Experiments to Determine Roundabout Safety in Consideration of Driver Behavior

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Abstract: In conjunction with the recent active installation of roundabouts in Western countries, this study focused on the collection and analysis of data relating to driver behavior on roundabouts and ground intersections during non-snowy and snowy seasons. The aim was to examine how different road conditions affect driving decisions in order to support determination of the potential usefulness of roundabouts in Japan. The results highlighted the role of roundabouts as a form of junction that allows drivers to check safety more easily than with regular ground intersections.

Keywords: Roundabout, Driving Behavior, Safety Checking, Intersection Type

1. INTRODUCTION

In Japan, serious and fatal accidents resulting from head-on crashes and collisions between right-turning and oncoming vehicles frequently occur at road junctions. In suburban areas, vehicles often have to stop at red lights and wait for a green signal even if there is no crossing traffic. It is also difficult for signal intersections to properly function in the event of massive disasters like the Great East Japan Earthquake that occurred on March 11, 2011, in the Pacific Ocean off the Tohoku coast and large-scale blackouts such as the one that occurred in the Iburi region of Hokkaido on November 27, 2012. To combat such problems, Western countries have actively introduced roundabout improvement measures to prevent serious accidents, reduce traffic light waiting times and ensure ongoing function in the event of a disaster (Photo 1). For example, the severe injury crashes decreased at the intersection having improved roundabout has been reported in the United States.

Photo 1. A roundabout intersection outside Japan

As few roundabouts have been installed in Japan, studies using simulated experiments, verification based on the results of investigations conducted on test driving courses, and pilot programs using actual roads are currently under way. However, despite such efforts, roundabout awareness remains low nationwide – a situation that highlights how far such facilities are from being put into practical use in Japan. Conventional roundabouts are designed for use at intersections with good visibility and dry road surface conditions. However, findings from the evaluation of practical roundabout usage under adverse conditions have been insufficient, and there is a lack of knowledge on driver behavior for use in educating road users and providing information. For example, it must be clear that roundabouts installed in cold snowy regions should be designed for safety and smooth traffic flow in consideration of driving behavior on winter road surfaces with snow or poor visibility conditions, and that appropriate measures should be taken

Accordingly, data on driver behavior at a roundabout and actual intersections in summer (the non-snowy season) and winter (the snowy season) were obtained and analyzed in this study. The aim was to clarify how differences in road surface conditions affect driving behavior and to support the design of roundabout safety measures in consideration of such conduct, thereby helping to promote the use of roundabouts nationwide.

2. STUDY METHOD AND PROCEDURE

2.1 Experiment overview

In this study, subjects participated in driving experiments at six sites (five actual intersections in Hokkaido and an experimental roundabout at the Tomakomai Test Track) in winter (January – February 2012) and summer (August 2012). The winter experiments were conducted on snowy roads when the maximum temperature was below freezing, and the summer experiments were conducted on dry roads. Ten male subjects in the twenties-to-fifties age bracket participated in each experiment at each intersection in each season.

2.2 Test-track roundabout

To simulate a two-lane-road intersection in suburban Hokkaido, an experimental roundabout was designed using German guidelines for a small roundabout with a daily traffic volume of up to 10,000 – 25,000 vehicles. The roundabout had a 26-m outer diameter containing a circulatory roadway of 5 m in width, a central island of 8 m in diameter and an apron of 4 m in width (Photo 2).

