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Influence of Vehicle Properties on Neck Injuries in Rear-End Collisions

Abstract

Analyses were conducted to clarify the features of rear-end collisions, using an integrated accident database developed by the Institute for Traffic Accident Research and Data Analysis (ITARDA). Focusing on neck injuries in rear-end collisions, analyses were made of the relation to struck-vehicle properties. Regarding the relation to the initial year of registration, the results did not show that newer vehicles tended to have a lower no-neck-injury rate, which was defined in this study as an index. On the contrary, in some passenger car classes, it was observed that the no-neck-injury rate was higher in newer vehicles. The effect of an active head restraint system, which is one type of anti-whiplash device, was analyzed by using not only the no-neck-injury rate but also a regression analysis. The results showed that the effect of an active head restraint system on suppressing the incidence of neck injuries was statistically significant.

Introduction

In Japan, the number of traffic accident fatalities occurring within 24 hours totaled 11,451 in 1992. It has decreased consistently since then, falling to 7,358 in 2004 and to 6,871 in 2005. The number of

fatalities occurring within 30 days has also steadily declined, dropping to 8,492 in 2004 and to 7,931 in 2005 as shown in Figure 1. This decrease is thought to result from various measures, including more extensive traffic safety education, road and vehicle improvements and better emergency medical care [1-3]. In contrast, the number of traffic accident injuries has been increasing for many years, totaling more than 1.1 million annually in recent years as shown in Figure 1, so further measures to reduce injuries are necessary.

This study focused on rear-end collisions which account for many traffic accident injuries. The situation (as of 2004) for rear-end collisions in Japan and resultant neck injuries was analyzed using an integrated accident database developed by the Institute for Traffic Accident Research and Data Analysis (ITARDA). An investigation was made of whether neck injuries tend to occur in newer vehicles in the context of the increasing number of traffic accident injuries overall, and the effect of anti-whiplash devices, which have been spreading in recent years, was also examined using the integrated accident database.

Actual Situation for Rear-End Collisions and Injuries

Rear-end collisions

The trends in the number of traffic accidents by type are shown in Figure 2. Rear-end collisions show a marked upward trend and have consistently been the most numerous of all types of traffic accidents since 1996. In 2004, they accounted for approximately 31% of all traffic accidents. Figure 3 shows the trends in the number of casualties by type of accident. The number of casualties occurring in rear-end collisions has also tended to increase and accounted for approximately 35% of the total in 2004.

The number of rear-end collisions between vehicles was 279,098 in 2004. Limiting rear-end collisions to the combination that the striking vehicle is the primary party (culpable) and the struck vehicle is the secondary party (less culpable), the number of such combinations that year was 266,391. The combinations are broken down by vehicle type in Table 1. According to the table, the number of rear-end collisions in which the striking vehicle was an ordinary passenger car was 160,426, or approximately 60%. Of them, the number of cases

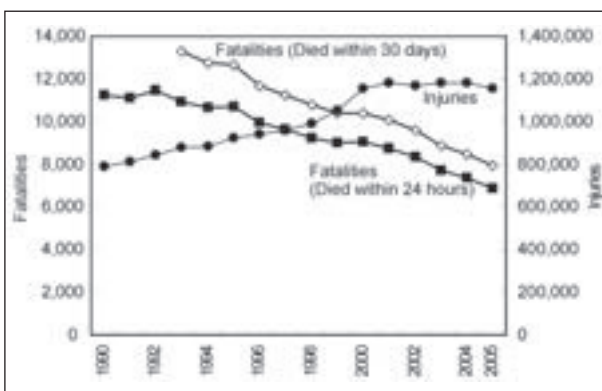


Figure 1: Trends in traffic accident fatalities and injuries

in which the struck vehicle was a “passenger car or truck” and “ordinary or light” was 159,543, or approximately 99%. The number of rear-end collisions in which the struck vehicle was an ordinary passenger car was 166,350, or approximately 62%, and, of them, the number of cases in which the striking vehicle was a “passenger car or truck” and “ordinary or light” was 161,827, or approximately 97%. These Figures

