

Features of Fatal Pedestrian Injuries in Vehicle-to-Pedestrian Accidents in Japan

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ABSTRACT

The number of traffic deaths in Japan was 4,612 in 2011. Looking at the road accident fatalities, it revealed that pedestrians accounted for the highest number in 2011 (1,686, 36.6%). To develop safety countermeasures to decrease the severity of injuries and to reduce the number of deaths in traffic accidents, the detailed characteristics of pedestrian injury in vehicle-to-pedestrian crashes are necessary. The purpose of this study is to understand the scenarios of vehicle accidents in which pedestrians suffer fatal injuries. In the present study, we investigated the characteristics of pedestrian injuries in fatal crashes from accident analyses and compared them to head injury severity levels in impact tests against a road pavement and vehicle contact surfaces. In the accident analyses, we investigated the main body regions injured, that is, the most serious extent of injuries over the whole body of pedestrians by using macro vehicle-pedestrian accident data from database of the Institute for Traffic Accident Research and Data Analysis (ITARDA) of Japan. In comparing the differences in injury frequencies for various body regions between 1999 and 2009, it is noted that the frequencies of pedestrian fatalities due to head injuries were significantly reduced. The result indicated that even though head injuries were the most frequent cause of pedestrian fatalities in traffic accidents, the introduction of pedestrian head protection regulation in Japan in 2005 could be considered effective in reducing fatal head injuries. On the other hand, the frequencies of pedestrian fatalities due to hip injuries increased significantly in sedans, light passenger cars, and light cargo vans.

Using the macro accident data in 2009, we investigated the frequency of pedestrian fatalities by gender, age group, vehicle travel speed, and fatal head injuries due to vehicle impacts or road pavement impacts. The results also indicated that the frequencies of female pedestrian fatalities due to hip injuries were significantly higher than those of males. Additionally, the results showed that the frequency of pedestrian fatalities due to hip injuries for the age group of over 65 years was significantly higher than that of the industrial age group (aged 13-59). Focusing on the frequency of pedestrian fatalities due to hip injuries in all age groups, vehicle travel speed appeared likely not to be an extremely important factor in increasing fatal hip injuries. In examining the differences in the frequency of fatal head injuries due to contacts with vehicles or road pavements, it is noted that injury frequency in crashes involving vehicles travelling at high speeds were significantly higher than those at lower speeds for pedestrians over 60 years of age.

Focusing on head injury severity levels in impact tests against a road and vehicle surfaces using an adult pedestrian headform impactor, the impacts against a road pavement (HIC 6525) was considered to be more severe than those against vehicle front components with high stiffness (HIC from 2600 to 4032).

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INTRODUCTION

The number of traffic fatalities in Japan was 4,612 in 2011. Looking at the road fatalities, it is evident that

pedestrians accounted for the highest number (1,686, 36.6%), as shown in [Figure 1](#). The Japanese government aims to reduce the number of annual fatalities to less than 2,500 by

2018 (Cabinet Office 2009). For example, the Japanese Ministry of Land, Infrastructure, Transport and Tourism (JMLIT) has begun assessing the safety performance of the bonnet tops of vehicles to reduce the contact force to the head, because head injuries have been the most frequent cause of pedestrian deaths in vehicle-to-pedestrian accidents (Matsui 2005, Matsui 2011). In order to adopt more effective countermeasures to decrease the number of deaths in traffic accidents, it is necessary to examine the details related to fatal injuries in vehicle-to-pedestrian accidents.

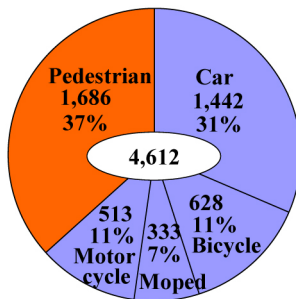


Figure 1. Distribution of traffic fatalities by crash types in Japan in 2011 (ITARDA 2012).

In Japan, since 2005 the Japanese government has introduced the safety regulation for pedestrian head protection by testing safety performance of bonnet tops of vehicles. It is therefore, reasonable to expect a reduction in pedestrian fatalities in vehicle-to-pedestrian crashes. In order to evaluate the effect of the regulation in the real-world, the change in fatal head injuries in pedestrian crashes before and after the regulation needs to be analyzed. Additionally, the effect gender, age, vehicle travel speeds and such other factors also need to be closely studied for establishing human injury tolerance levels for proper safety evaluations in the future. Further, the cause of injury to the victim's head and its severity based on the contacted surface also need to be investigated. The purpose of this study is to thoroughly assess vehicle crashes in which pedestrians suffer fatal injuries due to head contacts against vehicle bonnet and road pavement. In the present study, we investigated the fatal pedestrian injury from accident data analyses.

