2022
25th Presentation Session for Traffic Accident Investigations, Analysis, and Research

“Characteristics of Pedestrian Accidents in Low-Speed Range”

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1. Background and objectives

Among traffic-accident parties, pedestrians have continued to have the highest number of fatalities in Japan since they surpassed occupants of four-wheel vehicles in 2009 (Figure 1). Furthermore, looking at the past 10 years, pedestrian fatality & serious injury accidents have decreased very little in the low-speed range (20 km/h or below), and thus addressing this seems to be an upcoming challenge (Figures 2, 3). Against this backdrop, in this research, we investigated (1) the causes of accidents not decreasing in the low-speed range, and (2) mechanisms that lead to fatalities & serious injuries in the low-speed range.

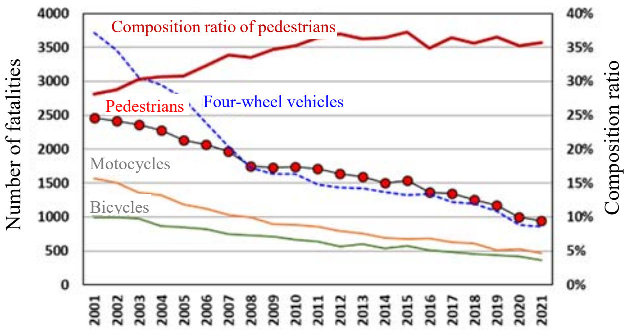


Figure 1. Trend in traffic-accident fatalities

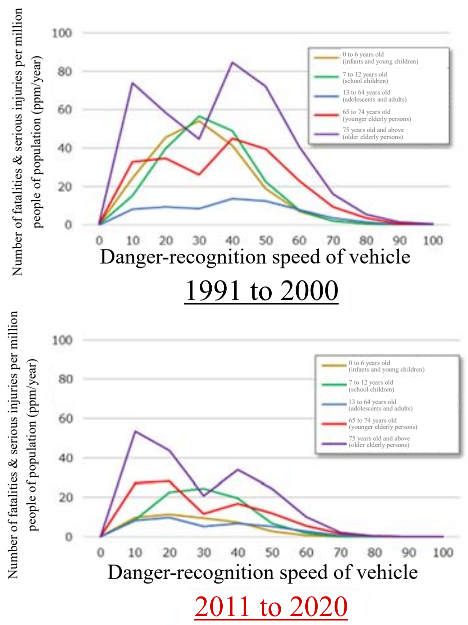


Figure 2. Relationship between speed and number of fatalities & serious injuries per population

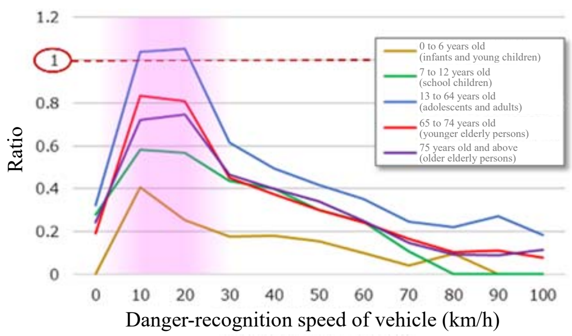


Figure 3. Ratios of 2011 to 2020 & 1991 to 2000

2. Examination method

Chart 1 shows the examination objectives, the accident data used, and a list of the analytical methods. In the case of Objective (1) mentioned above, we gained an understanding of actual conditions through cross tabulation, and estimated causal relationships through an RCT (randomized controlled trial). As for Objective (2), we narrowed targets through non-hierarchical cluster analysis (the k-means method), and then carried out cross tabulation.

Objective	Data	Analytical method	
(1)	ITARDA macro data •Person-to-vehicle accidents •1995/2010 to 2021 •n = 1,830,000/540,000 cases	・Cross tabulation	Understanding of actual conditions
		・RCT (randomized controlled trial)	Estimation of causalrelationships
(2)		・Non-hierarchical cluster analysis	Information compression
		+ Cross tabulation	Estimation of causes

Chart 1. Overview of examination method

3. Results

3.1 (1) Causes of accidents not decreasing in low-speed range

First, we checked annual changes in the danger-recognition speeds of pedestrian accidents. The average for six vehicle types ranging from "motorcycle" to "cargo" followed a consistent trend in which it continued to fall, and over 26 years, it declined by 9 km/h (Figure 4).

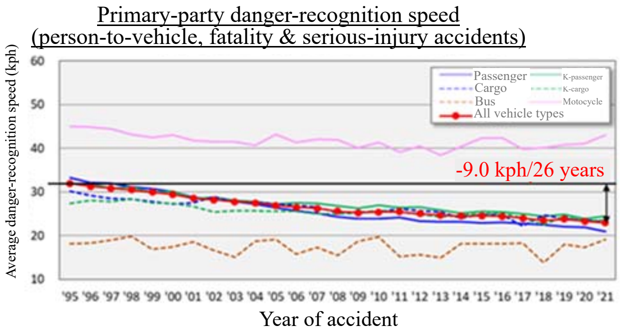


Figure 4. Trend in danger-recognition speed (pedestrian accidents)

Looking at the change in the number of accidents divided by speed, while the number has decreased for 30 km/h and above, it has stayed at the same level for 20 km/h or below. As a result of this, the composition ratio of 40 km/h and above has decreased, and the composition ratio of 10 to 20 km/h has increased (Figure 5). In other words, amid an overall trend in which speeds have been decreasing, the number in the medium to high-speed range has been flowing into the low-speed range, and this is why even though accidents have been decreasing overall, they have not been declining in the low-speed range.