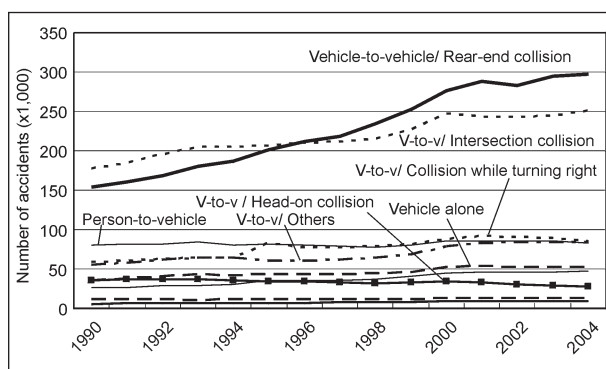


Figure 2: Trends in traffic accidents by type of accident

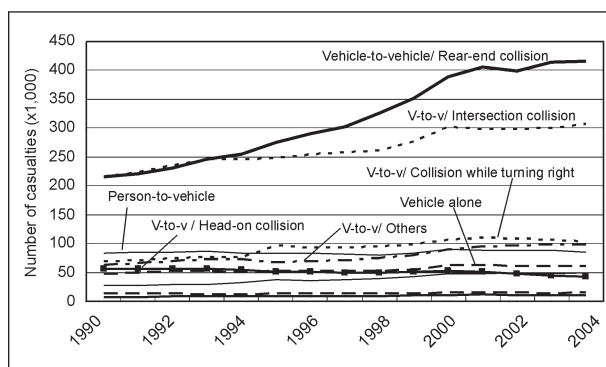


Figure 3: Trends in traffic accident casualties by type of accident

indicate that many of the striking and struck vehicles were ordinary passenger cars and that most of the other parties were passenger cars or trucks and were ordinary or light vehicles. Accordingly, the target vehicles for the subsequent analyses were limited to ordinary passenger cars whose other parties were passenger cars or trucks and were ordinary or light vehicles.

Injuries incurred by ordinary-passenger-car occupants in rear-end collisions

The injuries incurred by ordinary-passenger-car occupants in rear-end collisions in 2004 were analyzed in the striking and struck vehicles respectively under the following assumptions:

- Target vehicles for analysis: ordinary passenger cars.
- Other-party vehicle: passenger car or truck and ordinary or light vehicle.
- Striking vehicle: primary party (culpable).
- Struck vehicle: secondary party (less culpable) and struck in the entire rear-end area.
- Exclusion of multiple collisions.

The first analysis focused on the drivers. Figure 4 shows that approximately 99% of the 122,559 striking-vehicle drivers were not injured. In contrast, approximately 87% of the 126,618 struck-vehicle drivers were slightly injured, mainly in the neck, as shown in Figure 5. This suggests that attention should be paid to neck injuries in struck vehicles in rear-end collisions. On the other hand, approximately 73% of the 151,869 struck-vehicle occupants who mainly suffered neck injuries were

			Striking vehicle (primary party)							Special vehicle	Total
			Passenger				Truck				
			Bus, Minibus	Ordinary	Light	Mini-car	Large-sized special, Large-sized	Ordinary	Light	Special vehicle	Total
Struck vehicle (secondary party)	Passenger	Bus, Minibus	19	244	54	0	42	114	30	0	503
		Ordinary	444	104,340	25,357	2	4,028	21,502	10,628	49	166,350
		Light	98	32,323	11,288	2	1,062	5,868	4,227	25	54,893
		Mini-car	0	3	4	1	0	2	1	0	11
	Truck	Large-sized special, Large-sized	15	493	139	0	748	583	97	0	2,075
		Ordinary	76	10,641	2,352	1	1,324	4,818	1,350	12	20,574
		Special vehicle	1	143	38	0	13	40	25	1	261
	Total	694	160,429	43,031	6	7,758	36,113	18,266	97	266,391	

Table 1: Number of rear-end collisions between vehicle by vehicle classification (2004)

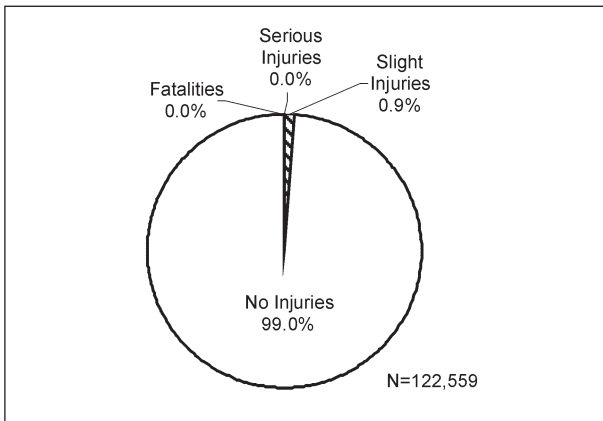


Figure 4: Injury severities of striking-vehicle drivers in rear-end collisions (ordinary passenger cars, primary parties, 2004)

