Research Note

Attention-attracting Facilities Utilizing Vection

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ABSTRACT

In an attempt to prevent excessive increases or decreases in speed when driving motor vehicles, Central Nippon Expressway Company Limited (hereinafter referred to as “C-NEXCO”) is currently conducting research on controlling a driver’s sense of speed, etc., by installing light-emitting devices on highway shoulders at regular intervals and by regulating their emission of light according to an arbitrary light-emitting pattern. Research results on the control of speed utilizing light-emitting devices have been accumulated. Regarding conventional research to urge drivers to regulate their traveling speed by drawing their attention or guiding their lines of sight to blinking or the turning on of light-emitting devices sequentially placed along potentially dangerous road areas, one issue of difficulty concerned responding to excessive traveling speed caused by becoming “acclimatized” to the speed and any excessive decrease in speed during sagging road section. In this paper, as an effort to control the sense of speed utilizing the perception of self-motion induced by visual sensation (hereinafter referred to as “vection”) and as a focus on taxis that move in response to the stimulus of light (hereinafter referred to as “phototaxis”), we would like to report on a basic examination conducted through a questionnaire experiment using CG simulation images and the actual effects thereof, as verified in experiments on actual roads conducted using an expressway under construction (based on the examination results).

KEYWORDS: traffic safety, attention-attracting facilities, drivers’ attention, speed control

1. Introduction

When driving a motor vehicle, a driver often fails to realize gentle grade road and experiences the illusion that the road is still level. When driving continuously on an expressway, the driver’s sense of speed declines as a result of becoming acclimatized to the speed itself. When a motor vehicle travels over a long distance at a fixed speed (as in the case of driving on an expressway), visual information becomes the main factor regarding the sense of self-motion. This is because the vestibular sensation system works as a detector of acceleration of motion while the touch and auditory sensation systems accommodate the stimuli of a fixed strength. This perception of self-motion by the visual sensation system is called “vection” and the scenes are input into the driver’s retina as a motion-like optic flow (the arrows) (Figure 1). Should the same motion be presented to a stationary observer, the observer will be able to perceive their self-motion only through said motion. Our research this time is aimed to help drivers limit or maintain their traveling speed by making them perceive the sense of an excessive increase or decrease in their traveling speed through the use of this sensation effect, thus making them increase or decrease their traveling speed.

2. Outline of conventional research

The sensation of self-motion is known to be created by consolidating information perceived by various sensation systems, such as visual, touch, and auditory sensation systems, along with vestibular sensations. When driving a motor vehicle, the driver is believed to judge the traveling speed of his/her vehicle by taking in and consolidating various input information, including the flow of surrounding scenes through the visual sensation system, changes in the sense of balance following acceleration and deceleration through the vestibular sensation system, and pressure on the accelerator pedal.

Figure 1 Perception of self-motion by visual sensation systems (vection)
through the touch sensation system, as well as engine and wind noises through the auditory sensation system. Among these various sensation systems, vection has been studied in terms of its various properties. When a motor vehicle is driven over a long distance at a fixed speed, as in the case of driving on an expressway, the vection created based on the visual information becomes a factor in determining the driver’s sense of traveling speed. This is because the vestibular sensation system works as a detector of the acceleration of motion while the sense of surrounding noises and pressure on the accelerator pedal accommodate the stimuli. On the other hand, drivers traveling at a fixed speed on an expressway can fail to perceive slight changes in slope visually and continue to apply the same pressure to the accelerator pedal to excessively increase or decrease their traveling speed. This will result in traffic accidents or traffic congestion. In order to cope with this situation, various research has been conducted to make drivers aware of changes in their traveling speed. As an example, in the area near Bijogi Junction of the Metropolitan Expressway Saitama-Omiya Route\textsuperscript{2}, figure patterns are painted on the road surface to cause a sense of change in traveling speed to the drivers. It has been reported from the Kotori Tunnel of Takayama-Kiyomi Road\textsuperscript{3} and the Inariyama Tunnel of Hanshin Expressway Route 8 (Kyoto Route)\textsuperscript{4} that installing on the walls of tunnels sequence designs that have traditionally been adopted in construction and other areas to reduce the sense of tension, etc., is effective in controlling traveling speed. Such conventional research, however, cannot respond to traffic conditions or external momentary environmental changes (time of day, weather, scenery of the area under construction, etc.) in a flexible manner, as they induce vection by the stimuli of the stationary figures on the road, and no research has been accumulated on these issues.

