The Influence of Traffic Environment on Collision Risk Assessment Based on Right-Turn Driving Behavior at Intersections

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**ABSTRACT:** In this study, the influence of traffic environment on collision risk assessed by driving behavior indices of right turns at intersections were investigated. A driving simulator (DS) experiment and a risk simulation using the data obtained in the DS experiment were performed to investigate the influence. As a result of the investigation, the influence of the traffic environment on the relationship between the driving behavior indices and collision risk was clarified. Moreover, factors related to the influence, and a solution to consider the influence in risk assessment methods were discussed.

**KEY WORDS:** human engineering, driver behavior, driving simulator / Risk Assessment, Right Turns, Traffic Environment [C2]

1. Introduction

In Japan, among the fatal accidents that occurred in 2019, “walking” accounted for the largest proportion of the state of fatalities [1]. Hence, it is necessary to prevent vehicle-pedestrian accidents to reduce the total number of traffic fatalities. Right turn at an intersection in left-hand traffic (left turn in right-hand traffic) is one of the typical accident scenarios of vehicle-pedestrian accidents. It is reported that drivers make more safety check errors [2] and the mental workload is higher [3] during right turns at intersections compared to other driving scenarios. Therefore, the difficulty of this right turn scenario is high and drivers driving this scenario needs support to prevent such accidents from occurring.

Warning and automatic emergency braking systems have been developed [4-7] as a means to prevent vehicle-pedestrian accidents, including right turn accidents at intersections. These systems can be classified as “safety barriers” as shown in Fig. 1 which prevent accidents by avoiding the consequence after some kind of sudden events or unsafe driving behavior. However, these systems based on sensors onboard will be ineffective if the pedestrians are somehow obstructed from view, such as cases where vehicles are turning [8]. If the collision risk against pedestrians can be evaluated in advance without the detection of pedestrians, “control barriers” can support the driver not to fall into an unsafe state, which may collide with crossing pedestrians, and prevent accidents from happening. This kind of assistance can be realized by detecting driver behavior with high collision risk, assisting the driver appropriately to change their driving behavior to low collision-risk driving, and preventing the driver from falling into an unsafe state. The system must be able to assess future collision risk from the current driving behavior to realize such assistance.

In our previous study, two driving behavior indices, which can assess the risk of collision against crossing pedestrians during right turns at intersections, were proposed for the driver assistance mentioned previously [9]. Collision risk against pedestrians in various traffic environments need to be assessable to realize driver support in public road environment using the proposed indices. However, the proposed indices have been verified only in a limited traffic environment. Previous studies are showing that road environments influence driver behavior [10, 11] and crash causation and severity at intersections [12-14]. Thus, there is a possibility that the collision risk assessed by the proposed indices may differ under different traffic environments. Specifically, a combination of driving behavior indices that is assessed as high risk in environment A may not be assessed as high risk in a different environment B. Thus, it is essential to understand the effect of the traffic environment on collision risk evaluated by the driving behavior indices to properly assess collision risk in each different environment. Therefore, the objective of this research is to clarify the influence of the traffic environment on the collision risk assessed with the proposed driving behavior indices. Among various traffic environment elements that may affect driver
behavior and collision risk, road environment elements are focused on in this research. It is assumed that road environment elements such as road width and the number of lanes can affect the relationship between driving behavior indices and collision risk because the differences in those elements would likely change the driver’s behavior as mentioned in previous studies and the positional relationship between the right-turning vehicle and crossing pedestrian that the vehicle may collide into.

Chapter 2 describes the definition of the driving behavior indices proposed in our previous study. Chapter 3 describes the methods, including an experiment and a simulation, to clarify the influence of traffic environments. Chapter 4 describes the results of the experiment and simulation, and chapter 5 discusses the results. Lastly, chapter 6 summarizes the findings of this study.