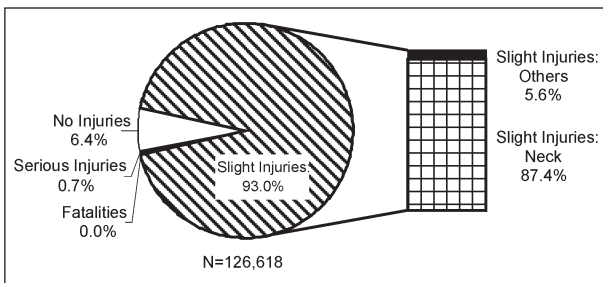


Figure 5: Injury severities of struck-vehicle drivers in rear-end collisions (ordinary passenger cars, secondary parties, 2004)

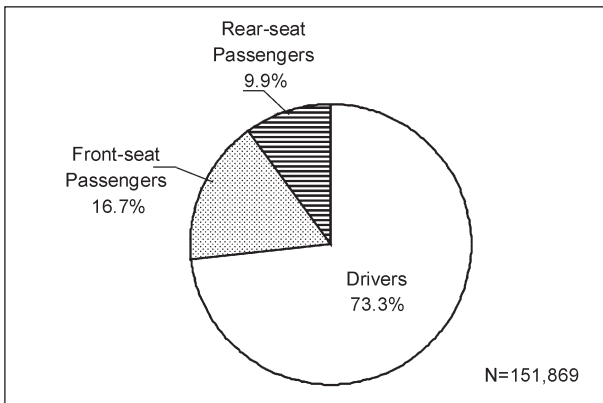


Figure 6: Seating positions of all occupants of struck vehicles in rear-end collisions (ordinary passenger cars, secondary parties, neck injured, 2004)

drivers, approximately 17% of them were front-seat passengers and approximately 10% of them were rear-seat passengers as shown in Figure 6. These figures indicate that struck-vehicle drivers have a high priority.

Neck injury incidence in rear-end collisions

Measures to prevent whiplash neck injuries in struck vehicles are desired. However, the

mechanism of whiplash injuries is not fully understood at present, and there are differing opinions about the mechanism causing such injuries [4-8].

Definition of No-Neck-Injury Rate

An analysis was made of the relation of struck-vehicle properties to neck injuries in struck vehicles, which account for the greater portion of rear-end collision casualties. The index used in the analysis was the no-neck-injury rate defined as follows, based on the injury severity of struck-vehicle drivers:

No-neck-injury rate=

$$\frac{\text{No injuries} \times 100 (\%)}{\text{Fatalities} + \text{Serious injuries} + \text{Slight injuries} + \text{No injuries}}$$

Casualties (fatalities, serious injuries and slight injuries) were restricted to those that mainly involved neck injuries. The types of serious and slight injuries were limited to sprains, dislocations or fractures in order to focus on injuries thought to be whiplash or an extension thereof. It will be noted that this index is used only for drivers because only drivers, as a rule, are counted among the no-injury vehicle occupants in ITARDA's integrated accident database.

The struck-vehicle properties analyzed in this study with this index were the initial year of registration and presence/absence of an anti-whiplash device.

Relation to Initial Year of Registration

Method and data

An investigation was made of whether neck injuries were apt to occur in newer struck vehicles, in view of the upward trend for casualties in rear-end collisions as shown in Figure 3. The relationship between the initial year of registration and the no-neck-injury rate of drivers in struck vehicles was analyzed using the integrated accident database. Each passenger car class was analyzed separately because the differing shapes and weights of different vehicle classes would affect the no-neck-injury rate. The definitions of the passenger car classes used by ITARDA are shown in Table 2. The analysis focused on rear-end collisions in 2004 that met the following conditions:

- Striking vehicle: passenger car or truck, ordinary or light, and primary party.
- Struck vehicle: secondary party and struck in the entire rear-end area.
- Exclusion of multiple collisions.

Results

The results in Figure 7 show that there was no tendency for the no-neck-injury rate of struck-vehicle drivers to decrease with a later initial year of registration of the struck vehicle. On the contrary, for the Sedan-B class (engine displacement of 1,500-2,000cc) and the Sedan-C class (engine displacement of over 2,000cc), the no-neck-injury rate tended to increase with a later initial year of registration of the struck vehicle.

Passenger car class
Family-Light
Sedan-A (engine displacement of under 1,500cc)
Sedan-B (engine displacement of 1,500-2,000cc)
Sedan-C (engine displacement of over 2,000cc)
Sports & Speciality
Wagon
1-Box & Minivan
SUV (Sport-utility vehicle)

Table 2: Definitions of passenger car classes

Effect of an Anti-Whiplash Device – Analyses 1

Method and data

To examine the effect of an anti-whiplash device, which has been spreading in recent years, vehicle models meeting the following requirements were selected, and the difference in the no-neck-injury rate between drivers of vehicles with and without such a device was analyzed:

- Ordinary passenger car with and without an anti-whiplash device (to exclude body influences such as the crash characteristics of the rear end).
- The device is not an option (to eliminate driver consciousness of whiplash).
- Presence of the device can be clearly distinguished according to the model (to calculate the no-neck-injury rate in the presence of the device).
- Vehicle models with and without the device were put on the market by 1999 (to secure a sufficient volume of accident data).