METHOD

Accident Analyses

Generally, pedestrians involved in fatal crashes would have multiple injuries, e.g., a combination of head and chest. When a victim is killed in a traffic accident, policemen and medical doctors determine the main body region causing death and their relative severities. The region is recorded in the macro accident ITARDA database. Using this database, we investigated the most serious body region injured in pedestrian crashes to determine their extent and severity. The present analyses were aimed at studying the differences of the different body regions injured according to the crash year, by

gender of the victim, by age group, and for two different travel speed ranges as given below in (1), (2), (3), (4). The sources for the cause of victim's head injury were also analyzed in detail as given in (5).

- (1). differences observed for the main body region injured in 1999 and 2009.
- (2). differences observed for the main body region injured between males and females.
- (3). differences observed for the main body region injured between an industrial age group (aged 13-59) and those over 60 years of age.
- (4). differences observed for the main body region injured for low travel speeds (less than or equal to 30 km/h) and high travel speeds (31 km/h to 60 km/h).
- (5). differences observed for the victim's head injury due to contacts with vehicle bonnets or road pavements at the different travel speed ranges selected.

Vehicle type

In the present study, the vehicle types are classified into two main categories - the ordinary automobile (sedan, mini van, box van), and the light automobile (light passenger car, light cargo van). Examples of them are shown in Figure 2. Engine displacement of an ordinary automobile is more than 660 cc and that of a light automobile is less than or equal to 660 cc.



(a). Sedan



(b). Mini van

Figure 2. Examples of classified vehicle types.



(c). Box van



(d). Light passenger car



(e). Light cargo van

Figure 2. (cont.) Examples of classified vehicle types.

In 2009, the number of traffic fatalities in Japan was 4914, of which pedestrian fatalities were 1,717 (35%). The total number of pedestrian fatalities categorized by five vehicle types as shown in Figure 2 was 1,089 in 2009. The distributions of pedestrian fatalities caused by five vehicle types in 2009 are shown in Figure 3. In fatal accidents, a sedan was the most frequent source (41%), a light passenger car was the second most frequent (26%), a light cargo van was the third (16%) followed by the minivan (13%) and box van (4%).

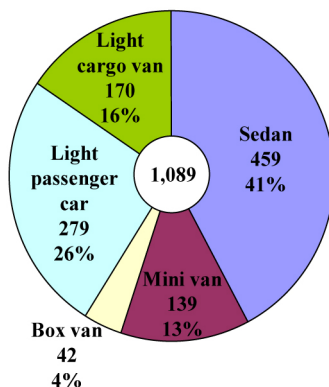


Figure 3. Distribution of pedestrian fatalities caused by five vehicle types in 2009.

Age groups

In this analysis, we focused on sedan-to-pedestrian accidents, considering that a sedan was the most frequent vehicle (41%) causing fatal pedestrian injuries (Figure 3). Figure 4 shows the distribution of pedestrians killed due to injuries in these crashes classified by age groups. To understand the differences in injuries among age groups, the age group of over 60 years was classified into three sub-groups; 60-64, 65-74, and over 75, in accordance with the classification for the elderly used in Japan health insurance system. Comparing pedestrian fatal injuries among the older age groups, the group over 75 years was found to have most frequent fatalities (226, 50%), while the other two age groups' fatalities occurred less frequently at 21% (98) for the age group 65-74 years and only 6 % (29) for the age group 60-64 years. Two other younger age groups (13-59 years) and those aged 12 years or less had frequency of fatal injury occurrence of (95, 21%) and (11, 2%), respectively. See Figure 4 below.

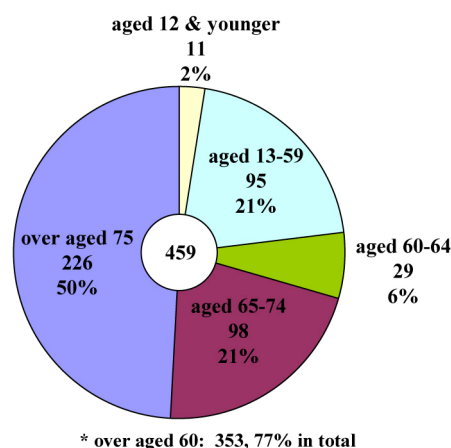


Figure 4. Distribution of pedestrian fatalities by age groups in 2009.

Vehicle travel speed

We divided vehicle travel speeds into two groups, a low speed - less than 30 km/h, and a high speed - 31 km/h to 60 km/h. Matsui et al. previously investigated serious injury risks to pedestrians by conducting simulated impact tests using a whole human FE model using a sedan, a SUV and a light passenger car. The pedestrian risks were calculated based on the head and chest serious injury risks. As a result, when the vehicle impact velocity was less than or equal to 30 km/h, the serious risk was less than or equal to 5% (Matsui et al. 2011a). Therefore, the lower limit for vehicle travel speed was established at 30 km/h.