2. Driving Behavior Indices for Collision Risk Assessment of Right Turns at Intersections

The driving behavior indices proposed in our previous study are the curvature of the right-turn trajectory $\phi_{cl}$ and the speed at the centerline pass timing $V_{cl}$ [9]. Both indices are calculated based on the position, heading, and speed of the right-turning vehicle when it passes the centerline of an intersection, and a target destination point near the exit of an intersection, which is a point that the vehicle will reach shortly after passing the centerline to complete a right turn. $\phi_{cl}$ is expressed by equation (1) in a situation shown in Fig. 2, where $\theta_{des}$ denotes the angular deviation between the target destination point and the vehicle’s heading, $D_{des}$ denotes the distance between the target destination point and the vehicle’s center of gravity (CoG), and $FL_{hv}$ denotes the front vehicle length from the CoG of the vehicle. $\phi_{cl}$ indicates the distribution of visual attention and has a relation with the lapse time until a driver finds a pedestrian walking on a crosswalk. $V_{cl}$ indicates the adjustment of vehicle speed and has a relation with the margin time that a driver can find a crossing pedestrian before reaching the crosswalk. Results of a driving experiment showed that the collision risk against crossing pedestrians can be assessed with the combination of these two indices.

$$\phi_{cl} = \frac{\theta_{des}}{D_{des} \cdot FL_{hv}} \quad (1)$$

In our previous study, a right-turn scenario where there are no other traffic participants other than the right-turning vehicle and a crossing pedestrian at the crosswalk (a cruising right-turn scenario) was focused on. This scenario is one of the three typical scenarios of near-miss incidents involving a right-turning vehicle and a crossing pedestrian at an intersection with a traffic signal [15]. Hence, the same cruising right-turn scenario was focused on in this study.

3. Method

A driving simulator is an effective tool to obtain driving behavior data of different traffic environmental conditions because various conditions can be set inside the virtual world. Moreover, it is a valid tool to clarify collision risk of driving behavior and acquire driving data of risk scenes because it can reproduce risk scenes safely. However, it is difficult to acquire driving data of several different risk scenes from the same driver with the same attitude, because a driver will likely change their attitude and behavior after experiencing a risk scene. Although it is difficult to acquire driving data of various risk scenes repeatedly, previous studies have pointed out that there is a correlation between driving behavior of risk scenes and non-risk scenes [16, 17]. Thus, the collision risk is computed by numerically simulating the driver’s behavior when a crossing pedestrian exists during a right turn at an intersection using the driving data of non-risk scenes obtained in a simulator experiment.

To clarify the influence of traffic environment on collision risk assessed by the driving behavior indices, the followings are the procedure in this study. First, traffic environmental elements were selected. Next, right-turn behavior data of different traffic environment conditions were obtained using a driving simulator (DS). After the experiment, collision risk against pedestrians during a right turn was quantified by simulating the behavior of the driver using the driving and behavior data acquired in the DS experiment. Finally, the relationship between driving behavior indices and collision risk of different environmental conditions was compared. Driving behavior indices are calculated based on the data measured in the DS experiment and collision risk is computed based on the numerical simulation using the driving data acquired in the DS experiment. The traffic environmental elements selected, the details of the DS experiment and collision risk simulation, and the evaluation method are described in the following sections.

3.1. Traffic Environmental Elements

When the collision risk indicated by the driving behavior indices is affected by environmental elements, it is necessary to consider the difference due to the elements in the assessment of collision risk. To enable this with a real support system, the system needs to know about the intersection and surroundings where a driver is making a right turn. In terms of cruising right turn, with no other traffic participants around the intersection, the road geometry of the intersection is the most important information that needs to be identified. A digital map database, which is already used in car navigation systems, contains information about various road environmental elements such as road width, number of lanes, etc. Our previous research showed that the entrance road width, exit road width, and crossing angle of an intersection have significant influences on the driving
behavior indices as a result of analyzing data of a naturalistic driving study (NDS) [18]. Therefore, to apply the driving behavior indices to a support system for cruising right turns in the future, the width of the entrance and exit roads of a right-turning intersection, and the crossing angle of an intersection were selected as road environmental elements to evaluate. Figure 3 shows the definition of these elements.