Only one vehicle meeting these requirements was found. This vehicle was Sedan-C put on the market in 1996. The anti-whiplash device fitted on this

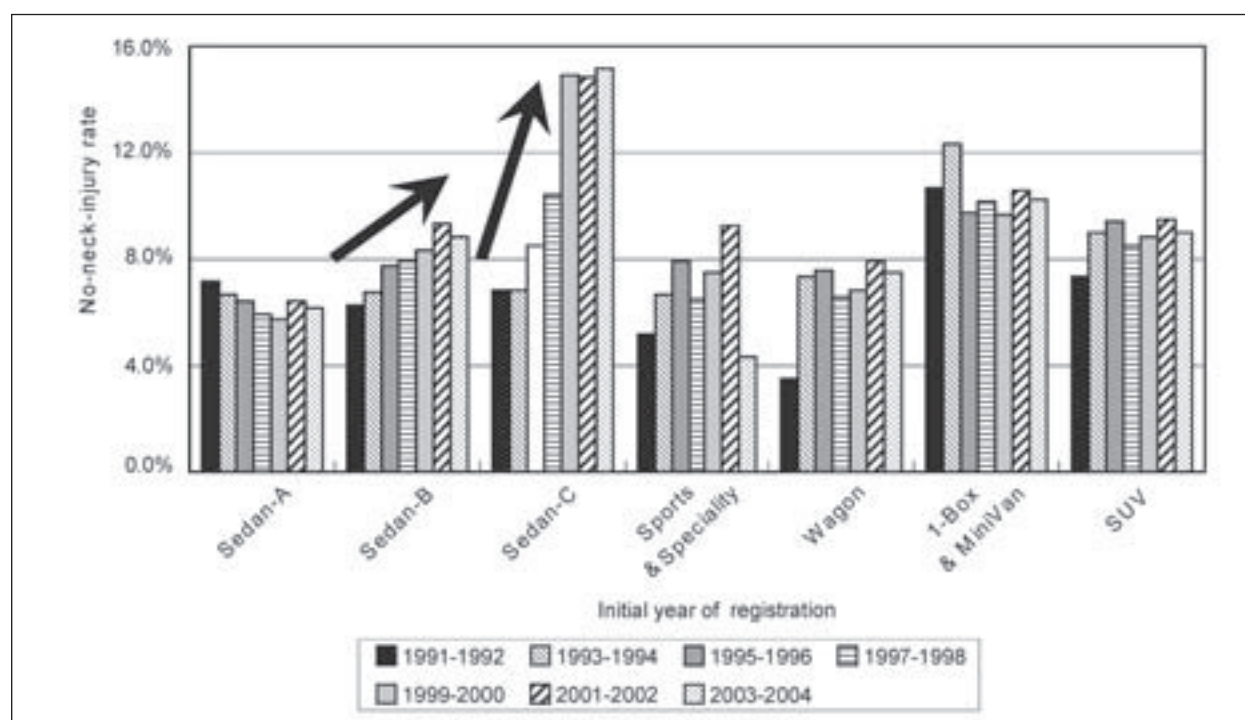


Figure 7 Relationship between no-neck-injury rate and initial year of registration of struck vehicles in rear-end collisions (ordinary passenger cars, secondary parties, 2004)

vehicle was an active head restraint (AHR) system [9]. An AHR system was not provided initially and became standard equipment on all models of this vehicle in the latter half of 1998.

The analysis focused on rear-end collisions occurring over five years from 2000 to 2004 and meeting the following conditions:

- Struck vehicle: the above-mentioned vehicle, struck in the entire rear-end area, and secondary party.
- Striking vehicle: passenger car or truck, ordinary or light, and primary party.
- Exclusion of multiple collisions.

Results

Under the conditions above, the numbers of drivers incurring mainly neck injuries or no injuries in this vehicle are shown in Table 3. Of 760 drivers, 105 suffered neck injuries with the AHR and 21 reported no injuries, whereas 587 incurred injuries without the AHR and 47 reported no injuries. The no-neck-injury rate with the AHR (16.7%) was higher than that without the AHR (7.4%) as shown in Table 3 and Figure 8.