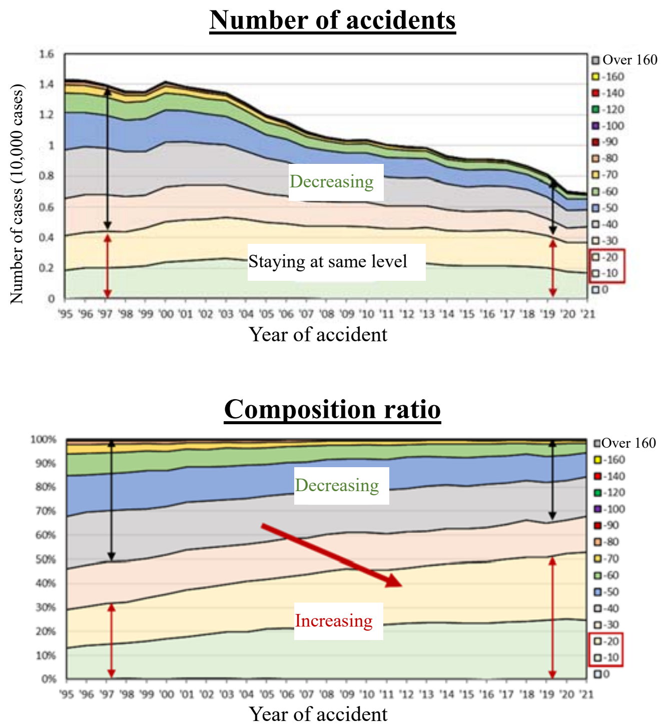
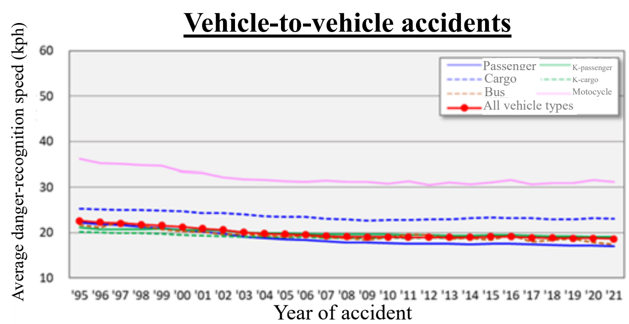


Figure 5. Change in number of accidents by danger-recognition speed (pedestrian accidents)

*In all cases, the speed is the primary-party danger-recognition speed (person-to-vehicle, fatality & serious-injury).

Next, we checked the trends regarding other accident types (vehicle-to-vehicle accidents and vehicle-alone accidents). As expected, the average speed of all vehicle types has been continuing to drop in a consistent manner (Figure 6), and thus there appears to be a declining trend that is not limited to pedestrian accidents and is shared by all of the main accident types. In light of this, it can be inferred that significant forces related with social changes of some kind have been at work in the background.



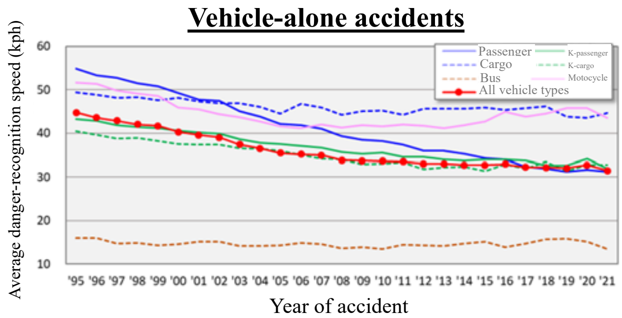
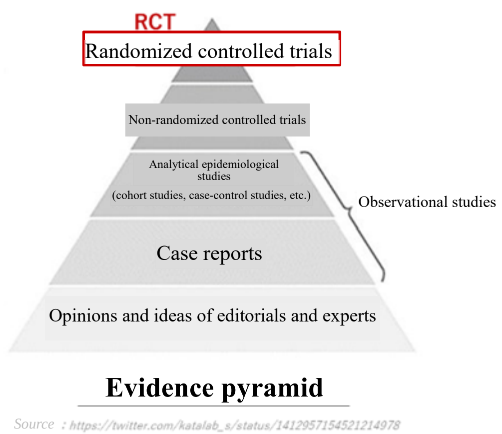


Figure 6. Trend in danger-recognition speed (vehicle-to-vehicle / vehicle-alone)

*In all cases, the speed is the primary-party danger-recognition speed (fatality + serious-injury + slight-injury).

In order to verify this hypothesis, it is necessary to identify factors that have a causal relationship with danger-recognition speeds, and to check how such factors are connected with social changes. Since it is difficult to evaluate causal relationships (≠ correlative relationships) with common statistical methods, in our research, we attempted the application of an RCT. RCTs are positioned at the highest rank in the evidence pyramid for clinical medicine, and thus they are deemed to be the method that has the most persuasiveness. Under this structure, a pair of populations regarded as being equivalent is prepared, and an intervention operation such as drug administration is only carried out regarding one of the populations. The results are then compared, and this enables the effects of the intervention to be verified (Figure 7).