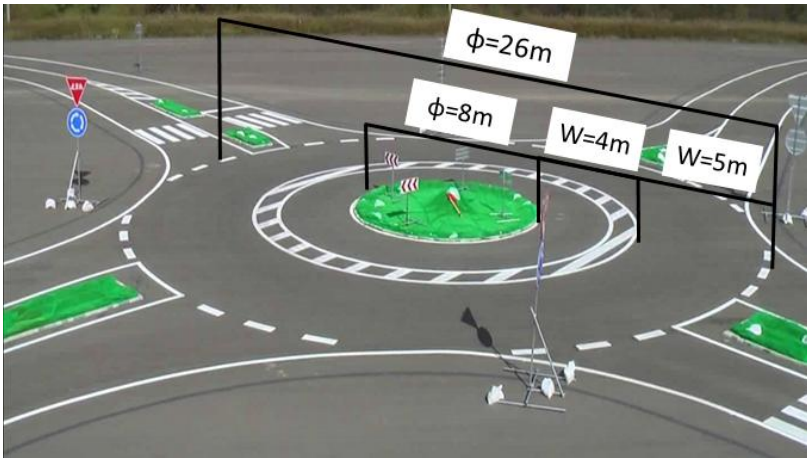

Photo 2. Simulated roundabout

2.3 Intersections on actual roads

A total of five intersections were used in the experiments: signalized and non-signalized four-way right-angle intersections in the Atsuma town of Yufutsu near the Tomakomai Test Track, a rotary intersection measuring 57 m in outer diameter (Photo 3), and signalized and non-signalized four-way right-angle intersections in the Sakura area of Otaru. The intersections in Atsuma were in a suburban area, and those in Otaru were in an urban area. Hourly traffic volumes for each intersection during the experiments in each season were as shown in Table 1.

Photo 3. Rotary intersection (Sakura, Otaru)

Table 1. Hourly traffic volume (total from all directions)

(Vehicles/h)

	Atsuma Signalized	Atsuma Non-signalized	Otaru Rotary	Otaru Signalized	Otaru Non-signalized
Summer	333	302	788	417	495
Winter	311	236	662	412	489

2.4 Driving conditions

Two vehicle flow patterns were set for the driving experiment on the test-track roundabout – one with test vehicles entering the roundabout from major street approaches, and the other with test vehicles entering from minor street approaches. Two dummy vehicles were used (one traveling in front of the test vehicles and one as an oncoming vehicle) in the pattern of flow from major street approaches, and were also used as vehicles entering from major street approaches (both directions) for the pattern of flow from minor street approaches.

As the traffic volume was very low at the non-signalized intersection in Atsuma, one dummy vehicle was used as a car traveling on the major road when test vehicles entered the intersection. This arrangement was introduced to avoid situations in which there was no general traffic at the intersection during the experiment. At the other four real intersections, experiments were performed in actual traffic conditions without the use of a dummy vehicle.

2.5 Data acquisition and analysis methods

In the experiments, each test vehicle was equipped with an accelerometer (DL1 manufactured by Race Technology), gyro sensors (Objet manufactured by ATR) and four video cameras recording the front-facing view, driver posture, steering, acceleration and braking for display on a four-way split screen (Photo 4). Using these images, analysis was performed to determine how the driver steered, accelerated and braked when the vehicle entered the intersection and moved through it.

Gyro sensors were affixed to the test vehicle, the driver’s cap and the driver’s right leg to record head and right-leg movement (three-directional acceleration) so that the speed of bodily motion could be analyzed. Data on vehicle speed and transverse acceleration were also collected from the accelerator and analyzed. After driving at each intersection, each subject was asked to evaluate on a scale of one to seven how easy it had been to check safety.