Being aware of the above problems, C-NEXCO has conducted research on a system to control the sense of speed by presenting the driver with vection corresponding to the external environment. This is done by setting the traveling speed of motor vehicles (hereinafter referred to as \textit{traveling speed} \( z \)) and the stimulus velocity of the vection used (hereinafter referred to as \textit{stimulus velocity} \( z \)), etc. as experimental variables, as well as by adjusting the blinking speed of the motion stimuli of the light-emitting equipment installed along-side the road (Figure 2).

![Optic Flow while Driving on an Expressway](image)

![Optic Flow under the Presentation of Vection Stimuli](image)

Figure 2 Changes in the sense of speed caused by vection stimuli

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Results of these experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items</td>
<td>Results</td>
</tr>
<tr>
<td>Effect of the vection</td>
<td>The sense of speed has changed in accordance with the traveling speed and stimulus velocity</td>
</tr>
<tr>
<td>Size of the light-emitting devices</td>
<td>The size does not affect the change in the sense of speed</td>
</tr>
<tr>
<td>Installation intervals of the light-emitting devices</td>
<td>As the installation intervals become shorter, the changes in the sense of speed become greater. There is no difference in the intensity of the sense of speed when the distances are two meters and four meters</td>
</tr>
<tr>
<td>Existence or non-existence of a motor vehicle traveling side-by-side and traffic lanes to drive on</td>
<td>These properties do not affect the change in the sense of speed</td>
</tr>
<tr>
<td>Installation positions of the light-emitting devices (installation on one side or both sides)</td>
<td>This does not affect the change in the sense of speed</td>
</tr>
</tbody>
</table>

3. Attention-attracting facilities utilizing vection

Research results have been accumulated on light-emitting devices aimed to attract the attention and guide the “line of sight” (hereinafter referred to as “light-emitting delineators”); however, research has not been...
accumulated on light-emitting devices to make the drivers aware of excessive increases or decreases in traveling speed (hereinafter referred to as “attention-attracting facilities”). For this reason, we are going to propose in this paper a technique to control the light-emitting devices that alter the sense of speed of the drivers while they are traveling on an expressway by regulating the emission of the light-emitting devices according to an arbitrary emission pattern and by confirming its effect. This research has been conducted according to the steps mentioned below.

(1) Experiments utilizing CG simulation images

Research has been conducted to measure the intensity of the sense of speed of the subjects by presenting the stereoscopic moving image stimuli found when driving on an expressway, which are created by CG simulation on a spherical stereoscopic display (approximately 8.5 m in diameter). The results of these experiments have already been published5), and we introduce in this paper the information obtained therefrom as shown in Table 1.

(2) Plan for experiments on an actual road

Based on the results of the experiments conducted using the CG simulation images, C-NEXCO conducted experiments on an actual road during the period from December 2010 to March 2011 by installing attention-attracting facilities along the Shimizu Access Road (upward lane), which is currently under construction (Figure 4). The Shimizu Access Road is approximately
4.5 km, connecting the Tomei Expressway and Shin Tomei Expressway. Since it consists of down slopes at −4% for almost its entire upward lane leading to the Tomei Expressway, there are growing concerns about the occurrence of accidents on the road due to excessive speed.

4. Assessment hierarchy

Attention-attracting facilities have been assessed in accordance with the assessment hierarchy structure as shown in Figure 5.

5. Assessment matrix, ETC

The assessment items and the measurement method for the respective requirements are set as shown in Table 2.

