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Effects of in-vehicle warning information on drivers' decelerating and accelerating behaviors near an arch-shaped intersection

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ABSTRACT

This paper attempts to evaluate the effects of in-vehicle warning information on drivers' decelerating and accelerating behavior when approaching an intersection near an arch-shaped bridge, where traffic accidents have often occurred due to poor visibility. The warning information was provided with images and/or voice, triggered by the actual presence of a stopped vehicle at the downhill road section of the intersection. An on-site driving experiment was conducted on a national highway in Hiroshima City, Japan, by involving 14 university students, and it was demonstrated that dynamic information seems more effective for drivers to avoid dangerous driving situations than static information. It was also found that having only the voice-based warning information may be as effective as having both the voice and image warning information.

1. Introduction

According to the National Police Agency in Japan (NPA, 2007), the number of traffic fatalities decreased to 6352 in 2006; however, the total number of traffic accidents is still very high, exceeding 800,000, and the number of injured people has exceeded more than 1 million for seven straight years. The NPA (2007) also reported that the number of traffic fatalities in Japan is 1.1 persons per 100 million vehicle kilometers, which is higher than those in developed countries such as France (1.0), the USA (1.0), Germany (0.8), and the UK (0.6). Focusing on the intersections of urban areas, which are of interest in this study, even though the number of traffic fatalities at such intersections had been decreasing from 1997 through 2005, it became the highest among all types of roads in 2006 (see Fig. 1). It is further confirmed that the number of traffic fatalities of primary party due to 'distracted driving' and 'looking aside while driving' has decreased at a very slow pace in recent years. This is also true for the numbers due to 'failure to confirm safety factors (e.g., failure to stop before the sign "Stop!")' and 'improper steering/braking' (Fig. 2). To reduce the number of traffic accidents, it seems important to assist drivers by providing them with proper information.

In line with such considerations, the Ministry of Land, Infrastructure and Transport (MLIT) has been actively promoting the development and application of advanced technologies such as AHS (Advanced Cruise-Assist Highway Systems) (MLIT, 2007). One of the key AHS technologies is the in-vehicle warning information system, whose effects on traffic safety have not yet been examined well.

Under such circumstances, while focusing on an intersection where traffic accidents have often been observed, this paper attempts to evaluate the effects of the in-vehicle warning information system on driving behavior. The information is shown to the drivers in the central–lower part of the windshield using a head-up-display device. The intersection is located on a national highway in central area of Hiroshima City, Japan, and since it is close to an arched bridge, there is poor visibility, which has frequently caused rear-end collision. There are many such types of roads in Hiroshima City, which is located in a delta region with many river-crossing bridges.

In this study, the effects of the warning information are evaluated based on an on-site driving experiment from the perspective of drivers' braking and accelerating behavior. The experiment, which is the first one to examine the effects of the warning information focusing on national highways in Japan, was conducted using an AHS test-vehicle equipped with a GPS sensor, enabling us to automatically record location information every 0.1 s, including information such as driving speed, acceleration, and deceleration. By analyzing the above experimental results, this paper aims to pro-

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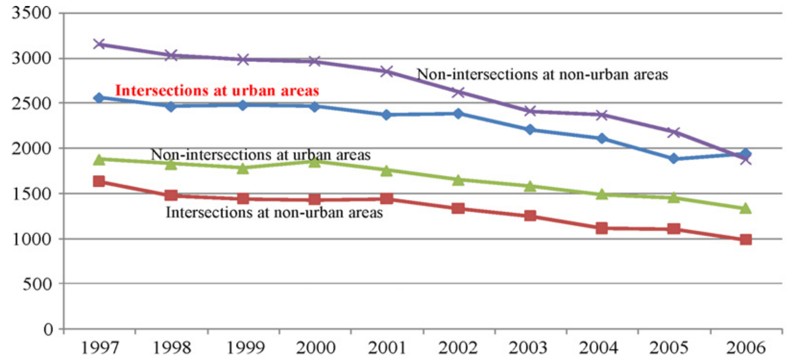


Fig. 1. Number of traffic fatalities by road type. *Source*: NPA (2007).

vide useful insights about how to effectively deploy the AHS across all of Japan.

In the remaining part of this paper, a review of literature is first given in Section 2, followed by an explanation of the on-site driving experiment in Section 3. Then, the effects of the in-vehicle warning information system on driving behavior are evaluated in Sections 4 and 5. Finally, conclusions are drawn in Section 6.

2. Literature review

Recently, a lot of research has been done with respect to the effects of traffic warning information on driving behavior. Focusing on emerging automotive safety technology which is designed to avoid rear-end crashes, Kiefera et al. (2005) attempted to clarify appropriate 'crash alert timing' that is enough for a driver to avoid the crash, but does not annoy the driver with alerts perceived as occurring too early or unnecessary. A field experiment was conducted on three adjacent lanes of a straight, level, six-lane skid pad by involving 72 participants from three age categories: younger, middle-aged, and older. Time-to-collision was used to measure drivers' braking behavior. Similarly, Abe and Richardson (2005) explored appropriate 'crash alert timing', but based on a driving simulator involving 24 persons. In contrast to those two studies, the current study does not deal with vehicle-to-vehicle communication; instead, this research focuses on the warning information that a driver cannot identify directly with his/her own eyes.

Maltz and Shinar (2007) evaluated the efficacy of an in-vehicle collision avoidance warning system under conditions of driver distraction, and found that distracted drivers responded by increasing their temporal headway to the less reliable system's alarm; but the warning system at higher reliability levels led to over-reliance and ultimately to maintaining shorter headway. Anttila and Luoma (2005) evaluated how different auditory and visual types of extra workload generated by an in-vehicle information system influence driving behavior in an urban environment by comparing factors with a rural environment. The test urban road section was 12 km long and included 20 intersections. They confirmed the effectiveness of in-vehicle information, but also found that the extra workload, due to response to the information provided, could cause substantial unnecessary waiting and poor driving behavior towards vulnerable road users. Even though the road structure of each intersection is beyond the scope of Anttila and Luoma's study, their study provides useful hints for us regarding side effects when evaluating the effects of in-vehicle warning information.

Chen et al. (2007) examined appropriate windshield positions for head-up-display (HUD) of an in-vehicle information system based on a driving simulator, in which a small group of young people participated. They found that the best HUD location is to show information on the part of windshield that is close to the steering wheel. Their finding supports our decision to show the warning information at the central–lower part of the windshield using an HUD device.

The above review reveals that most of the previous studies have not paid enough attention to road structure, and no research has been carried out to examine the effects of the warning information when an arch-shaped roadway is involved. When going up an arch, drivers usually face some difficulties to visually recognize traffic flow in front, consequently resulting in dangerous driving behavior or sometimes traffic accidents. It can be imagined that any city located in a delta region may face similar problems. In this sense, the findings from this study could also provide useful insights into improving traffic safety issues in other cities, too.