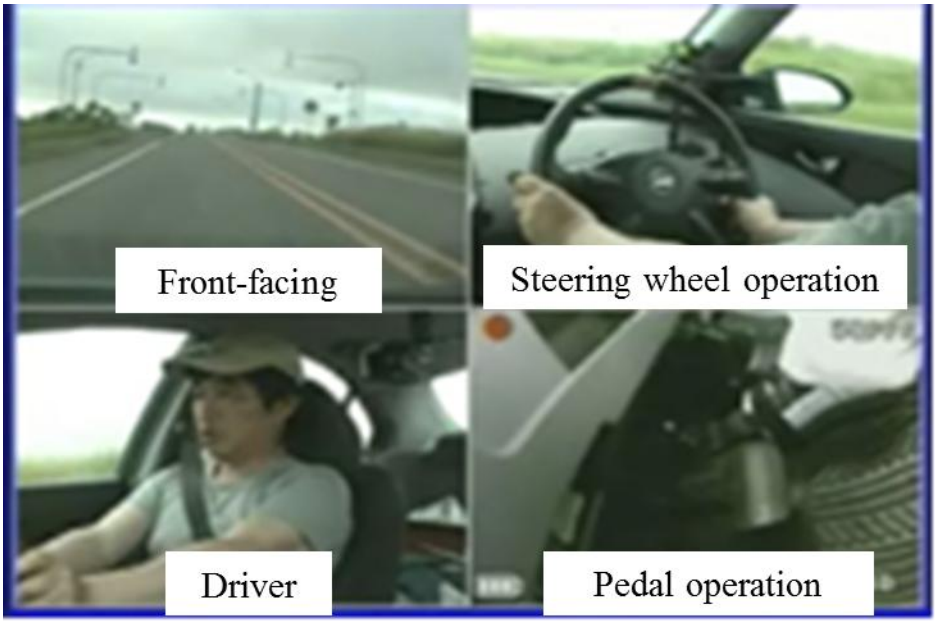

Photo 4. Four-way split-screen video display

3. STUDY RESULTS

3.1 Safety checking

To clarify differences in the subjects' safety-checking behavior at intersections, focus was placed on gyro sensor data showing the speed of head movement. This information indicated the speed of the head's lateral motion as seen when the driver checked safety upon entering, driving in and exiting the intersection.

Figure 1 shows the results of analysis for head movement as observed during right turns at each intersection. It can be seen that the 85th percentile for the speed of head movement at the roundabout was lower both in summer and in winter, and that variations among drivers were smaller than at other intersection types. This was presumably because drivers had to look only in one direction to check for vehicles when entering the roundabout, meaning that no rapid head motion was needed to check safety. Head movement tended to be faster in winter than in summer.

Moreover, the result of having performed the T-test about each crossing form between summer and winter is shown in table 2. As results, there are the differences at the roundabout. The reason is the practice of driver, because the roundabout is a minor intersection type overwhelmingly in Japan. And it can be judged that it is because there were fewer visual cues to support driver orientation in winter (the snowy season) than in summer (photo 5).