6. Conditions of the experiments

The configuration diagram of the attention-attracting facilities used in the experiments on an actual road is shown in Figure 6. For the experiments on an actual road, 250 units of light-emitting devices were installed at regular intervals on the shoulder of the road (a 500 m section) together with a system where the emission of the light-emitting devices can be regulated or where light-emitting delineators can be turned on through the operation of the control panel (main).

As in the case of CG simulation, confirmation has been made using this system by altering the experimental variables as to the existence/non-existence of a change in the sense of speed as well as a change in the sense of speed according to the traveling speed and the stimuli velocity, etc. The experimental variables have been set to be the traveling speed of the vehicle, the stimuli velocity, and the installation intervals of the light-emitting devices (Refer to Table 3). In the prepara-
In the preparatory stage of these experiments, however, it was confirmed that the lowering of the stimulus velocity of the vection resulted in the limiting of the actual traveling speed, while there was no change in the sense of speed. It can be understood that this is due to the phototaxis representing human movements in response to the stimulus of the light. Phototaxis generally refer to the phenomenon such that insects or cells, etc., move directionally in response to the stimulus of light and not to human behavior. However, Mr. Shinoda and his colleagues suggest that human beings also have what is called phototaxis. Since the current phenomenon regarding the limiting of the actual traveling speed is explainable when we think that the movement of the stimulus of light attracts human attention and induces an action, we have decided to handle the area where the relative speed between the traveling speed and the stimuli velocity is small (less than ±80 km/h: hereinafter referred to as the "phototaxis area") on an actual road, as an experimental variable.

### 7. Experimental driving

During the experiments on an actual road, each driver that was examined wore an eye-mark camera, accelerated to a speed designated as a condition for traveling in the acceleration and accommodation section, and then drove free in the subsequent section with attention-attracting facilities at a speed at which they felt safe. As subjects, five people aged 40 years of age or older with sight or color perception that does not disturb them in their daily lives were selected, while four others were selected from a younger age category (below the age of 40 years old). Each subject underwent the experiments twice every day.

### 8. Method of analysis

Speed-restraining effects were examined by recording speed information, acceleration rate information, and location information using the car-mounted GPS sensors, together with the result of the questionnaire surveys concerning glare, etc. In the questionnaire survey, we employed a subjective assessment (in five levels) of the way the illuminant appeared, along with the sensations felt during driving, as well as the sense of speed and the operation of the accelerator. We then analyzed the average values of the respective assessments. Impaired attention was also examined by analyzing eye movement data.

### 9. Results of the experiments on an actual road

The results of the experiments on an actual road as conducted and based on the above plan are as shown below. Although the attention-attracting facilities were installed in a section 500 m in length for the experiments on an actual road, it was confirmed during the preparatory stage that the first and last 100 m portions of the section were in use for acceleration/accommodation/stopping section, and only the remaining 300 m portion was used as the section for assessment.

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### Table 3 Conditions of the experiments

<table>
<thead>
<tr>
<th>Purpose of assessment</th>
<th>Travelling speed of own</th>
<th>Classification</th>
<th>Alternatives</th>
<th>Light-emitting device</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Installation</td>
</tr>
<tr>
<td>Countermeasures</td>
<td>120 km/h</td>
<td>Daytime</td>
<td>No measures taken</td>
<td>Turned off</td>
</tr>
<tr>
<td>against excessive</td>
<td></td>
<td>Night time</td>
<td>Light-emitting delineators</td>
<td>20 m</td>
</tr>
<tr>
<td>increase in speed</td>
<td></td>
<td></td>
<td>Attention-attracting facilities</td>
<td>2 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Countermelures</td>
<td>80 km/h</td>
<td>Daytime</td>
<td>No measures taken</td>
<td>Turned off</td>
</tr>
<tr>
<td>against excessive</td>
<td>60 km/h</td>
<td>Night time</td>
<td>Light-emitting delineators</td>
<td>20 m</td>
</tr>
<tr>
<td>decrease in speed</td>
<td></td>
<td></td>
<td>Attention-attracting facilities</td>
<td>2 m</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