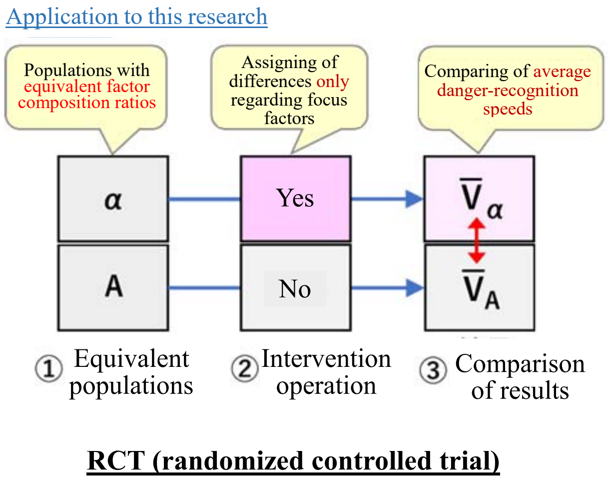


Figure 7. Overview of RCT (Reference 1)
and application to accident analysis

In this research, we first of all made a list of factors considered to be related with speed (Chart 2), and extracted multiple groups in such a way that the accident-number composition ratios of the factors would be equivalent with the overall population (with error within 0.1%). We then assigned differences regarding composition ratio only to factors that we focused on, and investigated disparities in the average danger-recognition speeds that could be calculated as a result of the above*.

*To learn about the limitations, etc. of this method, see the Appendix at the end of this document.

On this occasion, we extracted 2,000 cases for each level from the total data of 540,000 cases. Thus, the extraction rate was less than 1%, and due to throwing out over 99%, it became possible to create the type of artificially-controlled data set described above.

Chart 2. Factors (= explanatory variables) regarding danger-recognition speed, and their levels

Factor	Year of accident	Person					Vehicle		Road			
		Gender	Age	Intoxication while driving	Purpose of travel	Behavior type	Vehicle type of party	Vehicle age	Road configuration	Traffic light	Terrain	Day/night
Level 1	2010-12	Male	0 to 24 years old	Intoxicated	Business	Starting/backing up	Regular-passenger	0 to 2 years	Intersection	Lit	DID	Day
Level 2	2013-15	Female	25 to 44 years old	Not intoxicated	Commuting to work	Going straight ahead, etc.	K-passenger	3 to 5 years	Non-intersection	Flashing	Urban	Night
Level 3	2016-18		45 to 64 years old		Personal	Turning	Other passenger	6 to 8 years	Railway crossing	None	Non-urban	
Level 4	2019-21		65 to 99 years old			Other	Cargo	9 or more years	General area			

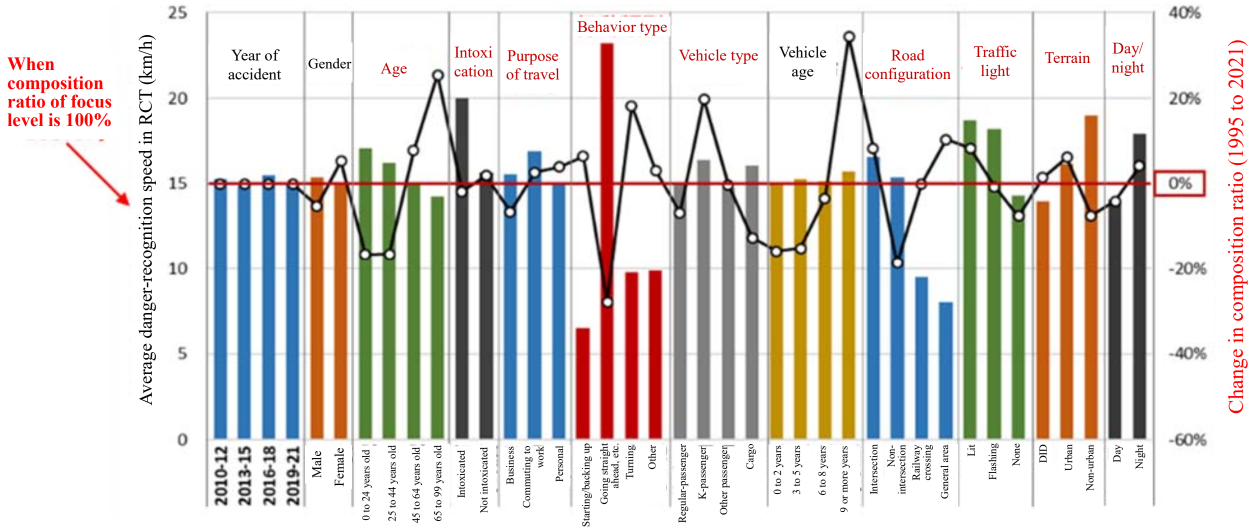


Figure 8. Average danger-recognition speeds for focus factors (levels), and changes in composition ratio

The results for the total of 39 groups that were extracted are shown in Figure 8. The bar graph shows the average danger-recognition speed (when the composition ratio of the focus level equals 100%), and the line graph shows the change in the composition ratio of the focus level (from 1995 to 2021). Furthermore, a t-test was carried out regarding each of the factors, and the significant factors (with a p-value of ≤ 5%) are shown in red text. First of all, looking at the group (on the far left) regarding which only "year of accident" has been changed and the other factors & levels have been made the same, there is a result in which there are no differences in the average speeds, and thus it is clear that there was no insufficiency in the types of factors (explanatory variables) that were extracted. Furthermore, results were obtained that did not seem particularly unusual, and these included age (slower speed as age increases), intoxication (faster speed), behavior type (faster for "going straight ahead" and slower for "turning/starting"), vehicle type (faster for "K" and "cargo"), road configuration (faster for "intersection" and "non-intersection" and slower for "parking area"), traffic light (faster when present), terrain (slower for urban areas), and day/night (faster for "night").