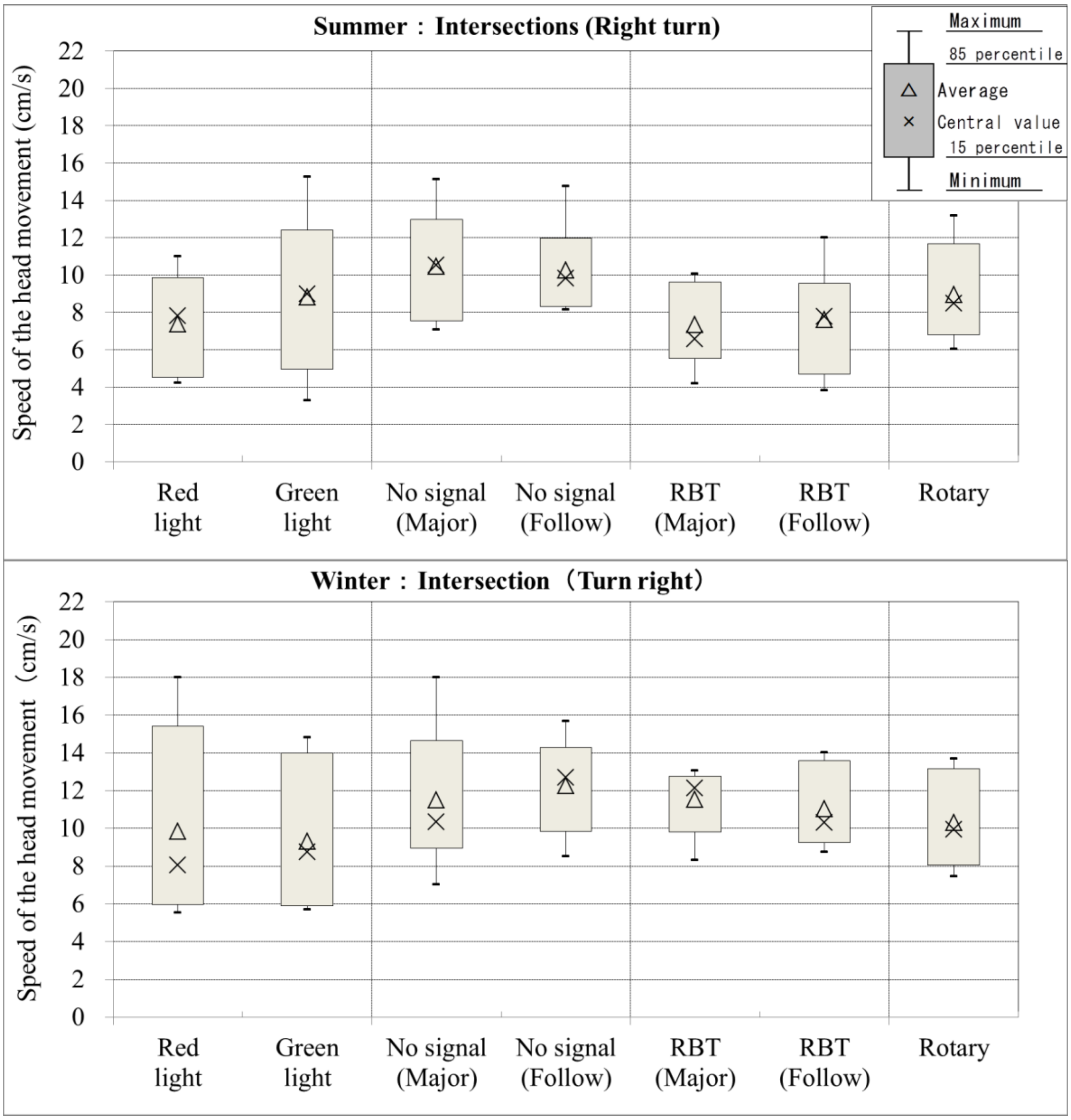

Figure 1. Speed of driver head movement (right turn)

Table 2. Comparison of a summer and winter (Figure 1)

	Red light	Green light	No signal (Major)	No signal (Follow)	RBT (Major)	RBT (Follow)	Rotary
t-value	1.170	0.322	0.768	2.048	4.768	3.287	1.302
P-value	0.260	0.751	0.452	0.055	0.000	0.004	0.209
Judgment					**	**	

Photo 5. Experiment situation at the roundabout

3.2 Steering, acceleration and braking

Table 3 shows the steering wheel rotation angle per meter as observed when the test vehicles turned right to enter and exit each intersection. As the drivers had to keep the steering wheel turned on the circulatory roadway, the figures for the roundabout were higher both in summer and in winter than those for other intersection types, and even higher than those for the rotary, which also had a circular intersection. This was presumably because the roundabout had a smaller inscribed circular diameter than the rotary, resulting in larger steering angles.

Table 3. Steering wheel rotation angle per meter of travel (right turn)

(°/m)

Intersection Form	Red light	Green light	No signal (Major)	No signal (Follow)	RBT (Major)	RBT (Follow)	Rotary
Summer	7.3	7.3	13.9	23.0	18.6	19.2	5.0
Winrer	9.3	8.4	20.9	19.3	23.3	22.7	3.9

Table 4 shows mean values for the frequency of foot movements between the accelerator pedal and the brake pedal as observed during right turns to enter each intersection and during travel through it. The summer figures for the roundabout are similar to those for other intersection types, while the winter figures are higher than those for signalized and non-signalized intersections. This was presumably because the drivers were more careful when entering the roundabout in winter.