3.2. Driving Simulator Experiment

In this experiment, a 4-screen DS with a field-of-view of 180 degrees (Fig. 4) was used. Using this DS, participants performed 36 right turns in total where no other traffic participants existed at an intersection with a traffic signal after sufficient practice of the DS. Oncoming vehicles and pedestrians randomly appeared within a range of up to 30 m before the intersection to prevent participants from becoming accustomed to a traffic environment in which no other traffic participants exist. Seven intersection conditions (I1-I7) were set with different properties of the selected environmental elements as shown in Table 1, and each participant drove 5 times for each condition and a risk scene in I1 at the last. The participants were ordered to drive as they usually do. Vehicle behavior and driver operation, videos of the vehicle’s surroundings and the driver were recorded during the simulator drive. Moreover, the driver’s gaze behavior and head motion were recorded using the Tobii Pro Glasses 2 (Tobii AB) to simulate the participants’ behavior during a right turn in the risk simulation. The participants were 38 healthy adults with a valid driver’s license (M age 26.7 years, SD 7.4 years, 27 male and 11 female). Drivers 65 years old and over were not recruited in this experiment to exclude the effect of the decline in physical and cognitive functions due to aging. The participants were thoroughly explained about the nature of the experiment beforehand and informed consent was obtained. This experiment was conducted under the approval of the ethics committee of the University of Tokyo.

3.3. Collision Risk Simulation using Driving Simulator Data

Our previous study [19] analyzing near-miss incidents against crossing pedestrians during a right turn at an intersection found that the drivers involved in the incidents tend to have a delay in finding and avoiding the pedestrians even though the pedestrians were not obstructed from view and visible from the vehicle cockpit. Concentrating toward the future traveling direction, distracted driving, and an environment where pedestrians are difficult to find are factors that may have contributed to this delay. This delay in the driver’s behavior is assumed to be the cause of the near-miss incident, and it will lead to collisions with the pedestrians as well. Hence, the risk simulation is conducted in a scenario where a driver is making a right turn and a pedestrian is crossing the crosswalk at the same time under the initial condition that the driver is not aware of the pedestrian to calculate the collision risk due to the delay in detection and avoidance of pedestrians observed in the near-miss incidents.

Collision risk against a crossing pedestrian of a right turn made at an intersection was simulated inside a virtual world of the DS by simulating the timing that the driver finds a virtual crossing pedestrian and starts pressing the brake pedal to avoid a collision numerically. In this simulation, the collision risk was calculated against a pedestrian that traveled straight at a constant speed (6 km/h) and will collide with the vehicle at the center of a crosswalk unless the driver finds the pedestrian and take an action to avoid the pedestrian. The pedestrian starts crossing the crosswalk from the front side of the vehicle as shown in Fig.5. This type of pedestrian was focused on in this simulation because near-miss incidents against pedestrians coming from the front-side were more frequent than those against pedestrians coming from the rear-side during daytime in the dataset of our previous study [19]. Moreover, other previous studies showed similar tendency [20, 21]. The behavior of the driver is simulated under
the condition that the driver was not aware of the pedestrian until he/she started to make a right turn, and the driver was able to find the pedestrian after the commencement of a right turn (when the vehicle entered the opposite lane).

Moreover, the initial position of the pedestrian was determined according to the right-turn commencement timing of each right turn. The virtual collision point, which the right-turning vehicle and the virtual pedestrian collides, was determined as the intersection point of the crosswalk center and the right-turn trajectory of the vehicle (Fig. 5).

The useful field of view is known to be approximately 4 to 20 degrees, and the peripheral vision is approximately 180 to 210 degrees [22]. The pedestrian will be findable not only in the useful field of view but in the peripheral vision as well. However, the size of the visual field changes due to various factors and it is difficult to imitate the behavior of a driver with a single constant size. Therefore, conditions of the size of the visual field were set in the range of 20 to 180 degrees with a 1-degree interval, and the average of the collision risk computed for each condition of the visual field was considered as the collision risk. The virtual crossing pedestrian was judged as found when the pedestrian was inside the set range of the visual field, the distance between the pedestrian and driver was under 50 m, and the pedestrian was not inside the blind spot made by the vehicle’s A-pillar where the pedestrian is not visible. The recorded data of the vehicle position, vehicle heading, driver’s gaze behavior, and head motion were used to simulate the timing that the driver finds the virtual pedestrian.

