out to evaluate the injury severity of rear seat passengers. Subjects of this analysis were vehicles with rear seat passengers of age 16 or over, including vehicles in which passengers were not injured. Although injuries of occupants located in a central seat might be different from those of occupants sitting seats to either side, this consideration can be disregarded due to the negligible number of center seat occupants. There were 9153 rear seat passengers in total after subtracting passengers of unknown belted/unbelted status. The following explanatory variables were used: pseudo-delta *V*, gender, age group and belted or unbelted status of rear seat passengers. The *2LL* was 1063 and the fraction of correct prediction was 0.895. As shown in Table 9, the estimate of unbelted rear seat passengers was 0.759; thus a positive value, and the 5% statistical significance was satisfied. The number of killed or seriously injured rear seat passengers is predicted to decrease by 45% owing to wearing of seat belts.

3.4. Analyses D and E (driver analysis and front seat passenger analysis)

These analyses cover individually the injury severity of drivers or passengers in front seats with or without seat belts. Analysis of drivers was carried out by use of vehicles in which no occupants existed except a driver and explanatory variables were as follows; pseudo-delta *V*, gender, age group and belted or unbelted status of drivers. Analysis of front seat passengers was carried out by use of vehicles in which two occupants, a driver and a front seat passenger, were present, and explanatory variables were as follows: pseudo-delta *V*, gender, age group and belted or unbelted status of front seat passenger.

Table 9
Results of Analysis C (rear seat passenger analysis)

Parameter	Estimate	S.E.	*t*-statistics	*P*-value
Constant	−5.318	0.183	−29.138	0.000
Pseudo-delta *V*	0.045	0.002	27.292	0.000
RR unbelted	0.759	0.135	5.620	0.000
RR female	0.093	0.078	1.194	0.232
RR 25–49 years	0.109	0.106	1.033	0.301
RR 50–64 years	0.677	0.109	6.196	0.000
RR ≥65 years	1.160	0.110	10.505	0.000

Table 10
Results of Analysis D (driver analysis (no passengers in a car))

Parameter	Estimate	S.E.	*t*-statistics	*P*-value
Constant	−7.873	0.052	−152.655	0.000
Pseudo-delta *V*	0.083	0.001	131.210	0.000
DR unbelted	1.199	0.036	33.627	0.000
DR female	0.150	0.037	4.047	0.000
DR 25–49 years	0.429	0.041	10.380	0.000
DR 50–64 years	0.908	0.047	19.330	0.000
DR ≥65 years	1.160	0.066	17.564	0.000

Table 11
Results of Analysis E (front seat passenger analysis (no passengers except a front seat passenger))

Parameter	Estimate	S.E.	*t*-statistics	*P*-value
Constant	−4.733	0.117	−40.414	0.000
Pseudo-delta *V*	0.041	0.001	29.635	0.000
AS unbelted	0.710	0.064	11.047	0.000
AS female	−0.005	0.066	−0.082	0.934
AS 25–49 years	0.405	0.082	4.912	0.000
AS 50–64 years	0.911	0.085	10.765	0.000
AS ≥65 years	1.119	0.099	11.307	0.000

The results of the logit model on driver analysis are shown in Table 10. The estimate of unbelted drivers was 1.199, slightly higher than the estimate of unbelted drivers in Analysis A.

The results of the logit model on front seat passenger analysis are shown in Table 11. The estimate of unbelted front seat passengers is slightly higher than the estimate of unbelted front seat passenger in Analysis B.

4. Discussion

4.1. Analytical method applying pseudo-delta V

An analytical method was studied to evaluate the injury severity of front occupants with or without seat belts due to rear seat passengers using the Linked Accident Database containing statistical accident data in Japan. Pseudo-delta *V*, which is an index of the impact severity of a vehicle, was applied as one of the explanatory variables, and regression analysis employing the ordered response model was carried out. Pseudo-delta *V* represents velocity change during a collision when making evaluations by use of statistical accident data. It is known that there is a relatively close correlation between pseudo-delta *V* and true-delta *V* (Shimamura et al., 2002; Shimamura, 2002).