As noted above, driving simulators can be used to evaluate the effects of warning information; but it is expected that under the simulated driving situations, the observed behavior might be strongly biased from that under actual situations. Also, it is

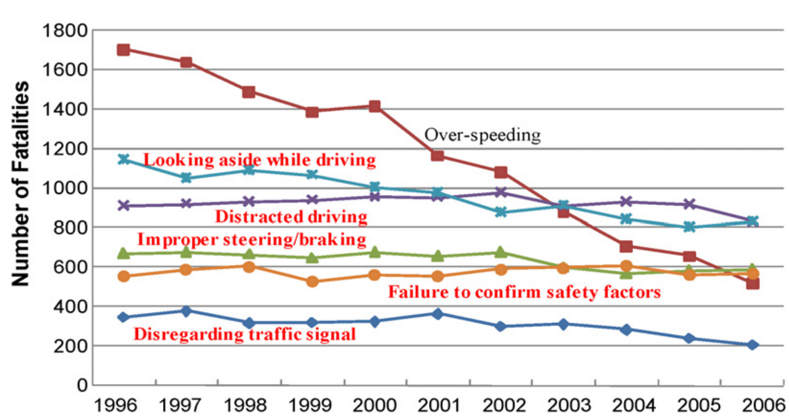


Fig. 2. Number of traffic fatalities of primary party by human errors. *Source*: NPA (2007).

sometimes very expensive to develop a simulation system with near-reality traffic situations. Based on such considerations, this study adopts the on-site driving experiment.

3. An on-site driving experiment

3.1. Background

To examine the effects of in-vehicle warning information on driving behaviors when approaching an arch-shaped bridge and then an intersection, an on-site driving experiment was conducted in 2006 as a part of a large-scale ITS deployment project in Hiroshima (Suto et al., 2006a,b). The project was jointly implemented by the authors' research group and the Japan Society of Civil Engineers, funded by the Ministry of Land, Infrastructure, Transport and Tourism, focusing on a road section of a national highway with the length of 3.2 km (Fig. 3). The project was planned to explore how to effectively deploy ITS technologies in practice, aiming to reduce not only the number of actual traffic accidents, but also dangerous driving behavior. This road section was selected because traffic accidents had been frequently observed at its four adjacent large-scale intersections. Note that in Japan, a large-scale intersection is defined as having four or more lanes in practice.

One of the above intersections is called Hiranobashi-Higashi (the third intersection circled in Fig. 3 from the left side), which is the target intersection in this study. Looking at the top-left picture in Fig. 5, this target intersection has three lanes for each direction. For the direction under study (the right side of the top-left picture in Fig. 5), nearby the intersection, there are two lanes for straight-through traffic, two lanes for right-turning traffic and one lane for both straight-through and left-turning traffic. Since the intersection is close to an arch-shaped bridge (Fig. 4), there is poor visibility (see the pictures in Fig. 5). Such poor visibility has frequently caused rear-end collisions. Even though a static pre-warning sign of traffic signal is installed on medial strip (see Fig. 4 and the top-left picture in Fig. 5), it is too close to the stop line of the intersection (only 50 m, in Fig. 4). Focusing on the traffic characteristics of this intersection, there is no relevant data, but the data collected from the neighboring intersections in 2005 by the national government (MLIT, 2005) indicate that on weekdays the congestion level (defined as the ratio between traffic volume to capacity) ranged from 1.07 to 1.62, shares of heavy trucks were 14.9–16.5%, and vehicle traffic varied between 57,976 and 74,910 vehicles/day (41,601–65,122 vehicles/day on weekends). In addition, the numbers of pedestrians and bicycles were 610–865 persons and 2936–4835 bicycles/half a day (mainly daytime) on weekdays (no available data on weekends).

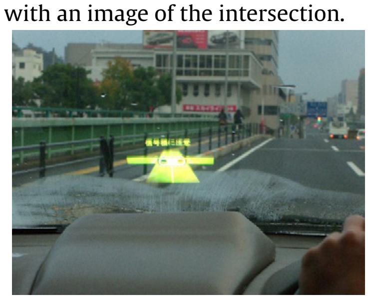
3.2. The in-vehicle warning information system and experiment scenarios

To deploy the in-vehicle warning information system, it is necessary to figure out not only what kinds of information are effective, but also how and when to provide such information to drivers. Therefore, the experiment was designed to examine the effects of different combinations of warning information provision methods and timing. Since the information under study is provided with respect to an intersection, the timing refers to the location of the information provision, which was identified using global positioning system (GPS) technology. The information provision method refers to human–machine interface (HMI), i.e., whether to provide the information in the format of voice and/or image in this study.

The information was provided via an on-board unit of navigation system and was shown in the central–lower part of the windshield using a head-up-display (HUD) device, which was processed using special glasses. Such design enables a driver to more easily recognize the provided information without greatly moving his/her face and/or eyes. Two types of image information were prepared, as well as two types of voice information, i.e., "Attention! Traffic signal ahead", called static information, and "Attention! Stopping vehicle ahead" called dynamic information (Table 1). The above warning information was provided depending on the actual presence of a stopped vehicle at the downhill road section. The image information was designed to include the message announced by voice together with an image of the intersection.

Table 1
In-vehicle traffic warning information.

HMI type	Static information	Dynamic information
Only voice	Attention! Traffic signal ahead	Attention! Stopping vehicle ahead
Voice and image		



In total, five scenarios were tested, among which one scenario without any information was included (Table 2). For the scenario without information, the navigation system was turned off. The scenarios with information were designed to cover both the timing and the type of HMI. The timing is represented by the location of providing warning information, where 200 and 300 m from the stop line of the intersection were used, considering the characteristics of the target road section. The types of HMI are described above. Two combinations of HMI types were set: one was only voice, and the other was voice and image. The "only image" HMI was not assumed because it is expected that the "only image" information is not enough to attract drivers' attention, considering the busy driving environment of the selected road section.