The timing when the driver starts to press a brake pedal was set as a timing which is a certain reaction time after the driver finds the crossing pedestrian. In this simulation, the median brake reaction time of 0.63 s was adopted from a previous study that measured the brake reaction time distribution when a pedestrian suddenly appeared from a blind spot of an intersection with a real vehicle [23]. The vehicle was simulated that it will travel according to the original trajectory after the driver finds the pedestrian. The time-to-collision at brake start timing ($TTC_{\text{brake}}$) was adopted as a reference measure of collision risk against crossing pedestrians. $TTC_{\text{brake}}$ is defined as equation (2) where $V_{\text{brake}}$ is the vehicle speed at brake start timing and $D_{\text{brake}}$ is the distance left to the virtual collision point on the crosswalk. In this study, $TTC_{\text{brake}}$ shorter than 2.0 s was assumed as relatively high risk because right turns with $TTC_{\text{brake}}$ shorter than 2.0 s had sudden and large deceleration brakes to avoid collision with a crossing pedestrian in our previous study [9].

$$TTC_{\text{brake}} = \frac{D_{\text{brake}}}{V_{\text{brake}}}$$

(2)

4.4. Evaluation of the Influence of Environmental Elements

If the environmental elements influence the relationship between collision risk and the driving behavior indices, the distribution of driving behavior indices of high-risk driving data is assumed to be different among the intersection conditions. Therefore, the difference in the distribution of $\phi_{cl}$ and $V_{cl}$ among different intersection conditions of high-risk driving data was investigated to evaluate the influence of traffic environmental elements on collision risk. The differences in the distribution of driving behavior indices among different intersection conditions were investigated in two ways: one is by comparing the scatter plots of the driving behavior indices visually and the other is by performing statistical tests to examine the significance of the difference. One method for evaluating the influence of traffic environment on the relationship between driving behavior indices and collision risk is to compare the boundary between high-risk and low-risk driving of each intersection condition. However, since the way to define the boundary is indefinite, this study used the aforementioned method for evaluation.

4.1. Driving Simulator Experiment

One participant was not able to finish the experiment due to simulator sickness and two participants were not able to successfully finish the calibration process of the eye tracker. The driving data of one participant was not recorded due to the malfunction of the data recorder. Therefore, the data acquired for the remaining 34 participants were used as simulation data and analyzed.

The Kruskal-Wallis test and a post hoc test based on the Bonferroni method were performed to examine the significant difference of the driving behavior indices between different intersection conditions as shown in Table 1. Figure 6(a) shows the comparison of $\phi_{cl}$ and Fig. 6(b) shows the comparison of $V_{cl}$ among different intersection conditions. As for $\phi_{cl}$, there was a significant main effect of all three environmental elements ($p < 0.01$). Moreover, besides the difference between I1 and I2, there was a significant difference between the conditions. $\phi_{cl}$ tends to be smaller when the road width was wider and the crossing angle was larger and obtuse. In terms of $V_{cl}$, there was also a significant main effect among all environmental elements ($p < 0.01$). $V_{cl}$ tends to be higher when the entrance and exit road width were wider and the crossing angle was larger and obtuse. This result was in line with the results obtained in the study analyzing right turns at intersections of an NDS [18]. This indicates that driving behavior during right turns in the simulator environment was similar to that in the real world. Hence, the validity of the right-turn driving data obtained in the simulator environment of this study was verified.