	With AHR	w/o AHR
Fatal neck injuries	0	0
Serious neck injuries (sprains, dislocations, fractures)	1	4
Slight neck injuries (sprains, dislocations, fractures)	104	583
No injuries/Overall	21	47
Total	126	634
No-neck-injury rate	16.7%	7.4%
Z-statistic	3.324	
P-value	0.0009	

Table 3: Incidence of casualties and no injuries with/without AHR and results of statistical analysis

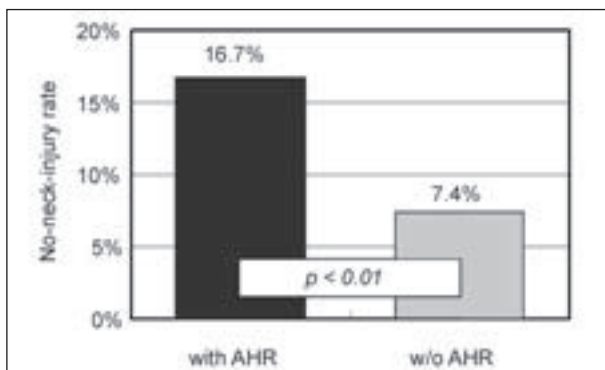


Figure 8: Influence of AHR on no-neck-injury rate

A two-sample test for equality of proportions was conducted between these no-neck-injury rates. The test statistic Z is given by:

$$Z = | p_1 - p_2 | / \sqrt{p(1 - p)(1/n_1 + 1/n_2)}$$

where,

$$p = (n_1 p_1 + n_2 p_2) / (n_1 + n_2)$$

According to these formulas, Z was 3.324, which means that the p-value in the two-sided test was 0.0009. These figures show that the no-neck-injury rate with the AHR was higher than that without the AHR at the 1% significance level.

Results of additional analysis following classification of factors

In the preceding discussion, it was statistically confirmed that the presence of an AHR influences the no-neck-injury rate. However, other factors that might influence the incidence of neck injuries in rear-end collisions, such as impact severity, gender and age, were not considered. For that reason, an investigation was made of whether there was a large difference in the composition of the factors in relation to the presence of an AHR. The results are shown in Figures 9 to 11. Pseudo-ΔV [10] is used

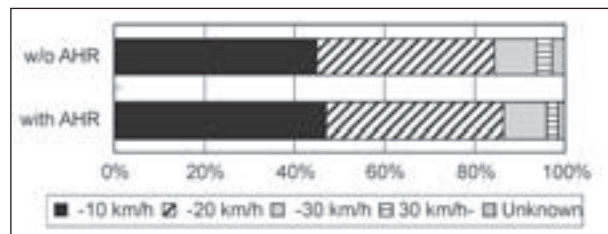


Figure 9: Distribution of pseudo-ΔV with/without AHR

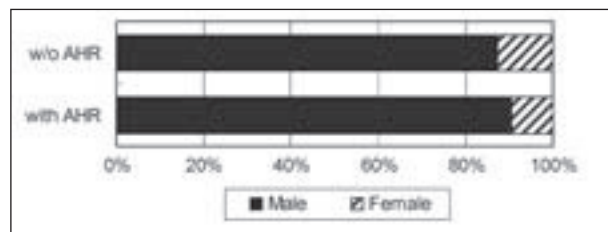


Figure 10: Distribution of gender with/without AHR

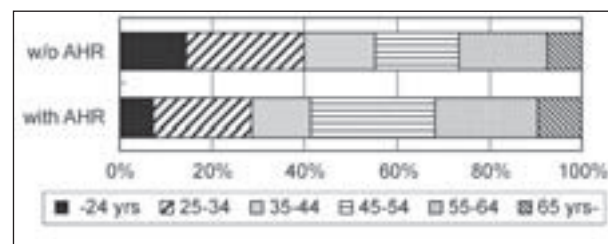


Figure 11: Distribution of age with/without AHR

as an index in Figure 9 to indicate the impact severity in a rear-end collision. Pseudo- ΔV of a struck vehicle can be calculated with the following equation, based on the struck-vehicle impact speed V_1 , struck-vehicle weight M_1 , striking-vehicle impact speed V_2 and striking-vehicle weight M_2 as shown in Figure 12.

$$\begin{aligned}\text{Pseudo-}\Delta V &= V - V_1 \\ &= (M_1 V_1 + M_2 V_2) / (M_1 + M_2) - V_1 \\ &= (V_2 - V_1) M_2 / (M_1 + M_2)\end{aligned}$$

Here, V means the speed of both vehicles after a rear-end collision and is assumed as follows:

- The impact speed is equal to the speed reported by the driver.
- The coefficient of rebound is 0 ($e=0$).