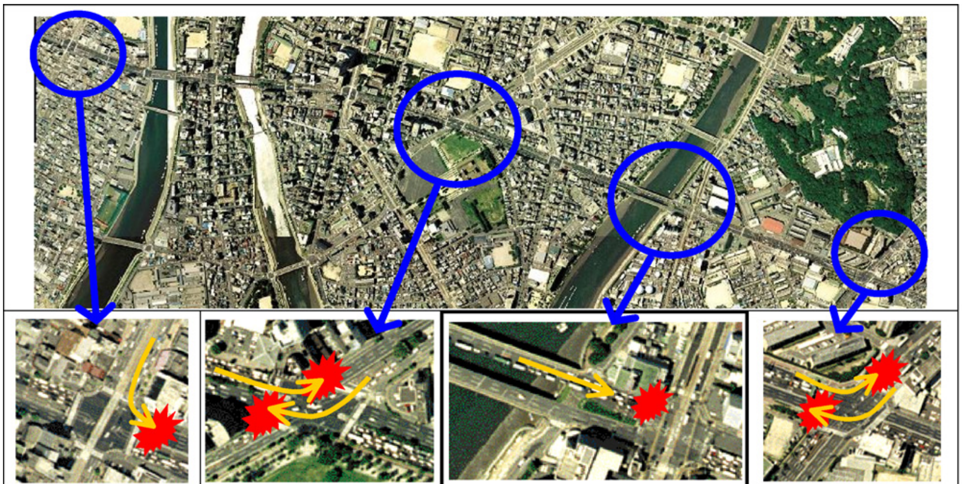
3.3. Implementation of the experiment

3.3.1. Vehicle

The experiment was conducted in November 2006, using an AHS test-vehicle developed by the National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure and Transport. This test-vehicle was designed to record very detailed

Table 2
Experimental scenarios for Hiranobashi-Higashi intersection.

Experimental scenario	Location of providing warning information	HMI type
Scenario 1	Without warning information	Without warning information
Scenario 2	200 m from stop line	Voice only
Scenario 3	200 m from stop line	Voice and image
Scenario 4	300 m from stop line	Voice only
Scenario 5	300 m from stop line	Voice and image



Funairi-Honmachi		Kokutaiji		***Hiranobashi-Higashi***		Deshio	
Vehicle-pedestrian accidents, left-turn		Vehicle-pedestrian accidents, right/left-turn		Rear-end collisions between top of arch and stop-line		Vehicle-pedestrian accidents, right/left-turn	
Accidents		Accidents		Accidents		Accidents	
2006	18	2006	18	2006	15	2006	20
2005	21	2005	20	2005	15	2005	24
2004	14	2004	14	2004	4	2004	25

Fig. 3. The targeted 3.2 km road section in the on-site driving experiment. *Note*: Photos are provided by Digital Earth Technology Corporation.

information of vehicle movement across space and over time. A GPS sensor was installed in the vehicle to automatically record the location information every 0.1 s including driving speed, acceleration, and deceleration. Other driving behavior histories, such as lateral acceleration, gap distance, and pressure of braking and handling, were measured using the built-in sensors in the vehicle.

3.3.2. Experiment period and participants

To comprehensively evaluate the effects of the in-vehicle warning information on driving behavior, ideally, various drivers should be involved in an experiment and the experiment should be conducted over a long time period to clarify the driving behavior across different contexts. Due to budget limitations, and for the ease of implementing the experiment, we conducted the experiment over a week, from 21 November (Tuesday) through 27 (Monday), 2006 (November 23 was a national holiday). We utilized 14 university students who were believed to show higher interest in traffic information and were more willing to participate in the experiment than other types of drivers. Among those students, 43% had daily driving experiences of at least one year, and only 14% had driven their personal vehicles on the targeted road section for more than one time a month.

Each day, two drivers were asked to drive the test-vehicle, by taking turns along the required route between the off-peak hours of 09:00 and 17:00. Such off-peak hours were selected because during peak hours the target road section was already occupied by many vehicles and consequently only the warning information "Attention! Stopping vehicle ahead" would have been observed. Before driving, each driver was informed about the driving task, i.e., to drive the test-vehicle along the required route as usual. They knew that they would be provided with some traffic information, but did not know when and what kind of information would be provided; in other words, they did not know the experiment scenarios. In the vehicle, for each time of driving, there were only two persons: one person was the driver and the other was a watchman to monitor the driver. A third student who was not driving the vehicle was asked to rest in a designated room prepared for the experiment (i.e., outside the vehicle) during the other student's driving. All students were allowed to take lunch during the rest period at noon.

3.3.3. Method to provide the information

At the Hiranobashi-Higashi intersection, the warning information was provided to drivers, depending on whether any vehicle stopped ahead in traffic when the test-vehicle approached the intersection. When there was a stopped vehicle between the stop line of the intersection and the top of the arch, the information "Attention, stopped vehicles ahead!" was announced via the navigation system. If there were no stopped vehicles, the information "Attention, traffic signal ahead!" was provided. To provide such dynamic information in reality, it is necessary to automatically detect the existence of stopped vehicles and to transmit the information to drivers. Since this was an experiment, such detection was done manually due to the limited budget. During the experiment, an experimenter (experimenter A) was required to stand beside the window of a room located on the 11th floor of a high-rise building nearby the intersection, where vehicles could be clearly identified. Experimenter A's task was to judge whether any vehicle was stopping on the road section between stop line of the intersection and the top of the arch when the test-vehicle was passing the location of information provision (LIP), and then to deliver this information via mobile phone to another experimenter (experimenter B) sitting on the rear seat of the test-vehicle. The LIP was determined beforehand. Before the test-vehicle approached the LIP, experimenter B

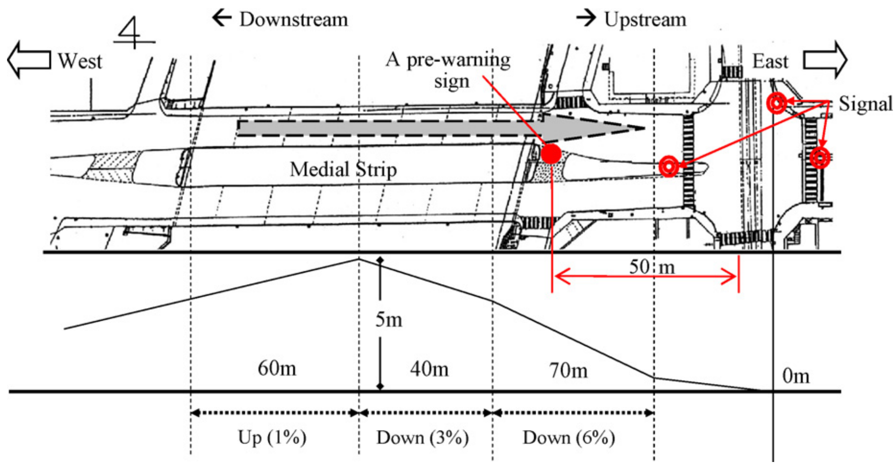


Fig. 4. The arch-shaped structure of Hiranobashi-Higashi intersection.

secretly phoned to experimenter A, who was required to continuously say quietly 'Yes' or 'No' about the existence of any stopping vehicle. The timing when experimenter B phoned to experimenter A was determined considering the delay of mobile phone communication. After receiving the information from experimenter A at the time when the test-vehicle was passing the LIP, experimenter B secretly operated a switch, connected to the navigation system, to show the required information on the screen of the navigation system, as mentioned above. The experimenters were trained carefully for this purpose. To reduce the burden due to long administration of the experiment (in total, about 8 h/day), two students were placed to be experimenters A and B, respectively (i.e., in total four students), and they were asked to take a rest (about 45 min to 1 h) after one round of test driving. To guarantee the consistent and reliable communications between the experimenters, they were given a careful training beforehand. In this sense, even though the communication between experimenters A and B was done via mobile phone, because such communication started before reaching the LIP, such manual operation did not generate a noticeable delay in the timing between detection and information delivery, and did not greatly impair the quality of the data collected.