Table 4. Frequency of foot movement between the accelerator and brake pedals (right turn)

(Frequency)

Intersection Form	Red light	Green light	No signal (Major)	No signal (Follow)	RBT (Major)	RBT (Follow)	Rotary
Summer	1.8	1.1	1.0	1.8	1.8	1.8	3.3
Winrer	1.6	2.1	1.6	1.8	4.1	5.0	4.8

3.3 Travel speed and transverse acceleration

Figure 2 shows the results of analysis for the speed of right-turning vehicles from entry to exit for each intersection. It can be seen that vehicle speed on the roundabout was lower than for other intersection types and that variations among the subjects were smaller. The speed of the vehicles on the roundabout in winter was 10 km/h or less.

Additionally, the result of having performed the multiple comparisons between roundabout and other intersection type in winter is shown in table 5. As results, the roundabout had the differences at the green light and the rotary. Moreover, since significant probability had become a value near 0.05 also about the red light, it turned out that vehicle speed at the roundabout becomes lower than these at the signalized intersections. About a difference with a rotary, it is able to estimate that the rotary tends to gather speed, because the difference of outer diameter.

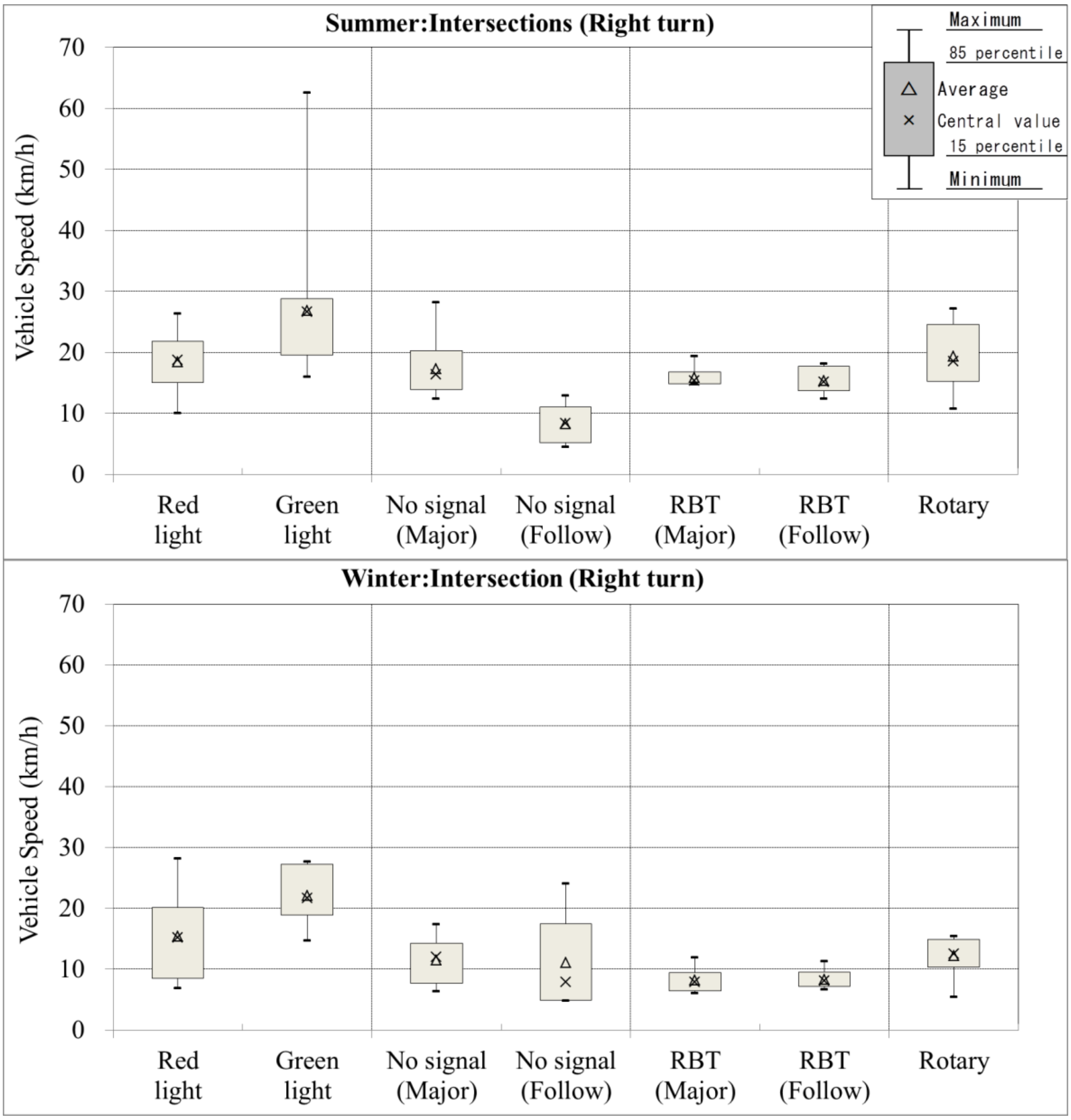

Figure 2. Average speed of vehicles traveling through intersections (right turn)

Table 5. The multiple comparison of a speed result (winter, right-turn)

Significance Probability

Type (VS.)	Green light	Red light	No signal (Major)	No signal (Follow)	Roundabout (Major)	Roundabout (Follow)	Rotary
Roundabout (Major)	0.000 *	0.060	0.345	0.998	-	1.000	0.054
Roundabout (Follow)	0.000 *	0.053	0.314	0.996	1.000	-	0.048 *

* There is a difference.

The results of analysis for the maximum transverse acceleration of the test vehicles turning right at each intersection show that the summer figures for the roundabout were similar to those for other intersection types, while those for winter were lower (Figure 3).

Additionally, like the above-mentioned, the result of having performed the multiple comparisons between roundabout and other intersection type in winter is shown in table 6. As results, there are non-differences except between no signal (major). Since this had vehicle speed at the roundabout lower than other intersection type, also in winter of bad road surface situation, it turned out that lateral acceleration (stability under run) is equal to the existing intersections.