The effect of pseudo-delta *V* on the injury severity of occupants was studied in regression analysis as one of

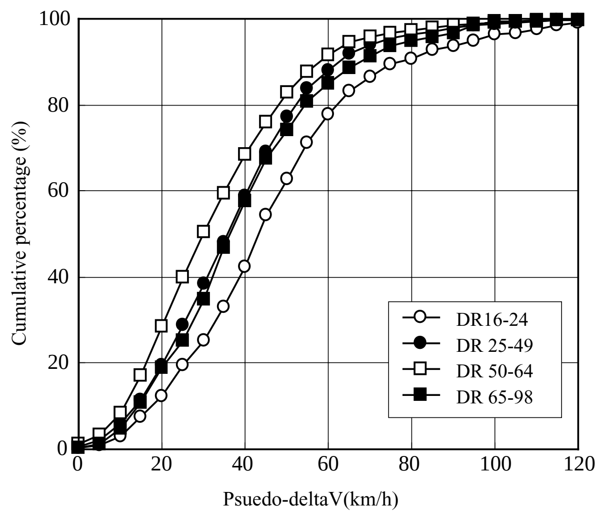

Fig. 6. Cumulative percentage curve of pseudo-delta V as a function of age groups.

the explanatory variables. Analysis A (driver and rear seat passenger analysis) was used. Firstly, as the *2LL* value of the likelihood ratio test and the fraction of correct prediction in the regression analysis with pseudo-delta V were larger than those without pseudo-delta V, the model including pseudo-delta V was found to be much better than that without the pseudo-delta V. Next, though the estimates about the 25–49 and 50–64 age groups were negative in the model without the pseudo-delta V, it was found that the older the driver the severer the injury in the model that includes pseudo-delta V. It has been indicated that the fatality rate becomes higher with increasing occupant age (Evans, 1988a,b). From these points of view, the model that includes pseudo-delta V is considered more appropriate for explaining injury severity. The cumulative percentage curves as a function of age groups are compared in Fig. 6. The difference in pseudo-delta V at the 50% point between the below 25 and 50–64 age group was about 13 km/h. It was estimated that the distribution of pseudo-delta V in the below 25 age group was at a higher speed than that in the other age groups, and the distribution in the 50–64 age group was at a lower speed than that of other groups. Because of such differences of pseudo-delta V distribution between age groups, it is important to include pseudo-delta V as an explanatory variable.

In this research, it was found that the number of rank "killed" was so small in some cases that the authors were afraid it would cause loss of stability in calculations. Further, whether a driver sustains slight injury or no injury in an accident depends on the level of fault. Considering the above problems, the authors decided to reduce the ranks of injury severity to binary choices. It cannot be denied that this results in some loss of advantages inherent in the ordered response model. Solutions to this problem will be a future theme of research.

4.2. Injury severity of front occupants due to rear seat passengers with and without seat belts

Cars with a hood involved in car-to-car frontal collisions were extracted, and there were 81,817 cars where at least one passenger was present. Among these cars, a total of 6847 cars in which all passengers were injured and had at least one rear seat passenger aboard were analyzed. As a result of analysis, the number of vehicles in which drivers were killed or seriously injured was estimated to decrease by about 25% and the number of vehicles in which front seat passengers were killed or seriously injured decreased by 28%.

In all the detailed accident data collected by ITARDA up to the end of 1999, there were 448 vehicles with more than one occupant among 1954 vehicles in 1542 accidents in which sedan-type or station wagon type vehicles were involved. There were 172 vehicles containing rear seat passengers, 93 containing occupants the right rear seat, 134 in the left rear seat and 27 in the central seat. Thus, in the majority of vehicles the rear seat passenger sat on the left, directly behind the front seat passenger. The percentage of vehicles where a passenger sat in the right rear seat (i.e. behind the driver) was 54%. There was a total of 123 vehicles with both a front seat passenger and rear seat passenger(s), and the number of vehicles in which a passenger sat in the left rear seat was 100 (i.e. 81%).

Without considering the above data, the following can be surmised. In Analysis A, vehicles in which no passenger sat in the rear seat behind the driver's seat were probably included. Similarly, in the analysis of front passenger, vehicles in which no passenger sat in the left rear seat were included. However, as some vehicles in which a passenger who sat in the left rear seat moved diagonally towards the driver were observed in on-site accident investigations (ITARDA, 2000), in this paper only the total effectiveness of rear seat passengers wearing seat belts is taken into account. If seating location of rear seat passengers does not change so much, the estimated results of reduction of injury severity caused by wearing seat belts of rear seat passengers would be the same.