The results in Figures 9 to 11 indicate that there was no large difference in the composition of these factors due to the presence of an AHR, so it can be concluded that the factors did not influence the no-neck-injury rate. Moreover, after classifying the 760 persons in Table 3 separately according to each factor, additional analyses were conducted for the sake of reference.

The results of a comparison of the no-neck-injury rate according to the presence of an AHR in each

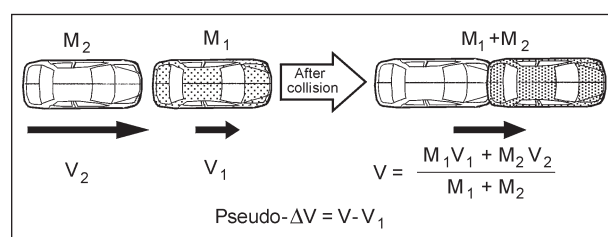


Figure 12: Definition of pseudo- ΔV

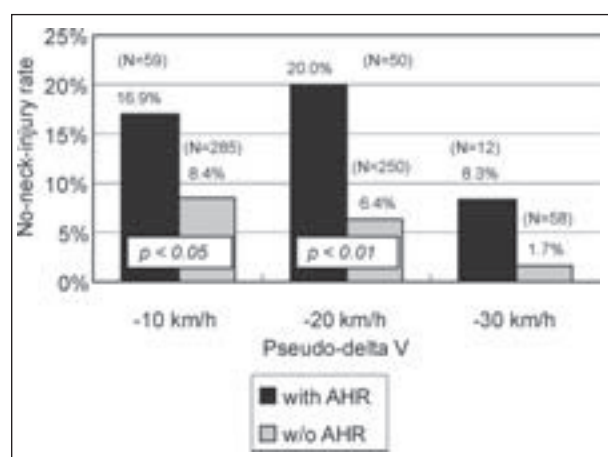


Figure 13: Influence of AHR on no-neck-injury rate by pseudo- ΔV

group into which the 760 persons were divided on the basis of pseudo- ΔV are shown in Figure 13. It is seen that the no-neck-injury rate with an AHR was statistically higher than that without an AHR for the 0-10km/h group and the 11-20km/h group that accounted for the majority of the 760 persons. It was significantly higher at the 5% significance level for the 0-10km/h group. For the 11-20km/h group, it was significantly higher at the 1% significance level. As for the 21-30km/h group, it is observed that the no-neck-injury rate with an AHR was higher than that without an AHR, but no statistically significant difference can be confirmed because of the limited data. As a whole, it can be concluded that the no-neck-injury rate with an AHR was higher than that without an AHR even when the influence of the impact severity in the collision was eliminated.

Figure 14 presents the results for the no-neck-injury rate when a comparison was made by gender in relation to the presence of an AHR, after the 760 persons were distinguished by gender. For males, it was confirmed that the no-neck-injury rate with an AHR was higher than that without an AHR at the 1% significance level. As for females, the no-neck-injury rate with an AHR was higher than that without an AHR, though no statistically significant difference can be confirmed because of the limited data. Overall, it can be inferred that the no-neck-injury rate with an AHR was higher than that without an AHR even after excluding the influence of gender.

Figure 15 shows that the no-neck-injury rate with an AHR was higher than that without an AHR for each age group into which the 760 persons were divided according to age (Figure 11). A statistically

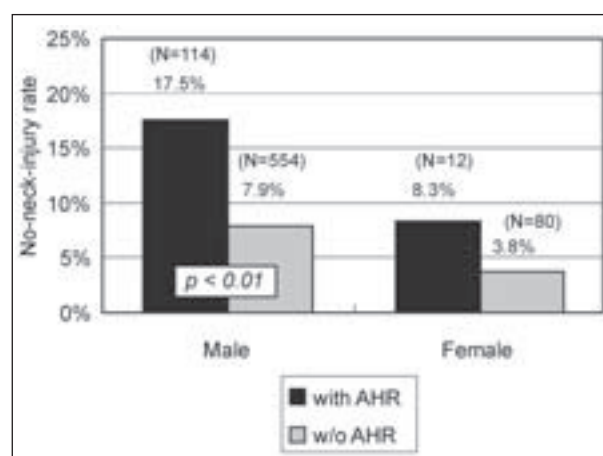


Figure 14: Influence of AHR on no-neck-injury rate by gender

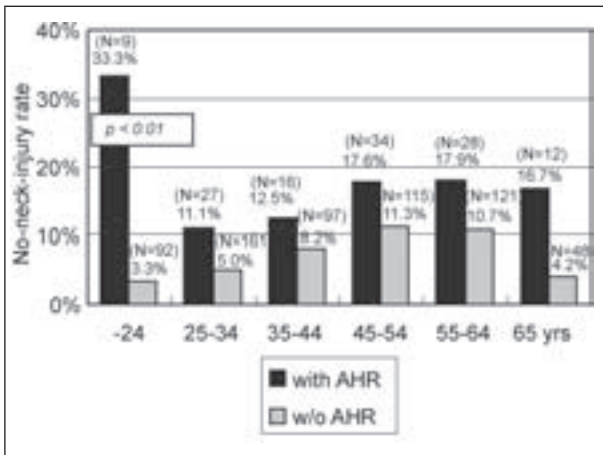


Figure 15: Influence of AHR on no-neck-injury rate by age (divided into six age groups)