Next, by multiplying the average danger-recognition speed by the change in composition ratio, we calculated the actual amounts of contribution of the factors to the change in speed over the past 26 years (Figure 9). The results show that behavior type particularly stands out, and that following this, age, road configuration, and terrain have contributed to the decrease in speed.

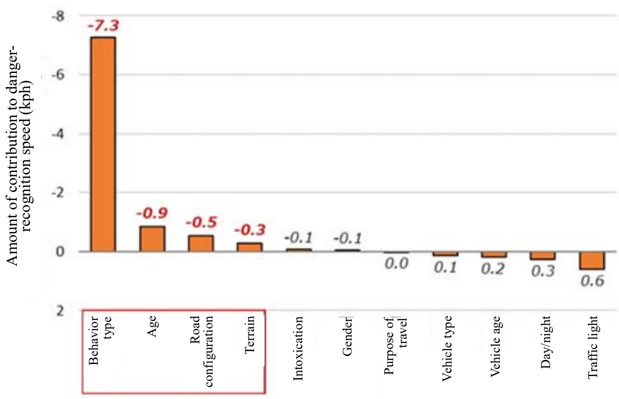


Figure 9. Contribution of various factors to danger-recognition speed (1995 to 2021)

3.2 (2) Mechanisms that lead to fatalities & serious injuries in low-speed range

The analysis procedure is shown in Figure 10.

(1) First of all, we made a list of 27 factors related with the level of injury of pedestrians, and then created a data set.

(2) Next, based on the danger-recognition speed, we divided the data set into the two groups of "medium to high-speed" and "low-speed."

(3) We carried out non-hierarchical cluster analysis based on the k-means method regarding each group. Upon carrying out trial calculations with the number of divisions ranging from 2 to 10, in both groups, when the number of divisions was 4, a cluster with a high fatality & serious-injury rate became apparent, and we set these as focus clusters.

(4) In regard to the focus clusters, we compared the distribution of all 27 factors, and thereby checked the characteristics of the low-speed group.

Upon comparing the frequency distribution of each of the factors in (4) above, it was possible to recognize notable difference between the focus clusters regarding 12 factors (Figure 11). These are compiled below.

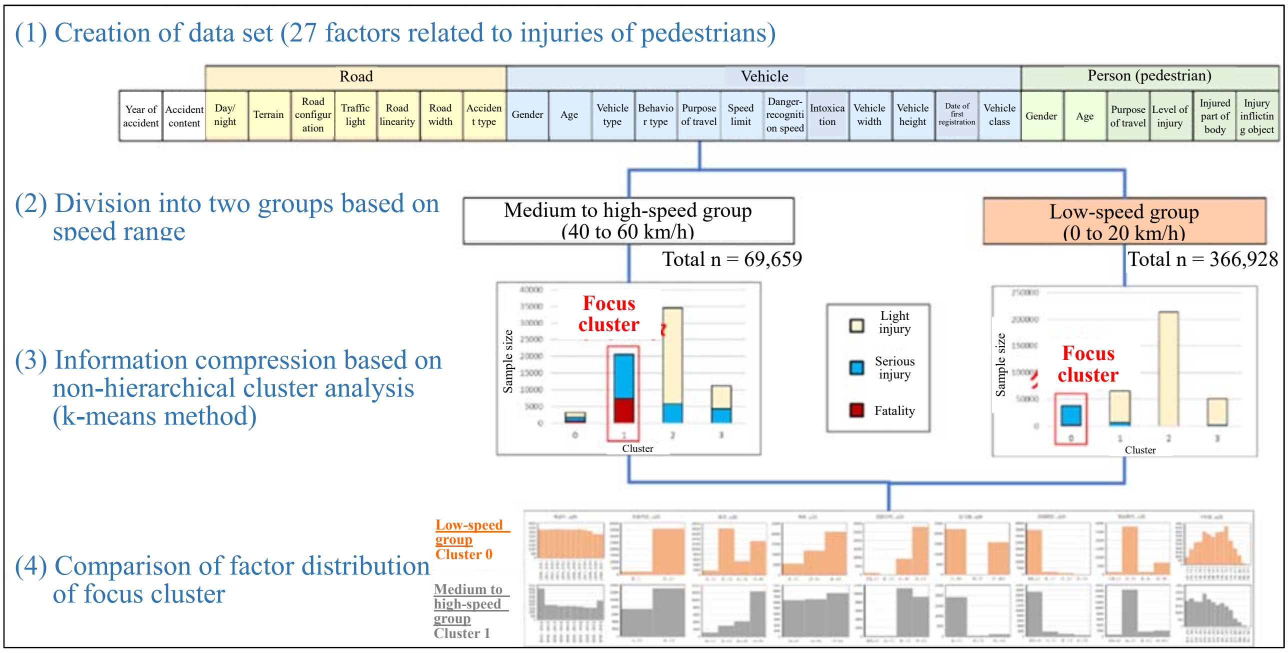


Figure 10. Procedure for analysis of factors that lead to fatalities & serious injuries in low-speed range