Next, the reduction rate of casualties was estimated from the total traffic accidents in Japan. There were 520,075 casualties resulting in death or serious injury. The reduction rate of casualties for both drivers and front seat passengers among 6847 vehicles was estimated at 0.05% in all accidents. As the casualties of rear seat passengers would decrease once those unbelted rear seat passengers in 6847 cars come to wear seat belt, the reduction rate of casualties would reach 0.12% in total. Though the figure is actually low, it would increase if vehicles with non-injured rear seat passengers aboard or vehicles involved in collisions with fixed objects were taken into account. As the reduction rate was estimated from the number of unbelted occupants, the figure would decrease if the seat belt use rate in rear seats became higher and the number of unbelted rear seat passenger became lower.

4.3. Results of regressions

Regarding drivers, firstly, the estimate of unbelted drivers in Analysis D (driver analysis) was larger than that of drivers in Analysis A. Moreover, the estimate of unbelted drivers in Analysis A was larger than that of rear seat passengers in the same analysis. Therefore, the reduction of the driver injury severity is more effective when seat belts are used by drivers themselves than when seat belts are used by rear seat passengers, and also the reduction of the injury severity for drivers who wear seat belts is the most effective when there is no occupants in a car except the driver. In this regard, vehicles used in Analysis A were vehicles in which all passengers suffered injury or death, which means that these vehicles could receive severer impact than vehicles used in Analysis D, in which no passengers were present and hence no consideration was given to their injury severity. Usually, the severer the impact, the lower the effectiveness of seat belt (Evans, 1996). In this context, it can be said that seat belt effectiveness is lower in Analysis A, in which all passengers suffered injury or death, than in Analysis D.

Next, regarding the front seat passengers, the results were almost the same as in Analysis A. The estimate of unbelted passengers in Analysis E was higher than that of passenger in Analysis B, and estimate of unbelted passengers in Analysis B was a little bit higher than that of rear seat passengers in the same Analysis. Because vehicles with non-injured front seat passenger were not included in Analysis B, it is difficult to directly compare results between Analyses B and A. It shall be noted that Analysis A included vehicles without a front seat passenger, and this means that some of these vehicles in Analysis A might have received an impact as small as a front seat passenger does not sustain injuries.

In the authors' analysis, the reduction rate of killed and seriously injured rear seat passengers was estimated to be 45%. Padmanaban and Ray (1992) reported that the reduction rate including the slightly injured was 31–65%. It can be said that similar results are obtained in both studies on rear seat passengers, while direct comparisons are not possible because collision type, occupant and other conditions are different.

The influence of other explanatory variables on the injury severity of front seat occupants was also studied. The results indicated that the injury severity was greater for females than male drivers, while for passengers in front and rear seats, the 5% statistical significance was not satisfied. Drivers in Analyses A and D included non-injured drivers, whereas passengers in Analyses B and E did not include non-injured passengers. In this regard, there would be difference of impact severity between Analyses A and D on one hand, and Analyses B and E on the other. The injury severity of females compared with that of males changes with age, and the fatality risk for females is greater than for males between ages 15 and 45 (Evans, 1988b). Another study concluded that risk of fatal injuries in females increased by 50% compared with males (Bédard et al., 2002). It can be said that the results in Analysis A or D supports these claims. However, further studies are needed for front or rear seat passengers to determine the influence of gender, because non-injured passengers were taken into account in Analysis B, C, or E, though non-injured drivers were considered in Analysis A.

When the number of rear seat passengers increases, the number of vehicles increases in which the injury severity of drivers or passengers in front seats is severer according to Analyses A and B. But the 5% statistical significance is not satisfied in Analysis B. As can be assumed from the detailed accident data, the first rear seat passenger usually sits down behind the front seat passenger and the next passenger sits down behind the driver. It is thus strongly assumed that there is a rear seat passenger behind the front seat passenger in Analysis B without considering the number of rear seat passengers. In other words, it is strongly supposed that there is no rear seat passenger behind the driver unless there are two or more rear seat passengers. The status as to whether a rear seat passenger is found behind the driver must have a great effect on the severity of driver injury. It can be thus assumed that the severity of driver injury is influenced much more by the number of rear seat passengers than that of a front seat passenger. Secondly, as described previously, vehicles used in Analysis B received severer impacts than vehicles used in Analysis A. This could be a reason why the influence of the number of rear seat passengers in the front seat passenger with rear seat passenger analysis is less than that in Analysis A.