3.3.4. Samples for analysis

As mentioned above, 14 university students (female: 1; male: 13) participated in the experiment over 7 days, and every day, two drivers were asked to drive the test-vehicle by turns. As mentioned

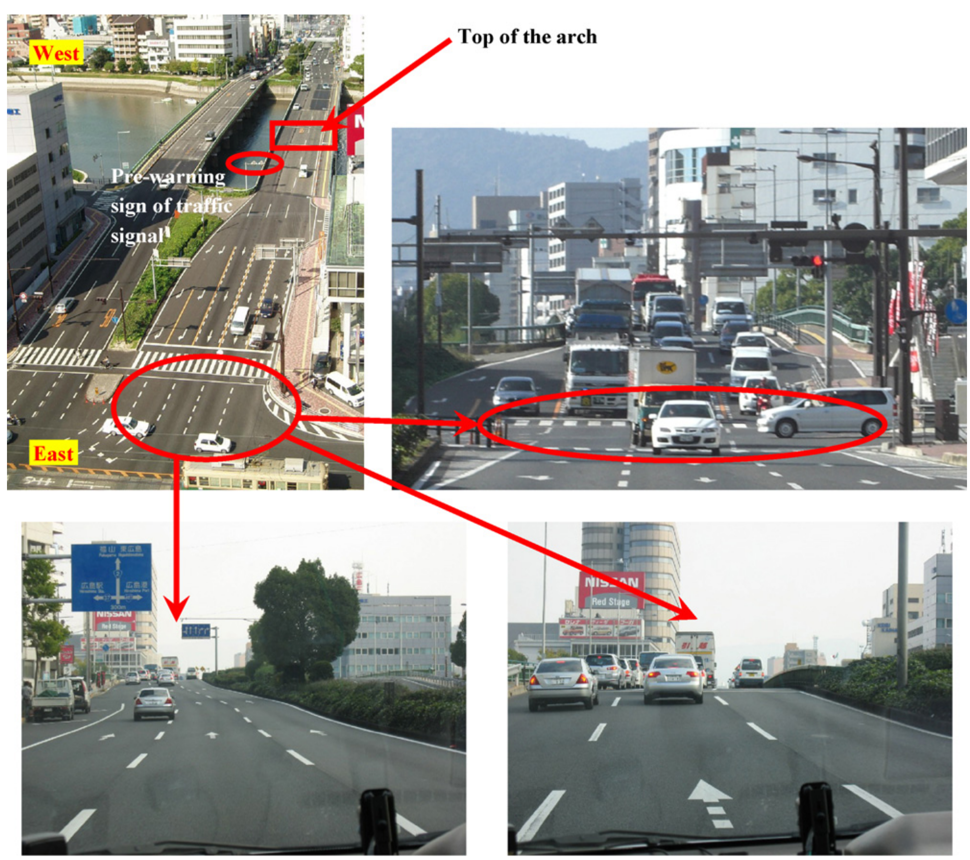


Fig. 5. Poor visibility nearby the Hiranobashi-Higashi intersection.

Table 3
Experimental results.

	Date							
	Nov. 21 Tue.	Nov. 22 Wed.	Nov. 23 Holiday	Nov. 24 Fri.	Nov. 25 Sat.	Nov. 26 Sun.	Nov. 27 Mon.	Total 7 days
Weather	Cloudy → rainy	Clear	Cloudy	Clear	Cloudy	Rainy	Cloudy → rainy	
Driving frequency (times)	10	10	12[a]	10	10	10	10	72 times
Participants	2	2	2	2	2	2	2	14 persons
Information provision	With information (4 scenarios) Without information (1 scenario)							

[a] Driving frequency on Nov. 23 was higher than those on the other days because average length of time used for one round of driving was shorter during the same experiment period. This is because Nov. 23 was a national holiday and traffic congestion was less serious.

previously, this experiment was a part of a large-scale ITS project, which covered a 2.3 km road section with four adjacent large-scale intersections (see Fig. 3). The 14 drivers were asked to drive the test-vehicle across the whole 2.3 km road section. It took about 1 h to run across the whole road section for each time of driving by taking a "zigzag" route to cover different traffic situations (left-turn, right-turn and/or through traffic) at the four interactions. The experiment results related to the Hiranobashi-Higashi intersection are shown in Table 3. Even though there were several rainy days, no heavy rain was observed. In principle, each driver was asked to experience the five scenarios (see Table 2) only one time. Note that some drivers actually experienced some scenarios more than one time. The five test scenarios were shown to drivers randomly. In total, the 14 drivers passed across the intersection 72 times, among which 16 times were for "Scenario 1" (see Table 2) and 14 times were for each of "Scenario 2"–"Scenario 5". Each drive is regarded as one sample for the analysis. In other words, 72 samples were collected.

4. Effects of warning information: aggregate analysis

4.1. Characteristics of deceleration conflicts

In this study, we use the term 'conflict' to represent the dangerousness of driving. When deceleration exceeds a certain threshold, we define that 'conflict' occurs. Usually, a traffic conflict is defined as an event involving two or more subjects (e.g., vehicles, bicycles and/or pedestrians), in which the action of one subject causes the other subject to make an evasive maneuver to avoid a collision (FHWA, 1989). For example, a driver might make a sudden braking to stop his/her car before the stop line of an intersection when he/she looks aside while driving and does not immediately recognize the change of a traffic signal. Even if such braking does not involve any other car on the same road section, we still use the term 'conflict' to describe such dangerous driving behavior.