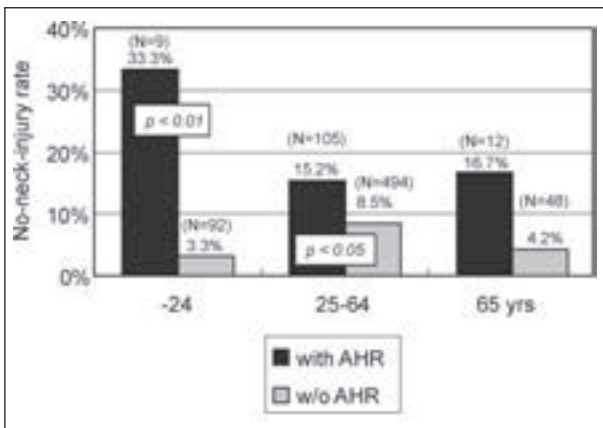


Figure 16: Influence of AHR on no-neck-injury rate by age (divided into six age groups)

significant difference was confirmed only for the 24-or-younger group at the 1% significance level, because of the limited data for the other groups. Considering the group from 25 to 64 years old, the no-neck-injury rate with an AHR was also higher than that without an AHR at the 5% significance level as shown in Figure 16. On the whole, it would appear that the no-neck-injury rate with an AHR was higher than that without an AHR even when the influence of age was removed.

Effect of an Anti-Whiplash Device – Analysis 2

Method and data

In Analysis 1, the influence of each factor was separately excluded when the no-neck-injury rate was calculated in order to analyze the effect of an AHR. A regression analysis was then conducted in which all of the factors, including the presence/

absence of an AHR, were treated at the same time. As the neck injury severity is a qualitative variable and also a ranked variable, an ordered response model was used in the analysis [11]. It was decided to treat the neck injury severity as a binary response of neck injuries (fatalities, serious or slight injuries principally to the neck) or no injuries. An explanation is given here of the method for conducting a regression analysis using an ordered response model. With an ordered response model, it is assumed that there is a latent factor Y_i^* which is a continuous variable that determines whether the neck injury severity Y_i is 1 (neck injury) or 0 (no injury). In this analysis, it is assumed that there is a linear relation between the continuous latent factor Y_i^* indicating the neck injury severity and the explanatory variables, including $X_{k,i}$ ($k=1,2,3,\dots$), pseudo- ΔV , which are considered as independent variables. Then, Y_i^* can be expressed with the following equations:

$$Y_i^* = Z_i + \epsilon_i$$

$$Z_i = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \beta_3 X_{3,i} + \dots + \beta_k \text{Pseudo}\Delta V$$

where,

$$Y_i = \begin{cases} 1 \text{ (neck injury):} & \text{in the case of } Y_i^* > 0 \\ 0 \text{ (no injury):} & \text{in the case of } Y_i^* \leq 0 \end{cases}$$

Z_i is a value which can be explained by $X_{1,i}$, $X_{2,i}$, $X_{3,i}, \dots$, and pseudo- ΔV . ϵ_i is a residual value. $X_{1,i}$, $X_{2,i}$, $X_{3,i}, \dots$ are explanatory variables and have a value of either 0 or 1 if they are dummy variables. $\beta_0, \beta_1, \beta_2, \beta_3, \dots, \beta_k$ are constant values which express the degree of influence of each explanatory variable on Y_i^* . The cumulative distribution function F of $-\epsilon_i$ is assumed to be the logistic distribution given in the following equation:

$$F = e^z / (1 + e^z)$$

Here, the explanatory factors are with/without an AHR, gender (male, female), age (24 years or younger, 25-34 years, 35-44 years, 45-54 years, 55-64 years, 65 years or older) and pseudo- ΔV . These factors, except pseudo- ΔV , are treated as dummy variables which have a value of either 0 or 1. A combination of without an AHR, male and 24 years or younger is assumed to be the standard combination, and the analysis is conducted. Concretely, k is set from 1 to 8, and $X_{1,i} = X_{2,i} = \dots = X_{7,i} = 0$ in the standard combination. $X_{1,i} = 1$ with an AHR. $X_{2,i} = 1$ in the case the gender is female. $X_{3,i} = 1$ when the age is 25-34 years, $X_{4,i} = 1$ when 35-44 years, $X_{5,i} = 1$ when 45-54 years, $X_{6,i} = 1$

when 55-64 years, and $X_{7,i}=1$ when the age is 65 years or older.