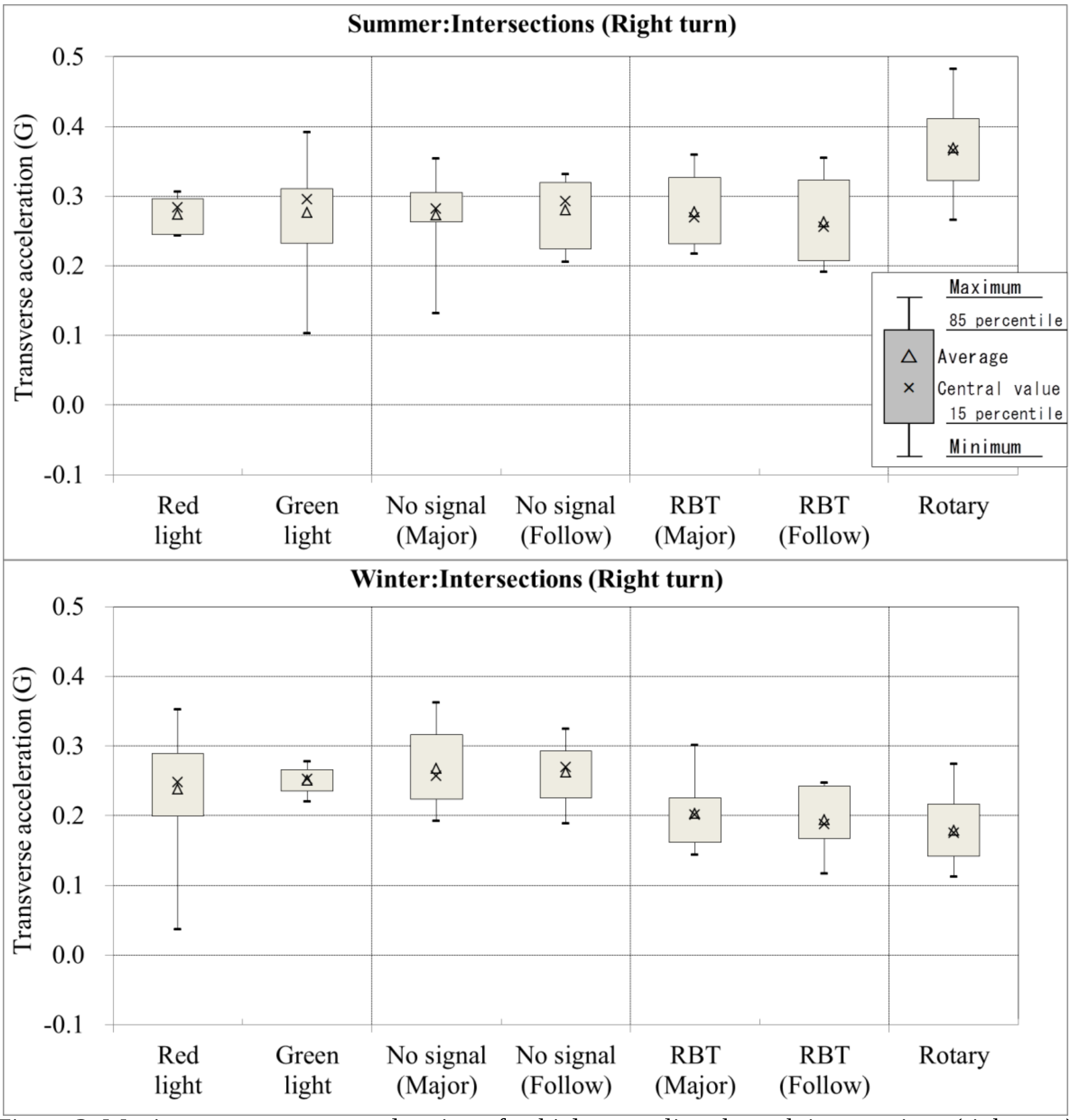

Figure 3. Maximum transverse acceleration of vehicles traveling through intersections (right turn)

Table 6. The multiple comparison of maximum transverse acceleration result (winter, right-turn)

Significance Probability

Type (VS.)	Green light	Red light	No signal (Major)	No signal (Follow)	Roundabout (Major)	Roundabout (Follow)	Rotary
Roundabout (Major)	0.455	1.000	0.039 *	0.082	-	1.000	1.000
Roundabout (Follow)	1.000	1.000	0.119	0.235	1.000	-	1.000

* There is a difference.

3.4 Questionnaire survey results

According to the results of a questionnaire answered by the subjects after driving through each intersection, it was easier to check safety on the roundabout than at non-signalized intersections and slightly easier than at signalized intersections both in summer and in winter (Figure 4).