In existing studies (Ng et al., 2006; Suzuki, 2004), the threshold of conflict has been set at 0.2 G (1 G = 9.806 m/s^2) for a passenger car; i.e., if deceleration is larger than 0.2 G, it implies that conflict occurs. This study also adopts the same threshold. Relating to the Hiranobashi-Higashi intersection, the observed conflicts between 0.2 and 0.3 G and the conflicts larger than 0.3 G are shown in Fig. 6. For the conflicts larger than 0.3 G, they are shown only with respect to the upstream test results, because the downstream results are not relevant to the intersection under study (note that the results of other intersections are shown as a reference because the driving experiment was conducted along the whole 3.2 km road section, as mentioned previously). Looking at Fig. 6, deceleration conflicts between 0.2 and 0.3 G occurred successively at the intersections, especially in the western side of the upstream traffic flow. Most of the decelerations larger than 0.3 G were observed at the locations where traffic accidents occurred frequently (i.e., the four intersections in the experiment: 14–20 accidents involving injuries or fatalities per year on average were observed during the period of 2003–2005, and the number of the accidents showed an increasing trend). At the Hiranobashi-Higashi intersection, conflicts were mainly observed at the downhill part of the road section. Even though traffic accidents at this intersection were observed near the stop line of the intersection, the observed conflicts indicate that dangerous driving also occurs at the upper side of the downhill part. In addition, the other larger values of decelerations were observed at some road sections where no accidents had been observed. These results reveal that deceleration conflicts occurred not only at road sections with the observed traffic accidents, but also at road sections without any accidents. In 2008, the ratio between fatalities (5155 persons), heavily injured persons (56,803), and slightly injured persons (888,701) due to traffic accidents in Japan (ITARDA, 2008) was 1:11:172. One can imagine that there should have more "near-accident" driving behavior behind these traffic accidents. Considering such facts, the observed conflicts could lead to serious traffic accidents in the future. These near-accidents can be prevented based on some proactive measures, rather than the widely applied reactive measures in practice. To support the decisions on proactive measures, it is obvious that the above-described conflicts are useful.

4.2. Effects of information provision

Table 4 shows average decelerations for dangerous driving and their standard deviations (static and dynamic information are not distinguished). Here, dangerous driving is identified if the value of deceleration is larger than 0.2 G. Statistical test results about whether decelerations with and without traffic warning information are different or not are also displayed in Table 4. As described previously, there are four scenarios of information provision. Looking at the average values, except for the scenario "voice and image" information provided at "300 m from stop line", all the other scenarios confirmed reduction of deceleration due to the information provision in the sense that the ratios of deceleration between "with" and "without" information are smaller than 1. This was especially true for the "voice" information provided at "300 m from stop line" and the "voice and image" information provided at "200 m from stop line", because statistically significant differences are observed. It was also a fact that the reduced decelerations under the other two information provision scenarios were not significantly different from that "without information". Such observed significant and insignificant differences might have been due to the way of confirming the differences, i.e., only average decelerations were analyzed. This suggests that the effects of warning information should be evaluated in a more convincing way.

In the above analysis, only the data with decelerations larger than 0.2 G were dealt with. As argued at the end of Section 4.1, there might be more "near-accident" driving behaviors related to

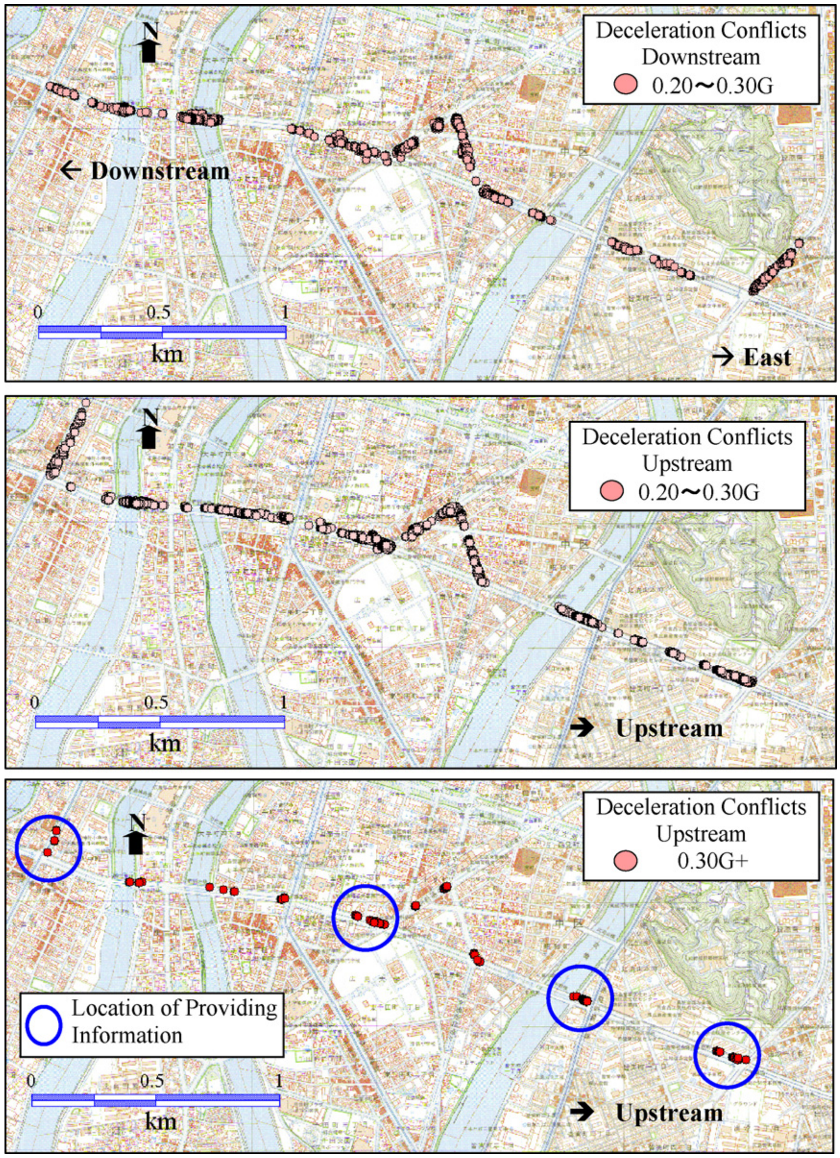


Fig. 6. Spatial distributions of deceleration conflicts.

the occurrence of traffic accidents, it might be noteworthy to give a look at all the data at a more detailed scale, as well as driving speed.

4.2.1. Accelerations and decelerations

All the observed accelerations and decelerations nearby the intersection were first aggregated by HMI type for every 5 m road section from the stop line of the intersection. The road section under study was 300 m long starting from the stop line, which was the most distant start point where warning information was provided in this study. Fig. 7 shows acceleration and deceleration distribution in cases of dynamic information and static information. It was found that decelerations in case of no information were larger than those in case of information provision in the road section "100–300 m". This suggests that, due to information provision, drivers might start to decelerate the vehicles earlier. Such a trend

Table 4
Average decelerations and standard deviations.

Intersection	Timing HMI	Without	200 m from stop line	300 m from stop line	Average
Hiranobashi-Higashi (upstream, see Fig. 4)	Without	0.239 [1.000] (0.042)	–	–	0.239 [1.000] (0.042)
	Voice	–	0.235 [0.983] (0.030)	0.232 [0.971]+ (*0.024*)	0.234 [0.974] (0.028)
	Voice and image	–	0.229 [0.958] (*0.023*)+	0.240 [1.004] (0.033)	0.236 [0.987] (0.031)
	Average	0.239 [1.000] (0.042)	0.234 [0.979] (0.029)	0.236 [0.987] (0.029)	0.236 [0.987] (0.033)

The value in () refers to standard deviation and the value in [] is the ratio of deceleration between "with" and "without" information provision scenarios.
+ Significant at 5% level.