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![Figure 7 Assessment items and measurement method](image-url)
Countermeasures against excessive increase in speed / daytime

Figure 8 Speed-restraining effect (speed rate)

Countermeasures against excessive increase in speed / night time

Figure 9 Sample of changes in motor vehicle

10. Countermeasures against excessive increases in speed

(1) Speed-restraining effect (speed)

Results of the assessment of the speed-restraining effect (speed rate) shown in the boxplot are as illustrated in Figure 8. From this we can understand that the effect is great in the area where the relative speed between the traveling speed and the stimuli velocity is large (the area where the effect of the vection is great; hereinafter referred to as the "vection area"), and the same applies to the phototaxis area. Furthermore, in comparison with the case when no countermeasures are taken, we can confirm the effect of a reduction of 2‒5 km/h in speed rate, respectively. The data of one of the subjects is shown in Figure 9 as a sample of changes in motor vehicle speed.

(2) Attention-attracting effects (questionnaire survey)

The results of the assessment of the attention-attracting effect (questionnaire survey) are shown in Figure 10, from which it is understood that the effect has been
obtained irrespective of the stimulus velocity.

And that there is no significant difference between the conditioned use of the light-emitting delineators and the conditioned use of the attention-attracting facilities, as well as that an effect equal to the standard countermeasures can be obtained.

(3) "Line of sight" guiding effects (questionnaire survey)

The results of the assessment of the "line of sight" guiding effect (questionnaire survey) are shown in Figure 11, which shows that the effect tends to be greater under the conditioned use of the attention-attracting facilities rather than under the conditioned use of the light-emitting delineators, as well as that the effect tends to be great when the relative speed is small.

(4) Glare and flickering (questionnaire survey)

The results of the assessment of glare and flickering (questionnaire survey) are shown in Figure 12. In this assessment, the assessment values of the respective items of "tired," "tense," "dangerous," and "nervous" have been summed up as the "unpleasant sensation of light" for further assessment. According to this assessment, the effects have been obtained irrespective of the stimuli velocity, and the unpleasantness regarding the light tends to be smaller under the conditioned use of the attention-attracting facilities rather than under the conditioned use of the light-emitting delineators.

(5) Impaired attention (questionnaire survey)

The results of the assessment of impaired attention (questionnaire survey) are shown in Figure 13. In this assessment, the assessment values of the four items of "tired," "tense," "dangerous," and "nervous" have been summed up as the "physical load" and further assessed based on the assumption that attention becomes more impaired as the degree of the feeling of the load becomes higher. The assessment shows that attention becomes impaired under the conditioned use of both light-emitting delineators and attention-attracting facilities, in comparison to the cases when no countermeasures are taken but when attention under the conditioned use of the attention-attracting facilities is rated equal or higher than under the conditioned use of the light-emitting delineators. Accordingly, it is understood that im-
Impaired attention is equal to the case of the conditioned use of the light-emitting delineators, which is a typical alternative.

Eye movement data was analyzed to examine impaired attention in the respective alternatives. The assessment was made by relatively comparing the gazing share of the respective alternatives in the visual point area established in the actual road environment of the experiments (Refer to Figure 14). The results of the gazing shares measured during the daytime are shown in Figure 15. When compared with the condition of no countermeasures taken, the share of the elements for road alignment perception under the conditioned use of the attention-attracting facilities shows an almost equal gazing share without giving any major influence over the movement of the driver’s visual point. Accordingly, it is understood that the attention-attracting facilities do not cause impaired attention. Under the conditioned use of the light-emitting delineators, however, the gazing share of the elements for road alignment perception is reduced slightly. This is considered to be due to the fact that blinking tends to cause slight glare and flickering for the drivers under the conditioned use of the light-emitting delineators, as noted from the (questionnaire) result of glare and flickering.