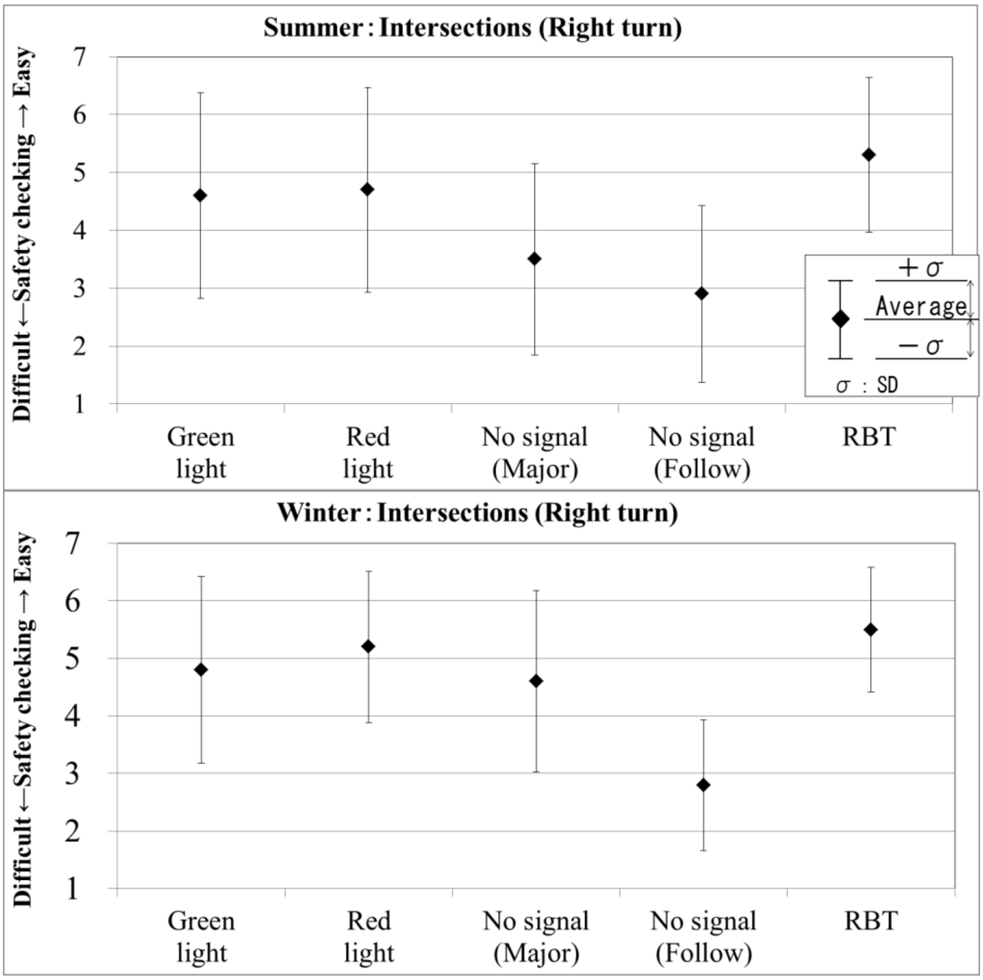

Figure 4. Ease of safety checking (right turn)

4. DISCUSSION AND CONCLUSIONS

The study results indicated that the roundabout supported driving without rapid head movement, unlike other intersection types. The questionnaire results also showed that the roundabout was rated highly for ease of safety checking. In addition, vehicle speed at the roundabout was lower and variations in vehicle speed among subjects were smaller than for other intersection types. It is therefore considered that serious accidents are less likely to occur on roundabouts, and accordingly that roundabouts are safer than other intersection types also in winter.

In the area of safety measures, comparison of winter and summer driving behavior on the roundabout revealed more rapid head movement as well as more frequent steering wheel operation and acceleration/braking in winter. This was presumably because roads were more slippery and there were fewer visual cues to support driver orientation in winter (the snowy season) than in summer (the non-snowy season). Accordingly, it is considered effective to take safety measures by installing snow poles and delineators on central islands and both sides of entrances to roundabouts to support driver orientation, and to implement winter maintenance in order to facilitate safety checking.

Based on this study, roundabouts were identified as an intersection type that facilitates safety checking for drivers, and can therefore be considered safer than four-way right-angled ground intersections.

In future work, the authors plan to quantitatively evaluate the effects of the safety measures introduced here. To support discussion of roundabout installation in cold snowy regions, further studies will be conducted based on driving experiments with conditions highly similar to those of actual roads in terms of traffic volume, pedestrian presence and other factors with focus on a variety of winter road surface conditions.

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