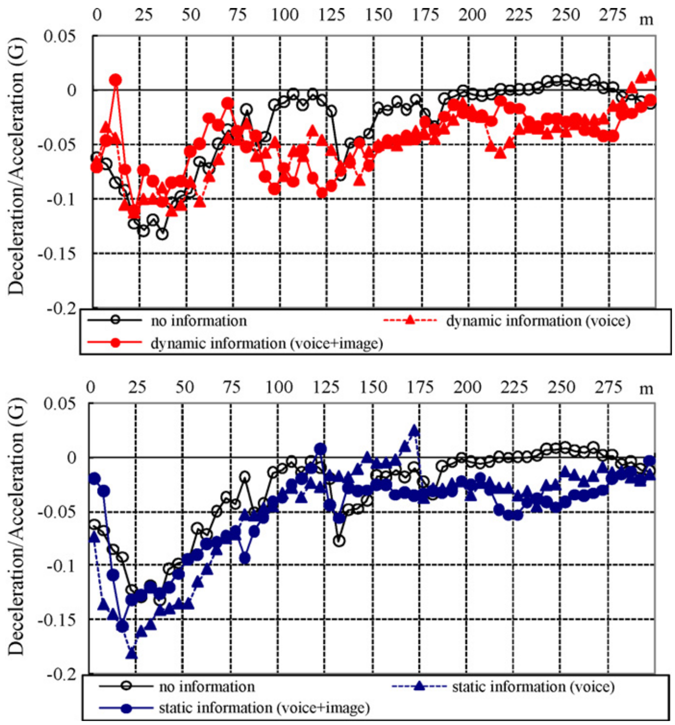


Fig. 7. Distributions of accelerations and decelerations.

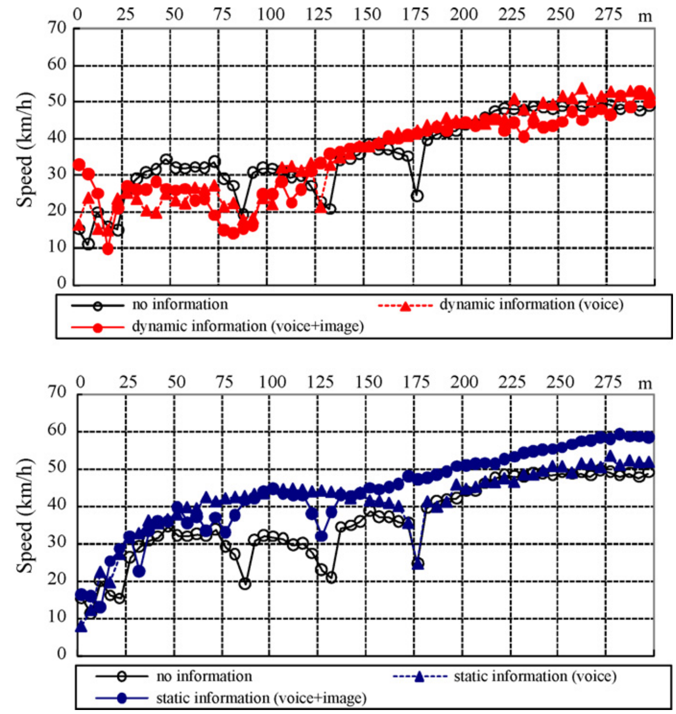


Fig. 8. Distributions of driving speeds.

was especially remarkable in case of dynamic information, and it was observed that deceleration was done at the top of the arch (120 m from the stop line). At the road section between the top of the arch and the stop line, decelerations became smaller in cases of dynamic information; but in cases of static information, no changes were observed.

4.2.2. Driving speed

Similar analyses were also conducted with respect to driving speed (see Fig. 8). In cases of dynamic information, no clear differences were observed at the road section between the top of the arch and the location of 300 m from the stop line; in contrast, at the road section between the top of the arch and the stop line,

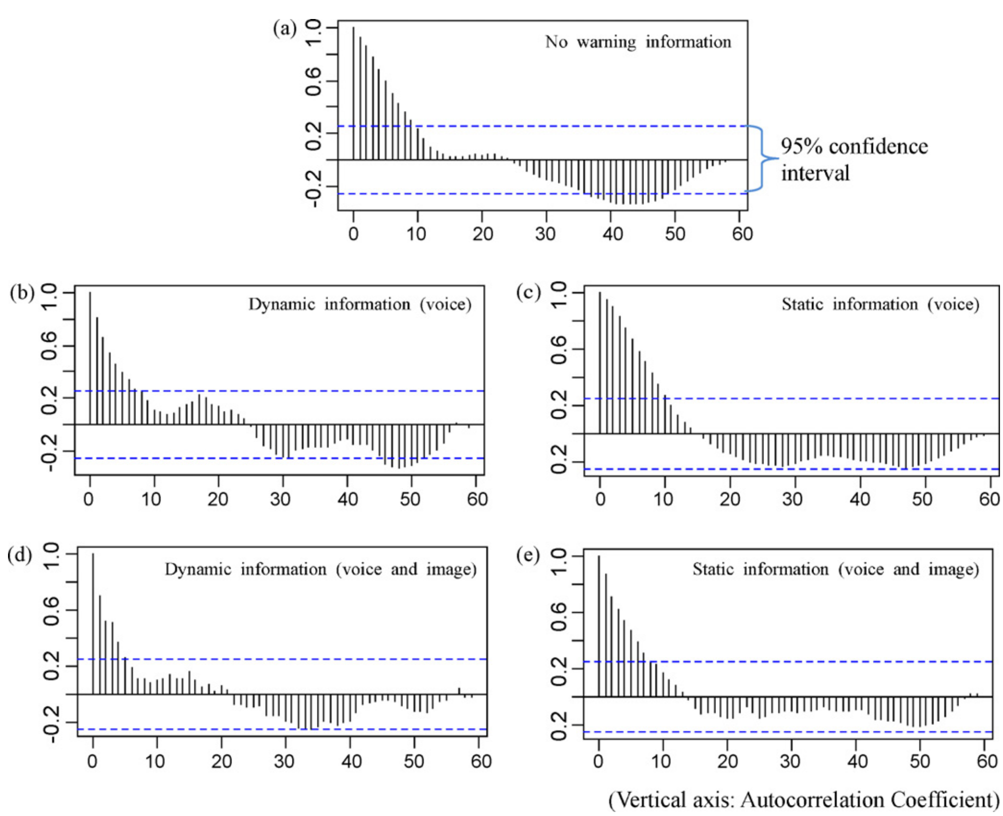


Fig. 9. Autocorrelation coefficients of accelerations/decelerations by HMI type (vertical axis: autocorrelation coefficient).

driving speeds were clearly lower than that without information. When static information was provided, driving speeds were higher than those without information. As a matter of fact, it was definitely observed that most of the cars crossed the signal during the provision of static information. But in cases of dynamic information, drivers were told that there were some vehicles stopped ahead. This might be the reason to cause such differences in driving speeds.