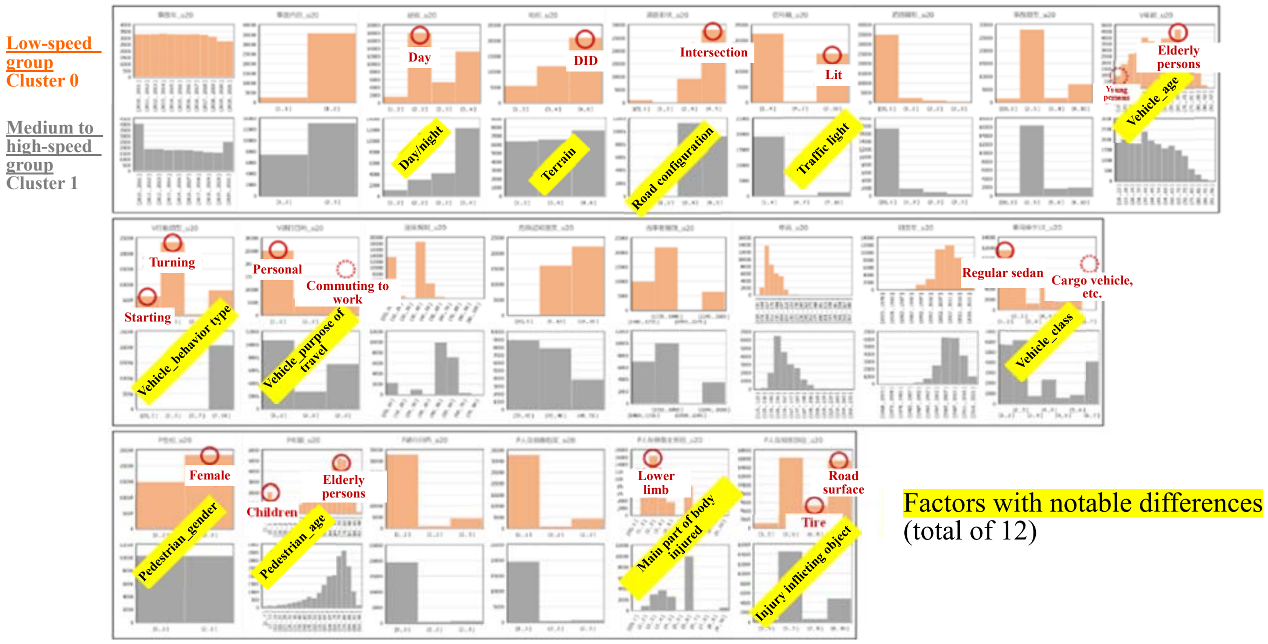


Figure 11. Frequency distribution comparison of all factors & levels in focus cluster

• Road: In the low-speed group, daytime, DID, intersection, and lit traffic light present were common.

• Vehicle/driver: In the low-speed group, regular sedan, starting turning, personal, and elderly driver were common.

• Person (pedestrian): In the low-speed group, lower-limb injury, injury inflicted by tire/road, and children/elderly person were common.

Within the focus clusters (fatality & serious-injury clusters), the factors & levels common for the low-speed group are shown in Chart 3. "Road" and "vehicle" include numerous factors that had also been confirmed in the RCT, and these seem to exclusively be the factors that are related with the reduction in speed. Thus, examination with two different approaches has shown consistent results.

Chart 3. Factors & levels more common in low-speed group

• Slowing factors: factors (levels) that "reduce speed" also confirmed with RCT

• Injury-related factors: factors (levels) related with "injury intensification at low speeds"

Road	Day, urban, intersection, traffic light	
Vehicle	Regular sedan, starting/turning, personal, elderly driver	
Person (pedestrian)	Age	Children, elderly woman
	Main part of body injured	Lower limb
	Injury inflicting object	Tire, road surface