The data for 21 of the 760 persons extracted in Analysis 1 were omitted in this analysis because of uncertain pseudo- ΔV . The data of the remaining 739 persons were used in the regression analysis conducted with the ordered response model. The constant values of $\beta_0, \beta_1, \beta_2, \beta_3, \dots, \beta_8$ were estimated by the maximum likelihood method, using the TSP 5.0 statistical analysis software [12].

Results

The results of the analysis are presented in Table 4 and Figure 17. The estimated values are the results of an estimation of the coefficient β_k . A likelihood ratio test was carried out to evaluate the null hypothesis, assuming that all the estimated values were equal to 0. The 2LL result of this test was 22.85, which was statistically significant because it was larger than 20.1 of the 1% chi-square of 8 degrees of freedom. The fraction of correct

		Estimated	Std. Error	t-statistic	p-value	
Constant	β_0	2.417	0.472	5.115	0	
With AHR	β_1	-0.871	0.293	-2.970	0.003**	
Female	β_2	0.800	0.539	1.483	0.138	
Age	25-34yrs	β_3	0.108	0.537	1.483	0.138
	35-44yrs	β_4	-0.514	0.542	-0.949	0.342
	45-54yrs	β_5	-0.785	0.497	-1.579	0.114
	55-64yrs	β_6	-0.564	0.504	-1.119	0.263
	65yrs	β_7	-0.018	0.678	-0.026	0.979
Pseudo- ΔV (km/h)	β_8	0.036	0.019	1.834	0.067	
Number of observations = 739		Fraction of Correct Predictions=0.912				
Log likelihood L=208.639		Log likelihood L_0 =-220.063				
2LL=22.85		**: p<0.01				

Table 4: Estimated results of regression analysis using an ordered response model (without AHR, male, 24 years or younger)

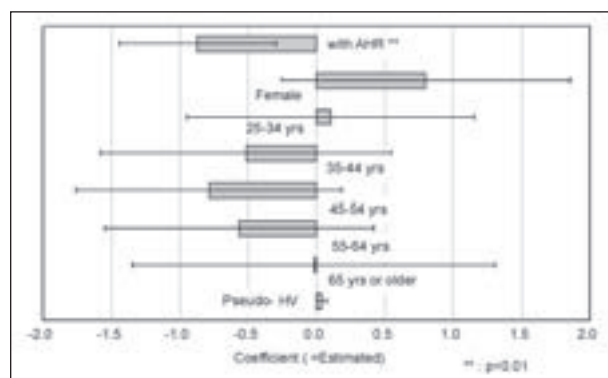


Figure 17: Coefficients and 95% confidence intervals

predictions was 0.912. Therefore, it can be concluded that the regression equation consisting of the explanatory variables such as with/without an AHR, gender, age and pseudo- ΔV is significant.

As for the effect of an AHR, the estimated (coefficient) with an AHR was negative at -0.871, and the t-statistic was -2.97, which satisfied the 1% significance level in the two-sided test. This indicates that Y_i^* becomes smaller and that the possibility of no injury increases when an AHR is installed.

Conclusion

The following results were obtained in this analysis of rear-end collisions in Japan using the integrated accident database developed by ITARDA.

1. The actual situation for rear-end collisions and resultant injuries of ordinary-passenger-car occupants was clarified.
2. It was shown that the no-neck-injury rate of struck-vehicle drivers did not tend to decrease with a later initial year of registration of the struck vehicles. On the contrary, in some passenger car classes, the no-neck-injury rate tended to increase with a later initial year of registration of the struck vehicles.
3. After eliminating various factors which were thought to influence the incidence of neck injuries, it was found that an active head restraint (AHR) system, which is one type of anti-whiplash device, was effective in suppressing the incidence of neck injuries in struck-vehicle drivers, though the verification was based on just one vehicle model. The various factors eliminated were the crash characteristics of the struck vehicle, impact severity estimated from the weight and impact speed of the striking and struck vehicles, and drivers' gender, age and consciousness of whiplash.

The incidence of no injuries in property damage accidents is not reflected in the no-neck-injury rate used in this study because of limitations of the integrated accident database. The accuracy of analyses based on the no-neck-injury rate could be further improved by using a database that included the incidence of no injuries in property damage accidents such as the database of the automobile insurance industry.

Acknowledgements

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