5. Effects of warning information: autocorrelation analysis

It can be imagined that driving behavior might change at different locations along a road section over time. Observing the data obtained in this study, it seems that such spatial and temporal variations are irregular, since short-term memory is closely related to driver's behavior. As a result, driving behavior might show spatial and/or temporal interdependency. Here, such interdependency is analyzed based on autocorrelations, which are widely used in time series analysis. In general, this time series analysis technique is used to clarify regularities in time-varying phenomena. This study attempts to apply such a technique to examine the spatial regularity nearby the intersection under study. The observed accelerations and decelerations are first aggregated for every 5 m road section (hereafter, called spatial lag). Such an aggregation is done over the 300 m road section from the stop line back to the direction of the top of the arch. This is helpful to easily find the statistical corre-

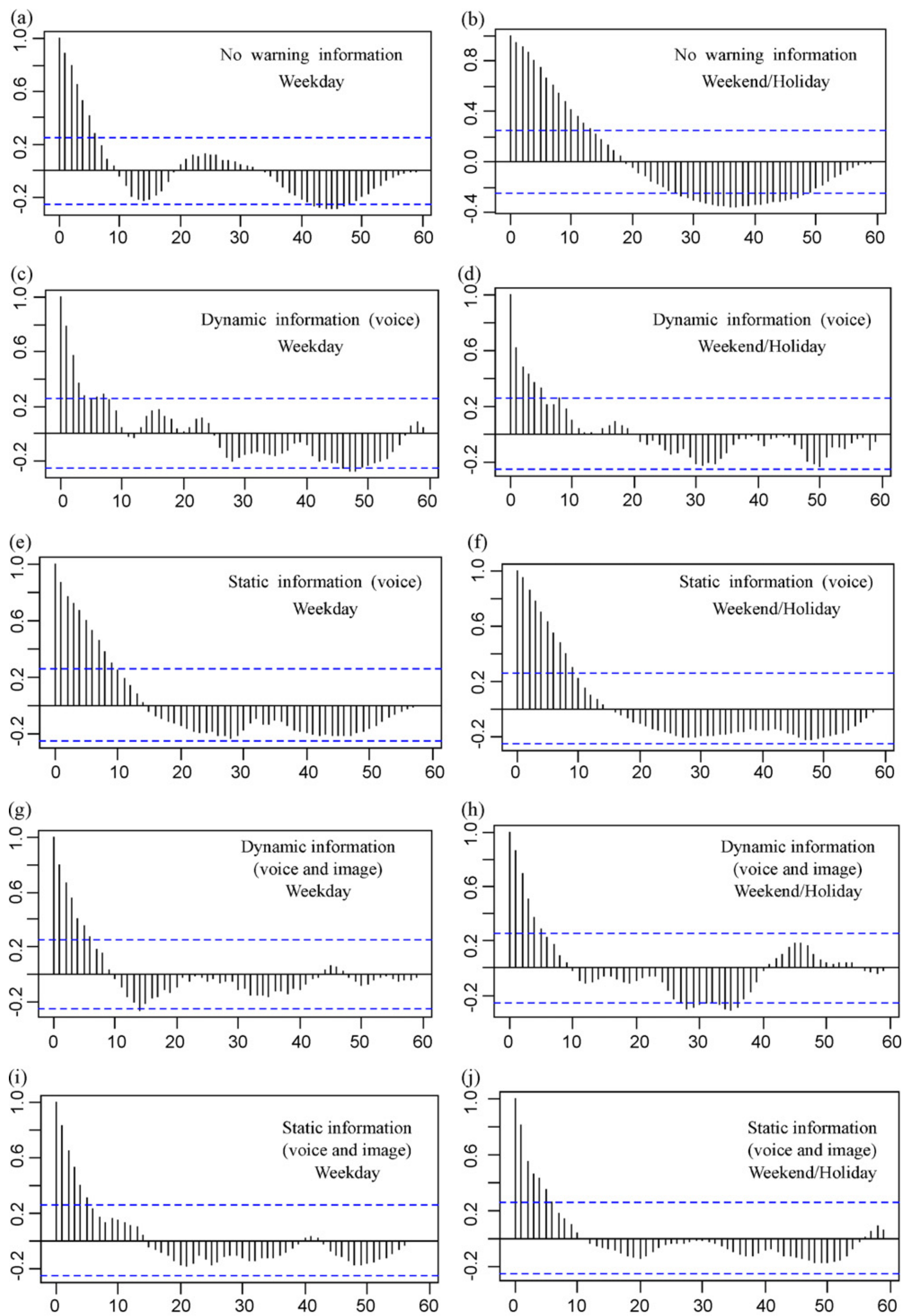


Fig. 10. Autocorrelation coefficients on weekdays and weekend/holiday (vertical axis: autocorrelation coefficient).

lations of driving behavior across space. Thus, the autocorrelation here indicates spatial correlation. It might be better to use the original driver-specific data; however, the existence of heterogeneity in driver's behavior under limited sample size (only 14 university students) makes it difficult to find the regularity in driving behavior.

Results of the autocorrelation analysis are shown in Figs. 9 and 10. The horizontal axis of each graph indicates the spatial lag (refers to 5 m, here) for autocorrelation analysis. For example, at the point '40' (i.e., the 40th spatial lag), it shows the autocorrelation value between the acceleration/deceleration series at any two locations with a distance of 200 m. The vertical axis shows the value of the autocorrelation, ranging over the interval of [−1, 1], and the dotted lines indicate 95% confidence interval.