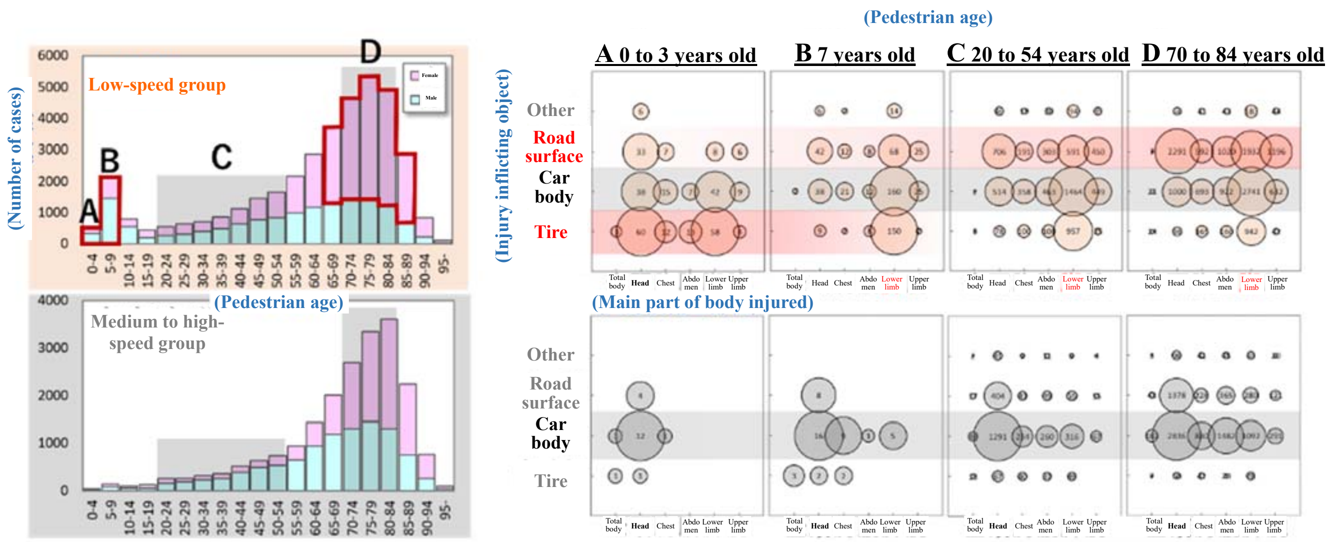


Figure 12. Differences regarding injury-related factors according to speed group

Meanwhile, since it seems that factors related with "person (pedestrian)" are related with injury intensification in the low-speed range, we analyzed differences among these according to the speed group (Figure 12). The bar graphs on the left show the frequency distribution of each age group and gender, and the bubble charts on the right show the frequency of occurrence of each "main part of body injured" and "injury inflicting object" with a drawing of four cross-sections that are in accordance with the age group of the pedestrian (A: infant to 3 years old, B: 7 years old, C: 20 to 54 years old, and D: 70 to 84 years old).

First of all, looking at the medium to high-speed group, in the frequency distribution, there is no uneven portion regarding children or bias toward women, and in the bubble chart, regardless of age group, the most common cases are those in which the injury is inflicted by a car body and the head is the main part of the body injured. Meanwhile, in the low-speed group, four characteristics can be recognized: (1) a high number of cases involving children (A & B), (2) a high ratio of women among elderly persons (D), (3) the injury inflicting object often being "road surface" and "tire" in addition to "car body" (particularly in A), and (4) an abundance of cases in which "lower limb" is the main part of the body injured.

Next, we inferred the mechanisms in the background behind these characteristics. With accident analysis alone, it is difficult to try to identify physical mechanisms, so we inferred these based on general knowledge in the field of crash safety related to the protection of pedestrians. Figure 13 shows the trend regarding degree of injury according to injury inflicting object and impact velocity. There is a trend in which the injury tends to be a mild one when the speed is lower, and in the low-speed range of 20 km/h or below, generally "mild injury" and "moderate injury" are common. Nevertheless, as for accidents under the same conditions in which there is a severe injury, it seems that there is an increase in the percentage of pedestrians who have a low level of physical tolerance. In particular, among elderly women, there are many cases in which tolerance is decreased due to osteoporosis, and this can be inferred to be the cause of (2). Furthermore, although the degree of injury significantly declines in the low-speed range when the cause is "car-body contact," there is not much change when the cause is "road-surface contact." Therefore, the injury-inflicting potential of "road surface" relatively increases in the low-speed range, and this seems to be the cause of (3).

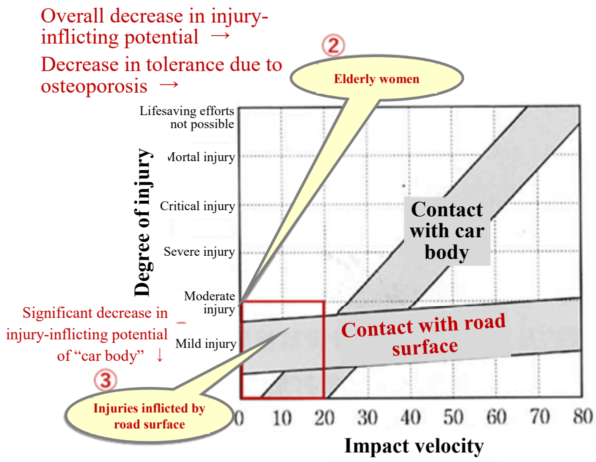


Figure 13. Trend regarding degree of injury and injury inflicting object & impact velocity (Reference 2)

Figure 14 shows the typical collision behavior regarding pedestrians (in a time series). When adult pedestrians are hit by a car with a bonnet, first of all, their legs are swept by the bumper, they fall over and hit their head on the bonnet side, and then their body rotates. Then, since the car then applies the brakes, they slide down and fall off the front of the car. At medium to high speeds, the pedestrians forcefully strike their head, their body somersaults from this position, and then they fall onto the road surface from mid-air. At medium to high speeds, the head is often the main part of the body injured due to the timing with which the car body and head come into contact. Nevertheless, at low speeds, the level of force is weak, so often the main part of body injured is determined by the timing with which the leg is first hit, and this seems to be the cause of (4). Furthermore, in the case of children, who are shorter in height, rather than a leg, the upper body comes into contact with the bumper, so they fall onto the road-surface side, which is the opposite from adults. Furthermore, since the speed is low, they are not thrown far, and it seems that they are more frequently run over by a tire. This seems to be the cause of (3) (infliction of injury to young child by tire).