Main body region fatally injured

For the analyses of main body regions injured and the extent of injuries over the whole body of pedestrians, we focused on pedestrians' head, chest and hip; the top three body regions commonly found injured in fatal pedestrian

crashes are the head (56%), the chest (16%), and the hip (11%). (ITARDA 2012).

Analysis method

The differences in the distribution were investigated in the following statistical test of the sample rates. When variable Z in the statistical test is defined by equation (1), Z follows a standard normal distribution.

$$Z = \frac{\frac{n}{N} - \frac{m}{M}}{\sqrt{P^* (1 - P^*) \left[\frac{1}{N} + \frac{1}{M} \right]}} \quad (1)$$

Where

$$P^* = \frac{n + m}{N + M}$$

In the analyses of the body regions injured in fatal pedestrians (from analyses (1) to (4)), n and m are the number of cases of specific body regions injured in vehicle-to-pedestrian traffic accidents. N and M are the total sample sizes restricted by the given two groups in consideration such as year 1999 and 2009. An example of dataset is shown in Table 1-1 which is referred from Table 2. For example, n and m are the number of victims' hips involved in fatal injuries occurred in year 1999 and 2009, respectively. N and M are the total number of fatal injuries including hips and other body regions injured in the year 1999 and 2009.

Table 1-1. An example of dataset for body region analyses.

Vehicle type	Body region	1999		2009	
		n	N	m	M
Sedan	Head	593	940	257	459
	Chest	71		61	
	Hip	70		56	
	Others	206		85	

For the analyses on sources of injury (vehicles/roads) causing fatal injuries to pedestrians' heads (analysis (5)), we investigated the differences in head injury distribution caused by vehicles and road pavements at the two travel speed ranges considered using equation (1). n and m are the number of pedestrian fatalities due to head injuries because of contacts with vehicles and roadways. N and M are the total number of fatality cases due to head contacts with vehicles and road pavements under low travel speed and high travel speed conditions, respectively.

For the accident data analyses, we investigated the variables in the vehicle, age groups and vehicle travel speeds as given in Table 1-2.

Table 1-2. Accident analysis conditions.

Analyses	Focus	Vehicles		Age group			Vehicle travel speed		
		5 types of vehicles including sedan	Sedan	All age including ≤12	13-59	60-	All speed	≤30 km/h	31-60 km/h
(1) Year: 1999/2009	Main body region injured	√	-	√	-	-	√	-	-
(2) Gender: male/female		√	-	√	-	-	√	-	-
(3) Age groups		-	√	-	√	√	-	√	√
(4) Vehicle travel speed		-	√	-	√	√	-	√	√
(5) Head severity by vehicle/road impact	Head injury by vehicles/roads as main cause	√	-	-	-	√	-	-	√

Impact Tests

Drop impact test against a road pavement using a pedestrian headform impactor was conducted to investigate the potential injury severity of pedestrian heads due to contact with road pavements. Additionally, impact tests against a vehicle front with high stiffness using a pedestrian headform impactor were also conducted for comparing the severity of head injury potential from vehicle tests to road pavement tests.

Considering 98% fatal pedestrian accidents involving sedans were adults in Japanese traffic accidents as shown in Figure 4, a pedestrian adult headform impactor with a mass of 4.5 kg (Matsui and Tanahashi 2004) was used to examine potential injury severity of a head impact against a road pavement and vehicle front area. The headform impactor is used by the Japanese Ministry of Land, Infrastructure, Transport and Tourism (J-MLIT) for regulatory testing and by the Japan new car assessment program (J-NCAP) when assessing the safety performance of the front end of vehicles. The headform impactor consists mainly of a hemispherical part representing the head and a baseplate all made of aluminum; the hemisphere is covered by a skin (polyvinyl chloride: PVC), as shown in Figure 5. At the center of gravity of the headform impactor, three axial accelerometers are installed. In the impact tests against a road pavement, three damped uniaxial accelerometers (Kyowa ASE-A-500) (Matsui 2011), currently employed in J-MLIT tests were used. In the impact tests against vehicle front ends, three damped uniaxial accelerometers (Kyowa AS-500HA) (Matsui and Niimura 2005), employed in J-NCAP tests, were used.

The average eye height of a Japanese male over 13 years is 1.53 meters according to the Research Institute of Human Engineering for Quality Life, 1997. In the present drop impact test, the drop height from the road pavement was 1.5 meters as shown in Figure 6. The drop angle of the headform impactor was 65 degrees from the horizontal. As for the headform impactor, there are two types of impactors in use - with and without cables. In the test for the safety regulation, in pedestrian head protection performance assessment of vehicle front-ends, headform impactors with cables are generally used. However, in the current drop tests recently developed cable-less data acquisition system (KYOWA DIS-503A) was installed on the baseplate of the headform