Fig. 9 shows the autocorrelations of accelerations/decelerations by HMI type. It is obvious that in case of no information, strong positive autocorrelations are observed at the 1st–10th lags (5–50 m interval) and strong negative autocorrelations at the 35–50th lags (175–250 m interval) (see (a) in Fig. 9). Without this information provision, drivers have to make decisions to control their vehicles based on their daily experiences. It is expected that drivers can clearly identify the traffic situations ahead of a short distance and consequently control their driving behavior in a consistent way (i.e., keep their driving behavior that was decided just before a short time period based on visible traffic flow). This may lead to a strong positive autocorrelations at the 1st–10th lags. Concerning the 35–50th lags (actual distance is 175–250 m), over such longer distance it is difficult for drivers to clearly recognize the traffic flow ahead using their eyes, especially considering the arch-shape of the road section near the intersection. The existence of the arch could be considered as the major reason to cause the negative autocorrelations. Such negative peak of autocorrelations might be closely related to dangerous driving and is not desirable from the perspective of traffic control. Measures should be taken to reduce and to disperse such a peak. It is expected that providing traffic information to drivers could play such role. Comparing with the case of no information, more peaks of autocorrelations are observed under information provision (see (b)–(e) in Fig. 9). This might be because that under information provision, drivers may show heterogeneous responses to information and consequently behave differently. Comparing dynamic and static information, one can see that there are more peaks in cases of dynamic information than in cases of static information (see (b) vs. (c) and (d) vs. (e) in Fig. 9). Since static information tells drivers to pay attention to traffic signal ahead, there might be smaller variations of recognition of the signal location among drivers than the recognition of the location of stopped cars under dynamic information. Provision of image information of stopped cars ahead might be helpful for drivers to clearly recognize the existence of stopped cars. In this sense, dynamic information could be more effective than static information to avoid dangerous driving. Based on the above discussion, it can be concluded that in the arch-shaped road section under study, if information provision could generate more peaks in the distributions of autocorrelations, then the information might be more effective in reducing dangerous driving behaviors.

According to the Japan Road Traffic Census of 2005, traffic volume along the targeted driving route on weekends are 10–20% lower than those on weekdays. In this experiment, at the 300 m road section from the stop line of the intersection, the average driving speed on weekends (36.4 km/h) is higher than that on weekdays (32.1 km/h). As a result, it is expected that driving on weekends might depend more on drivers' own feelings or intentions than it does on weekdays. This stimulates us to further confirm the differences in driving behavior on weekdays and weekends. Distributions of autocorrelations on weekdays and on weekend/holiday are shown in Fig. 10. (Remember that one of the experimental days, i.e., 23 November, was a national holiday.) It is obvious that the autocorrelation in the case of no information shows stronger negative values over a wider range of space on weekend/holiday than on weekdays (see (a) and (b) in Fig. 10). This might be considered as a mark of driving behavior under free driving situations. Autocorrelations under information provision become smaller and largely disperse across space on both weekdays and weekend/holiday (comparing (a) and (b) and (c)–(j) in Fig. 10). Especially, autocorrelations in case of no information show clear regularity on weekend/holiday (see (b) in Fig. 10); however, under information provision, such regularity becomes unclear (i.e., more peaks are observed) and autocorrelations show similar distributions on both weekdays and weekend/holiday. This may suggest that information provision could be more effective to avoid dangerous driving behavior under traffic flows with higher speeds. Similar to Fig. 9, more peaks of autocorrelation distributions are observed under dynamic information provision than static information (see (c) vs. (e), (b) vs. (f), (g) vs. (i) and (h) vs. (j) in Fig. 10). Static information with both voice and image results in more peaks than the same type of static information with only voice (see (e) vs. (i) and (f) vs. (j) in Fig. 10), but such a trend is not so clear in the case of dynamic information (see (c) vs. (g) and (d) vs. (h) in Fig. 10). These results might suggest that when providing dynamic information, the simplified HMI could have the same effects as the complicated HMI could achieve. For example, dynamic information with voice and image on weekend/holiday results in a clear flat peak between the 28th and 26th spatial lags (see (h) in Fig. 10); in contrast, such a wide peak does not occur under the dynamic information with only voice.

6. Conclusions

To reduce the number of traffic accidents and the damage caused by the accidents, it is important to know how to reduce the number of human errors occurring during driving. Due to progress in the areas of information and communication technologies, it is expected that in-vehicle traffic warning information can play such a helpful role. In Japan, the in-vehicle warning information system is positioned as an important part of AHS (Advanced cruise-assist Highway Systems), aiming to realize fully automatic driving in the future. However, the effects of such warning information on driving behavior have not been satisfactorily evaluated yet. This study has attempted to evaluate the effects of the in-vehicle warning information, especially on drivers' braking and accelerating behaviors, focusing on a large-scale arch-shaped intersection, where traffic accidents had been frequently observed due to poor visibility. This study first designed an in-vehicle traffic warning information system, which provides information to drivers via an on-board unit of navigation system by showing information in the central–lower part of the windshield using a head-up-display device, which was processed using special glasses. Five scenarios were used, four with information and one without information. The scenarios with information include both dynamic and static information provided in the formats of voice and voice and image (i.e., human–machine interface). Next, to evaluate the effects of the warning information in a realistic way, an on-site driving experiment was conducted over a week, by inviting 14 younger drivers, to test how the timing of information provision and different human–machine interfaces influence driving behavior based on a comparison with the case of no information.

The driving experiment results confirm that locations of decelerations over 0.3 G were observed nearby road sections with frequently occurring traffic accidents, while some of the larger decelerations were also found at road sections with traffic accidents. This suggests the necessity to take proactive measures to prevent the occurrence of dangerous driving behavior. The on-site driving experiment can serve as an effective tool to detect such dangerousness in driving. Autocorrelation analysis reveals that dynamic information seems more effective for drivers to avoid dangerous driving than static information. In static information, providing the information with both voice and image is better than the information with only voice; however, such a trend is not clear for dynamic information. It is also found that the simplified HMI (i.e., only voice) could have the same effects as the complicated HMI (i.e., both voice and image) could achieve in cases of dynamic information provision.

Since the above-mentioned conclusions were obtained by using an on-site driving experiment with only a limited number of younger drivers, it is still too early to make any sound conclusion related to the provision of an in-vehicle traffic warning information. In the future, other types of drivers should also be tested to reflect the influence of drivers' heterogeneity, and the test period should be further extended to evaluate the variations of driving behavior across different contexts over a longer time period. Since a sound driving experiment usually asks a driver to repeat his/her driving over several times, evaluation of the effects of warning information should be carried out with a better consideration of the learning effects of information. Such learning effects include both short-term and long-term learning effects. It is expected that the effects of in-vehicle warning information might be more affected by the short-term learning effects due to the influence of human short-term memory. Long-term learning effects might be more related to driving habit and responses to regular features of safety-related road facilities. In addition, deceleration and autocorrelation are used in this study to measure the effects of the warning information due to the simplicity and ease of understanding. However, such indicators do not give us any information about the change of inter-vehicle relationship. In this sense, it is worth exploring other indicators such as time-to-collision. Furthermore, the analyses should be refined by comprehensively incorporating other influential factors such as road structures, traffic flows and other environmental factors. By doing so, the analyses could contribute to both better understanding of driving behavior and better policy making to effectively reduce traffic accidents. The in-vehicle traffic warning information systems should be supplemented with the help of roadside traffic information systems. Even though there are some roadside traffic warning signs, since they can only provide static information at some specific locations, drivers may get used to them and eventually ignore the signs due to the potential long-term learning effects. This should be given a proper evaluation in the future.

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