Lastly, although this differs from mechanisms of injury intensification, we will touch upon the background of (1) (a high number of cases involving children [A & B]). Based on accident analysis carried out separately by ITARDA (Figure 15), A seems to be accidents involving a young child during vehicle starting. In particular, since children of age 3 and below have a height of around 90 cm, when they are standing in close proximity to vehicles with a high seating position, such as minivans, they are difficult to see from the driver's seat of such vehicles. Because of this, there are many accidents that occur close to home in which children are run over during vehicle starting. Since such accidents occur during starting, they are of course low-speed accidents. B is accidents involving first graders. When children begin school, they quickly become active in a much wider area, and this is what causes accident frequency to sharply increase for this age group alone. Such children often get into accidents when commuting to and from school, so it seems that they are prone to low-speed accidents along school-commuting routes.

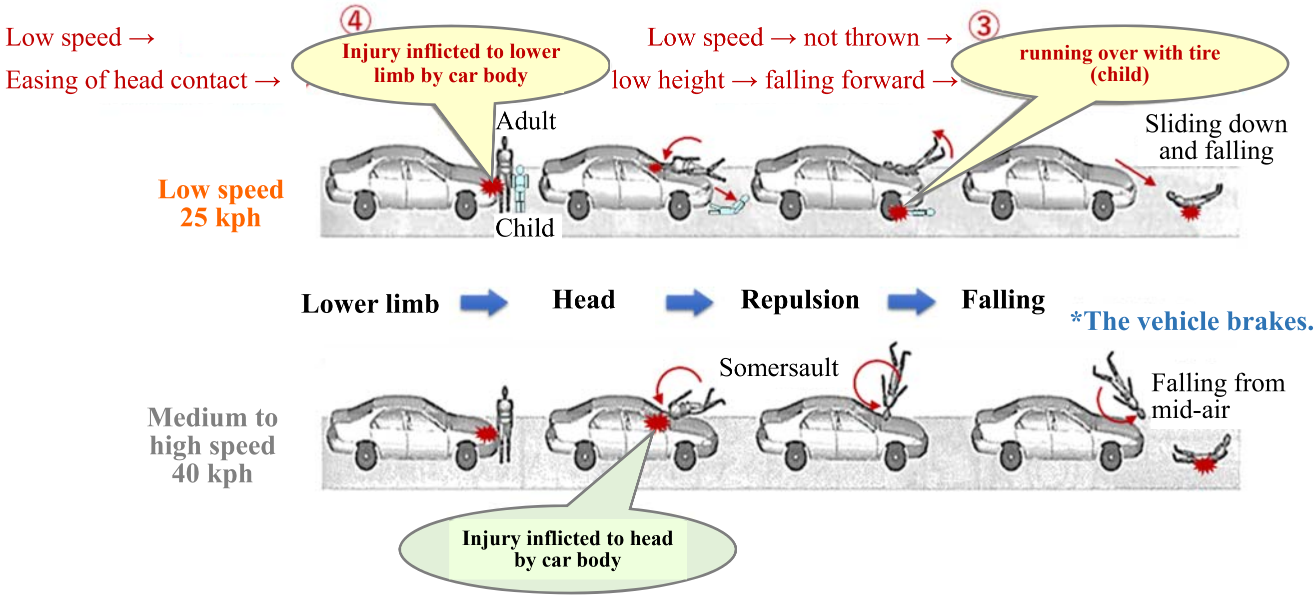


Figure 14. Differences regarding injury-related factors according to speed group (Reference 2)

A: Accidents involving young children during vehicle starting

[Causes]
- Low in height → difficult to see from driver's seat
- During starting → accidents are low-speed accidents

B: Accident involving first graders

[Causes]
- Becoming active in much wider area after starting school → sharp increase in accident frequency
- Commuting to and from school → large number of low-speed accidents along school-commuting routes

Figure 15. Low-speed accidents involving children (References 3, 4, 5)

4. Conclusion

In regard to pedestrian accidents in the low-speed range (danger-recognition speed of 20 km/h or below), we investigated (1) the causes of accidents not decreasing, and (2) mechanisms that lead to fatalities & serious injuries at low speeds. As a result, the following became clear.

(1) Since 1995, there has been an ongoing trend in which danger-recognition speeds have been decreasing among almost all accident types. As a result of this, the number in the medium to high-speed range has been flowing into the low-speed range. This seems to be why accidents have not been decreasing in the low-speed range (even though they have been decreasing overall). The main factors related to decreases in danger-recognition speed are (i) behavior type (less accidents for going straight ahead and more for turning), (ii) age (less accidents for 44 years old or below and more for 65 years old or above), and (iii) road configuration (less accidents for non-intersection and more for intersection/parking area). As for social changes in the background, although population aging can first of all be pointed to, taking into consideration changes regarding (i) and (iii), it seems that the urban concentration of the population may also be having an impact.

(2) In the low-speed range, injury factors become more diversified, and compared with the medium to high-speed range, there are increases in the percentages of: (a) low-tolerance pedestrians, (b) injuries being inflected by the road surface, (c) pedestrians being run over, and d) lower-limb injuries. Addressing (a) through (c) with conventional collision safety measures (structures for protecting pedestrians) would be difficult, so it seems that measures to prevent collisions from occurring are needed.

References

1) https://twitter.com/katalab_s/status/1412957154521214978

2) Koji Mizuno, *Jidosha no Shototsu Anzen Kiso-ron (Introduction to Crash Safety of Passenger Vehicles)*, The University of Nagoya Press, 2018, p. 207/220.

3) Institute for Traffic Accident Research and Data Analysis, "ITARDA Information No. 141," June 2022.