Countermeasures against excessive increases in speed (summary)

It has been confirmed from the result of the experi-
ments on an actual road that attention-attracting facilities are most effective as countermeasures against excessive increases in speed. Since, however, it is confirmed that the attention-attracting facilities cause slight glare for the drivers in the vection area according to a conflicting requirement, it is considered desirable to take countermeasures toward using the phototaxis area against excessive increases in speed (Refer to Table 4).

Table 4 Assessment of countermeasures against excessive increases in speed (summary)

<table>
<thead>
<tr>
<th>Assessment item</th>
<th>Speed-restraining effect</th>
<th>Attention-attracting effect</th>
<th>Sight line guiding effect</th>
<th>Flickering</th>
<th>Glaring</th>
<th>Impaired attention</th>
</tr>
</thead>
<tbody>
<tr>
<td>No measures taken</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Light-emitting delineators</td>
<td>△</td>
<td>○</td>
<td>○</td>
<td>△</td>
<td>△</td>
<td>○</td>
</tr>
<tr>
<td>Attention-attracting facilities</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Table 5 Assessment of countermeasures against excessive decreases in speed

<table>
<thead>
<tr>
<th>Assessment item</th>
<th>Speed-restraining effect</th>
<th>Flickering</th>
<th>Glaring</th>
<th>Impaired attention</th>
</tr>
</thead>
<tbody>
<tr>
<td>No measures taken</td>
<td>×</td>
<td></td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Light-emitting delineators</td>
<td>×</td>
<td>△</td>
<td>△</td>
<td>○</td>
</tr>
<tr>
<td>Attention-attracting facilities</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Countermeasures against excessive decrease in speed / daytime

Countermeasures against excessive decrease in speed / night time

Figure 16 Speed-restraining effect (speed and acceleration rate)

11. Countermeasures against excessive decreases in speed

(1) Speed-restraining effect (speed rate)

The results of the assessment of the speed-restraining effect (speed rate) are shown in Figure 16. From this assessment, it is understood that the effect becomes larger as the relative speed between the traveling speed and the stimuli velocity becomes greater. In addition, the speed-increasing effects of 2–13 km/h in speed rate are confirmed in comparison with the condition of no countermeasures taken. The data of one subject is shown in Figure 17 as a sample of a change in motor vehicle speed.

Figure 17 Speed and acceleration rate

※Relative speed (km/h)–Stimuli velocity–Vehicle speed
※Difference in speed between starting point and end point of section for analysis
As in the case of countermeasures against excessive increases in speed, confirmation has been made with respect to attention-attracting "line of sight" guiding effects, glare, flickering, and impaired attention. The result of the confirmation is similar to the result of the countermeasures against excessive increases in speed, and a report thereof is omitted from this paper due to limitations of space.

(3) Countermeasures against excessive decreases in speed (summary)

From the results of the experiments on an actual road, the effectiveness of the attention-attracting facilities as countermeasures against excessive decreases in speed has been confirmed. Since, however, no change in the driver's sense of speed has been observed in this experiment, it seems that this phenomenon is attributable to the phototaxis. With respect to the countermeasures against excessive decreases in speed, conflicting requirements including glare have been restrained, although the experiment has been conducted only in the phototaxis area (Refer to Table 5).

12. In conclusion

In this paper, with an aim of providing our customers with a safe expressway space that they can use with a sense of security, and in an effort to control the sense of speed through the use of vection and phototaxis, we have conducted basic examinations through the questionnaire experiment utilizing CG simulation images and have verified the actual effects in the experiments on an actual road using an expressway under construction.

As a result, it has been confirmed that the control of the light-emitting devices utilizing vection and phototaxis has certain effects on the countermeasures against excessive increases and decreases in speed when driving a motor vehicle. In the future, it will be necessary for us to: built attention-attracting facilities along the Shimizu Access Road of the Shin Tomei Expressway, further increase the number of samples taken regarding traffic conditions and the external environment (including time of day, weather, and the scenes of areas under maintenance), and deepen statistical and quantitative studies toward the development of the most appropriate control program for light-emitting devices.

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