4.2. Collision Risk Simulation using Driving Simulator Data

$TTC_{\text{brake}}$ of all right turns was computed based on the simulation method described in section 3.3. Figure 7 shows the
frequency of high-risk driving data whose $TTC_{\text{brake}}$ is shorter than 2.0 s for each intersection condition. The result shows that the frequency of high-risk right turns was small below 20 at intersections with small (I6) and large (I7) crossing angles. As for I6, as shown in Fig. 6, $V_{cl}$ was much slower than other conditions and this is assumed to be the reason for the small frequency of high-risk right turns by making the $TTC_{\text{brake}}$ longer. In terms of I7 and other conditions, high-risk right turn frequency and $D_{\text{diss}}$, a parameter used in $\phi_{cl}$ calculation described in Fig. 2, showed a strong negative correlation. The distance to the crosswalk at which the driver starts a right turn tended to be different in different intersection conditions, which is assumed to have affected $TTC_{\text{brake}}$ and the frequency of high-risk right turns.

4.3. Evaluation of the Influence of Environmental Elements

First, scatter plots of the driving behavior indices of high-risk data between different intersection conditions were compared. Each figure in Fig. 8 is comparing the relationship of $\phi_{cl}$ and $V_{cl}$ between different entrance road widths (Fig. 8(a)), exit road widths (Fig. 8(b)), and crossing angles (Fig. 8(c)). When the widths of the entrance and exit roads are narrower and the...
Among the small crossing angle condition (I7), the entrance road width was narrower. In terms of the crossing angle, the high-risk driving was more acute when the road width was smaller and higher when the road width was larger and obtuse. This result shows that the distribution of the driving behavior indices of high-risk debris differs between the different conditions of the intersection environment.

Next, a significant difference in the driving behavior indices of high-risk driving data among different intersection conditions was examined by performing the Kruskal-Wallis test and a post hoc test. Test results of the driving behavior indices of high-risk driving data showed significant main effects of each environmental element on both indices (Fig. 9). When the entrance road width was wide (I3), $\phi_{cl}$ and $V_{cl}$ were significantly small and high respectively than the control condition (I1). However, there was no significant difference in the indices when the crossing angle was smaller and acute (I7) compared with I1. As for the exit road width, both indices were significantly different when the width was narrow (I2) compared with the control condition. $\phi_{cl}$ and $V_{cl}$ of high-risk data were smaller and higher when the road width was narrower. In terms of the crossing angle, $\phi_{cl}$ and $V_{cl}$ were small and high respectively when the angle was large and obtuse (I7), which are similar to the wide road width conditions. Among the small crossing angle condition (I6), although there was no significant difference of $V_{cl}$, $\phi_{cl}$ was significantly larger than that of I1.

Investigation of the scatter plots and examination with statistical tests showed that the combination of indices with high-crossing angle of the intersection is smaller and acute, high-risk driving tended to exist in areas where $\phi_{cl}$ was larger and $V_{cl}$ was lower. On the contrary, $\phi_{cl}$ and $V_{cl}$ of high-risk driving are smaller and higher respectively when the road widths are wider and the crossing angle is larger and obtuse. This result shows that the distribution of the driving behavior indices of high-risk debris differs between the different conditions of the intersection environment.

Fig. 9 Comparison of driving behavior indices of high-risk driving between different intersection conditions.

Discussion

From the results based on simulation and right-turn driving data at intersections with different environmental elements obtained using a driving simulator, driving behavior indices of high-risk driving data were significantly different among different intersection conditions, and environmental elements influenced the relationship between collision risk and the driving behavior indices. Specifically, there were significant differences of $\phi_{cl}$ and $V_{cl}$ among different intersection conditions and high-risk driving existed in smaller $\phi_{cl}$ and higher $V_{cl}$ areas when the road widths of the intersection was wider or the crossing angle was larger. To further investigate the reason for this influence on the relationship is different among intersections with different environment properties. This indicates that environmental elements influence the relationship between collision risk and driving behavior indices. There were few cases where the environmental element did not have a significant influence on the relationship. This may be due to the setting of the condition. For example, the road width difference between I1 (7.0 m) and I2 (5.5 m) is smaller than the difference between I1 and I3 (14 m). Significant differences were observed for almost all intersection conditions. Therefore, it is suggested that collision risk assessment using the driving behavior indices needs to consider the difference of entrance road width, exit road width, and crossing angle.