4) Institute for Traffic Accident Research and Data Analysis, "ITARDA Information No. 116," June 2016.

5) Institute for Traffic Accident Research and Data Analysis, "ITARDA Information No. 121," March 2017.

Appendix: Limitations, etc. of RCT method in this research

In the case of the method that we adopted on this occasion, even if there is a linkage relationship between the factors as shown in Figure A, the effects of the upstream factors (in red text) are nullified through adjustments to the composition ratios of the downstream factors. Accordingly, causal relationships can only be evaluated regarding the factors (in green text) that are directly connected with danger-recognition speed (objective variable). As for methods for evaluating the upstream factors with linkage relationships, although there seem to be approaches such as "changing the objective variable to each of the downstream factors, and repeating the RCT with a brute-force approach," if the number of factors is large, realistically implementing this is difficult.

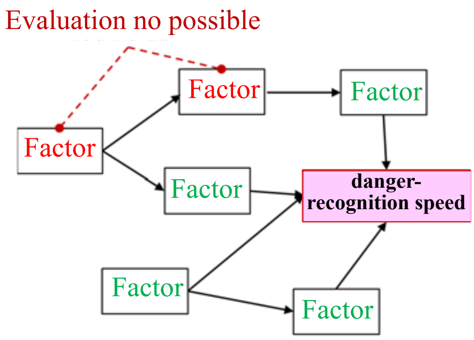


Figure A. Scope of evaluation of factors

Furthermore, in this research, the amounts of contribution of the various factors to danger-recognition speed, which are shown in Figure 9, are calculated by multiplying (1) the sensitivity of the factors/levels (independent) by (2) the change in the composition ratio of the factors/levels (Figure B).

The former is the danger-recognition speed when the composition ratio of the focus factors/levels is 100%, and that of the other factors/levels is equivalent with the population. Thus, the sensitivity has been calculated under the condition that there are no effects from the other factors, such as confounding and interactions, and nonlinear response characteristics have not been taken into consideration. On this occasion, although there was a 13% error between the actual measurement value of the amount of change in danger-recognition speed (accident data), and the calculated value (∑ sensitivity of each level × change in composition ratio), it is possible that this is the effect of nonlinear characteristics. The latter is the actual measurement value from accident data, and as a result, all of the various interactions between the factors are included.

As for the the sensitivity of the factors/levels in a broader sense, although it seems that there must be inclusion of (2), in other words, the effect of the change in the composition ratio of the relevant factors/levels on the change in the composition ratio of the other factors, this would require the implementation of RCTs regarding the composition ratios of all the factors/levels, so this was skipped on this occasion.

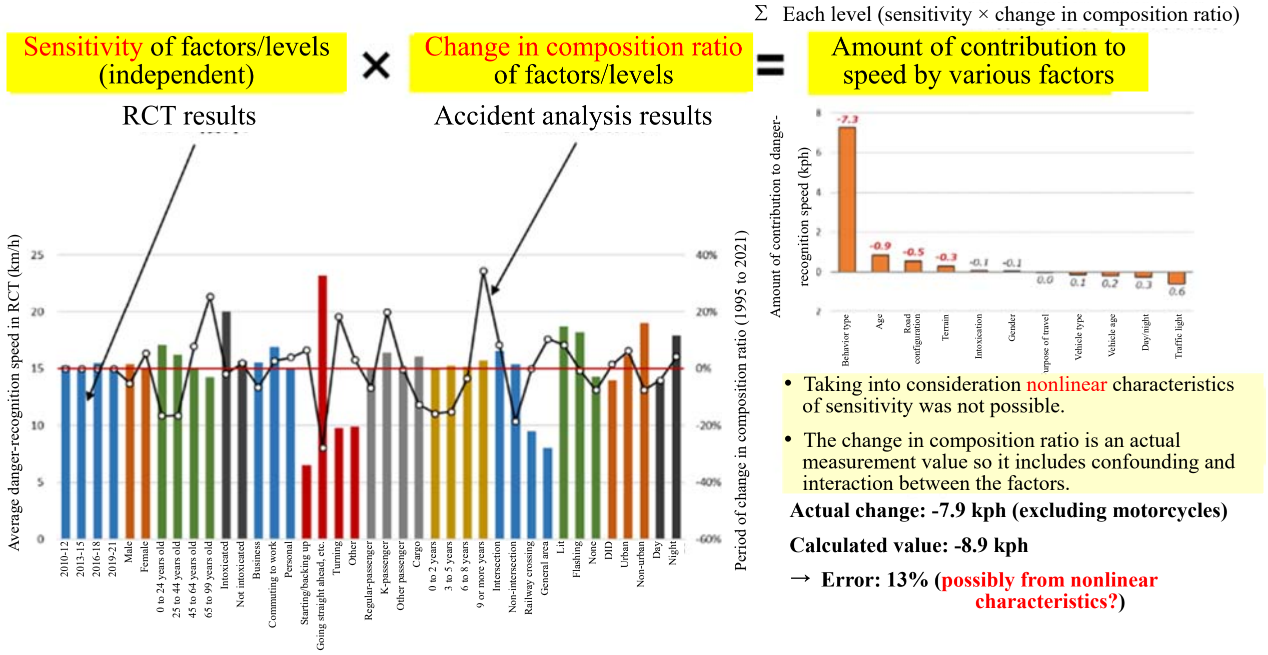


Figure B. Process of calculating amount of contribution of various factors to danger-recognition speed