As Analyses D and E were carried out to evaluate the explanatory variables in Analyses A and B, it is not our purpose to obtain the reduction rate of casualties sustained by drivers and front seat passengers in vehicles without rear seat passengers. However, the reduction rate of killed or seriously injured casualties was estimated at 49% for drivers in Analysis D and 42% for front seat passengers in Analysis E once unbelted occupants wear seat belts. According to NHTSA (1996), fatality risk was reduced 45% by wearing seat belts. It can also be said that injury reduction rate due to wearing seat belts correspond to our results, even though collision type, objective injury severity and other conditions are different.

The following brief comments concern the selection of explanatory variables of the model, which influence the latent factor representing the injury severity. First of all, it should be noted that there are two types of seat belts used in rear seats: the three-point type and two-point type. 'Belted' means passengers who wear either of these seat belts. In sedan cars or station wagons used in the authors' analysis, the maximum number of passengers is limited to four (the number of occupants is five with a driver). There are seldom four passengers in a vehicle. The center rear seat is not often used by rear seat passengers. Installation of three-point seat belts on the right and left rear seats has been required by law since 1994 in Japan. It is estimated that 61% of belted rear seat passengers wear three-point type seat belts according to data in our study. Further, in Analyses A and B all age groups of rear passengers were considered and the number of rear seat passengers whose age is lower than 16 years old was 17%. Airbag deployments occurred at a rate of about 7% for all vehicles analyzed. Most of front seats were separate type, while some of them were bench type. The strength of seat back of front seats is certainly an influential factor but was not considered in this analysis. As the purpose of our research is to reveal the difference in the injury severity of front occupants under the influence of belted and unbelted groups of rear seat passengers, the influences of any factors mentioned above are relatively small compared with the seat belt use.

In cases where wearing seat belts is mandatory, the seat belt use rate reported by the police is usually higher than the actual rate because occupants usually claim to have worn seat belts even when no evidence of this is observed. According to a field survey (NPA and JAF, 2002), the seat belt use rate of drivers was 88.1%. As the seat belt use rate in traffic accident data was 94.7%, it is 6.6 points higher than the results of the field survey. But, this difference does not seem to make the results of this paper greatly different. However, the reliability of the seat belt use rate and its influence should be taken into account in the future.

5. Conclusions

The injury severity of front seat occupants (drivers or front seat passengers) in relation to belted and unbelted status of rear seat passengers was analyzed by use of the Linked Accident Database, which compiles statistical accident data in Japan. The following ideas were introduced to solve difficulties in use of the comprehensive accident data for the evaluation of the influence of belted and unbelted rear seat passengers.

- The regression analysis based on the binary model of the ordered response model was carried out to analyze the influence of explanatory variables including pseudo-delta V on the injury severity.
- Subject vehicles were chosen in which all passengers were injured or killed.

Appropriate evaluations on the injury severity could be carried out by including pseudo-delta V as an explanatory variable in a regression analysis even when distributions of pseudo-delta V were different between groups.

Cars receiving frontal impacts in the form of head-on collisions or rear-end collisions were extracted from the statistical data on accidents in Japan. Among 81,817 cars, where at least one passenger was present, a total of 6847 cars in which all passengers sustained injuries and which had at least one rear seat passenger aboard were analyzed. The following were confirmed as a result of analysis of data involving vehicles with all rear seat passengers belted and all rear seat passengers unbelted.

- In the case of vehicles with belted rear seat passengers, the injury severity of front occupants (a driver or a front seat passenger) is lower than in case of vehicles with unbelted rear seat passengers.
- The number of vehicles with the killed or seriously injured is expected to decrease by about 25% for drivers and by about 28% for front seat passengers, once unbelted rear seat passengers come to wear seat belts.
- In a separate analysis from the above, as regards injury severity of rear seat passengers to themselves, there was a reduction of 45% in the killed or severely injured owing to unbelted passengers coming to wear seat belts.

It is revealed from the investigation of the statistical accident data that rear seat passengers' wearing seat belts is effective for reducing not only their own injury severity but also the injury severity of front occupants who sit in front of rear seat passengers.

Acknowledgements

The authors wish to thank the anonymous reviewers for their helpful comments and suggestions.

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