5. Discussion
between the driving behavior indices and collision risk, the difference in the relationship between the driving behavior indices and factors related to collision risk was examined. $T_{\text{lappe}}$ is the lapse time until the driver finds a crossing pedestrian after it appeared, and $T_{\text{margin}}$ is the margin time that the driver can search for the pedestrian, which can be defined as the time duration from commencement of a right turn to arrival at the crosswalk in our simulation. In our previous study [9], $T_{\text{lappe}}$ and $T_{\text{margin}}$ showed a significant correlation with $\phi_{cl}$ and $V_{cl}$ respectively in an experiment using a real vehicle. Collision risk is assumed to be related to the remaining time to reach the crosswalk after the driver finds the pedestrian, which can be roughly expressed as the substitution of $T_{\text{lappe}}$ from $T_{\text{margin}}$.

The relationship between $\psi_{cl}$ and $T_{\text{lappe}}$, and $V_{cl}$ and $T_{\text{margin}}$ were examined respectively among different intersection conditions. Figure 10 shows a sample result of comparing the relationships between intersection conditions I1 and I3, which is a combination of conditions showing significant differences in both $\phi_{cl}$ and $V_{cl}$ among high-risk driving. As shown in Fig. 8(a), high-risk right turns of I3 existed more in the area where $\phi_{cl}$ is small and $V_{cl}$ is high compared to I1. Figure 10(a) shows the relationship between $V_{cl}$ and $T_{\text{margin}}$. Although there was no significant difference in $V_{cl}$, there was a significant difference in $T_{\text{margin}}$. $T_{\text{margin}}$ of I3 was significantly longer than that of I1 ($p < 0.01$). As the figure shows, $T_{\text{margin}}$ of I3 was longer than that of I1 overall at any $V_{cl}$. The entrance road width of I3 is wider than that of I1, indicating that the length of the right-turn trajectory at intersection I3 is longer as well. When the vehicle speed is similar and the length of the right-turn trajectory is longer, it will take a longer time to make a right turn. Thus, this difference in trajectory length is assumed to explain the difference in the relationship between $V_{cl}$ and $T_{\text{margin}}$ of I1 and I3. Figure 10(b) shows the relationship between $\psi_{cl}$ and $T_{\text{lappe}}$. There were significant differences for both indices ($p < 0.01$). $\psi_{cl}$ and $T_{\text{lappe}}$ of I3 were smaller and longer than those of I1. The area where $T_{\text{lappe}}$ is long, in other words, the area where it took a long time to find the pedestrian was different for the two conditions. For I3, $T_{\text{lappe}}$ was long in a smaller $\psi_{cl}$ area compared to I1. In summary, the $T_{\text{margin}}$ of I3 was longer than I1 overall, and the $T_{\text{lappe}}$ of I3 was longer in the small $\psi_{cl}$ area around 0.04 rad/m. Focusing on the small $\psi_{cl}$ area, the time difference between I3 and I1 of $T_{\text{lappe}}$ was larger than that of $T_{\text{margin}}$. This indicates that the remaining time to a collision of I3, which can be expressed as $T_{\text{margin}} - T_{\text{lappe}}$, is shorter than I1 in the small $\psi_{cl}$ area. It is considered that such a difference appeared in the difference of the relationship between $\psi_{cl}$ and $V_{cl}$ of high collision risk, and this result can explain why high-risk driving existed in small $\psi_{cl}$ and high $V_{cl}$ areas with wide road widths. Similar results were obtained from the examination of other intersection conditions. When the road width is narrow, high-risk driving existed in an area where $\psi_{cl}$ is large and $V_{cl}$ is low because $T_{\text{margin}}$ is shorter overall and $T_{\text{lappe}}$ is long in the area where $\psi_{cl}$ is relatively large. For cases with different crossing angles, it showed a similar trend with cases with different road widths. The tendency of small and acute crossing angles is consistent with the tendency of narrow road width. Therefore, it is suggested that the difference in the relationship between collision risk and the driving behavior indices among different intersection conditions are due to the difference in the relationships between the driving behavior indices and collision-risk related factors (e.g., the margin time for a driver to search a crossing pedestrian and the lapse time until the driver finds the crossing pedestrian). Moreover, considering the difference in these risk-related factors among different environmental conditions is a solution to take the influence of traffic environment on collision risk into consideration when evaluating collision risk based on driving behavior.

As shown in Fig. 10(b), $T_{\text{lappe}}$ was long at different $\psi_{cl}$ areas among different intersection conditions I1 and I3. This suggests that there is a certain area of $\psi_{cl}$ that makes it difficult for drivers to find a crossing pedestrian during a right turn depending on the intersection condition. As previous studies point out that A-pillars play an important role in the driver’s error overlooking pedestrians [24, 25], it can be considered that $T_{\text{lappe}}$ was long at a certain area of $\psi_{cl}$ because the pedestrian was occluded by the A-pillar during the right turn. From this, it is assumed that this area of $\psi_{cl}$ differed among the intersection conditions I1 and I3 because the position of the pedestrian’s walking path (e.g., crosswalk) with respect to the right-turn vehicle was different. It is expected that this area of $\psi_{cl}$ will also differ depending on the exit road width, crossing angle, and other road environmental elements that affect the positional relationship between the right-turn vehicle and crossing pedestrian. Thus, in addition to the road width and crossing angle focused in this study, it is suggested that road environmental elements that affect the positional relationship between the right-turn vehicle and crossing pedestrian may also affect the relationship between the driving behavior indices and collision risk. Moreover, the shape and position of an A-pillar, which affects the appearance of crossing pedestrians seen from the right-turn vehicle, may affect the relationship as well.

This study has the following limitations. The results obtained in this study are based on driving in a driving simulator, not in an actual vehicle. However, it was confirmed that the results of driving behavior indices among different intersection conditions are consistent with the results of NDS analysis in our previous study, suggesting that the results are reliable. Another limitation of this study is the limited property of the road environmental elements evaluated. Although there were significant differences in driving behavior indices among the limited properties, investigation of more diverse properties is necessary to generalize the findings in this study and apply them to the public road environment. The condition of the right-turn driving scenario was also limited in this study. In the experiment, participants made a right turn in an environment where no other traffic participant exists, thus, the findings of this research are limited to the scope of this elementary right-turn driving scenario. However, this simple scenario is considered to be the basis of other right-turn scenarios. Thus, the outcomes of this study may be applied to more complex scenarios. Although the participants in this study include middle-aged drivers, the participants were mainly composed of young drivers in their 20s. Hence, the relatively biased sample is another limitation of this study. However, it could be suggested from the data acquired in this study that the influence of traffic environments on the relationship between driving behavior and collision risk of middle-aged drivers is similar to that of young drivers.

6. Conclusion

To clarify the influence of road environment on collision risk against crossing pedestrians assessed with the driving behavior indices of right turns at intersections, a DS experiment and a risk simulation using the DS driving data were performed. Using the DS driving data and risk simulation results, the influence of environmental elements was examined by comparing the relationship between the driving behavior indices and collision risk among different intersection conditions with different properties of the elements. As a result of performing the above, the following results were obtained:

- Widths of entrance and exit roads of an intersection and crossing angle of an intersection had a significant influence on the relationship between collision risk and the driving
behavior indices. When the widths are narrow or the crossing angle is small and acute, high-risk driving exists in the area where the right-turn curvature is large and the speed is low.

- The difference in the relationships between the driving behavior indices and the risk-related factors among different environmental elements reflected the influence of traffic environment on collision risk. Consideration of this relationship is a solution to evaluate collision risk based on right-turn driving data among intersections with different environmental elements.

Investigation of the relationship between the driving behavior indices during right turns at intersections and the risk-related factors, examination of how the boundary between high-risk and low-risk driving is influenced by environmental elements, and development of a collision risk assessment method that can be applied to various environments are our future work. Furthermore, the development of a system that can evaluate collision risk on public roads using the assessment method is our future goal.

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