Effect of Repetitive Patterns with Brightness Gradient on Vehicle Speed Perception

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ABSTRACT

Suppression of vehicle speed is very important for decreasing fatal accidents caused by speeding violations. The purpose of this study was to reveal the effects of repetitive patterns painted on the road, which creates a moving visual illusion, on the driver’s speed perception. First, we investigated the moving illusion effect of repetitive patterns with a brightness gradient in images with pictorial depth cues. Then, we performed an experiment using a computer driving simulator. Results showed that these gradient patterns on the road led observers’ to overestimate vehicle speed by 13–19% compared to a road without patterns.

KEYWORDS

Vehicle speed suppression, Visual Illusion, Motion enhancement, Brightness pattern, Fraser-Wilcox illusion

1 INTRODUCTION

According to an investigation of the Metropolitan Police Department of Japan, the number of traffic accidents in Japan in 2012 was 637,100 and number of fatal accidents was 3,909. In addition, speeding violations were the most frequent reason for the fatal accidents. Decreasing the number of speeding violators is needed for reducing number of traffic fatalities; thus, we have to find ways to encourage vehicle speed suppression in drivers.

Previous studies reported several factors pertaining to vehicle properties that affect perceived speed: vehicle size [1], vehicle height [2], and interior car noise [3]. These reports suggest that one strategy for speed suppression is contrivance of the automobile itself.

Another strategy is contrivance of the road. Various ideas have been suggested to promote vehicle speed suppression: a hump on the road can prompt the driver to reduce vehicle speed (Fig. 1), narrowing the road by poles and white lines can prompt drivers to drive more carefully and reduce vehicle speed (Fig. 2). These physical structures are useful at very low vehicle speeds but are not utilized on highways, which have the highest occurrence of fatal accidents.

Figure 3 shows a road painting that prompts drivers to reduce vehicle speed on a highway, which is called “optical dots.” The key feature of the optical dots is the interval between the dots: the non-regular intervals create an illusion of increasing speed perception. Han et al. [4] reported the effect of the optical dots. This moderate illusion leads to speed reduction without drivers’ conscious awareness of the manipulation. However, the effect of the dots is limited at a local area on the road, and the dots cannot suppress vehicle speed for long periods.

In this study, we focused on repetitive patterns with brightness gradients that create a motion illusion. Fraser and Wilcox discovered this motion illusion in 1979. A still image consisting of repetitive brightness gradients seems to be moving slowly (Fig. 4) [5]. The authors noted that the apparent movement depended on the observers and that there were three types.

Kitaoka reported an optimized Fraser-Wilcox illusion (Fig. 5) [6] and stated that the apparent movement of this image did not depend on the observer. When the outer regions of the
gradient patterns are brighter than the inner regions, the observer perceives the direction of the rotating motion going from dark to light.

These reports confirm that the brightness gradient of the pattern affects motion sensitivity of our vision system. The purpose of this study was to reveal the effects of the gradient pattern on the drivers’ speed perception. In the first experiment, we investigated the motion illusion of 7 still images with gradient patterns and pictorial depth cues. We then selected one gradient pattern to be applied in the second experiment, where we investigated the effects of the gradient pattern on vehicle speed perception. Finally, we describe the possibility of vehicle speed suppression by painting a gradient pattern on the road.

2 EXPERIMENT 1 (ILLUSION EFFECTS OF GRADIENT PATTERNS WITH DEPTH CUES)

2.1 Purpose of Experiment

Previous studies reported that the Fraser-Wilcox illusion occurs in two-dimensional images. It has not yet been clarified whether the illusion also occurs in three-dimensional images. There were two aims in this first experiment. The first was to confirm whether the gradient pattern creates the motion illusion in images with pictorial depth cues. The second was to find the specific characteristics needed for the motion illusion in order to use them in the next experiment.

In this experiment, we created 6 types of road images with brightness gradient patterns and 2 types of road images with simple stripe

![Figure 1 Hump](image1)

![Figure 2 Structure (“Kyosaku”)](image2)

![Figure 3 Optical dots](image3)

![Figure 4 Fraser-Wilcox illusion [5]](image4)

![Figure 5 Optimized Fraser-Wilcox illusion [6]](image5)
patterns using three-dimensional computer graphics software. Then, we verified whether the motion illusion occurs for each image.

2.2 Stimulus

Still images portraying a road were rendered by a computer graphic software (blender 2.69). The road width was set to 7 m, the road length 800 m, the height of the guardrail was set to 0.8 m, and the interval between the stands of the guardrail was set to 4 m. These settings were in accordance with a standard road design established in Japan. The height of the camera was set to 1.2 m. This is consistent with the driver’s point of view. The angle of view was 60 degrees.

We used a brightness gradient pattern shown in Fig. 6. In order to avoid ambiguity of the direction of the moving illusion, a white band was painted among the gradient patterns according to the optimized Fraser-Wilcox illusion.

The following 8 types of stimuli were created: The first 5 stimuli were road images with repeated gradient patterns, which had different pattern lengths ranging from 2 to 10 m (Figs. 7–11). Stimulus 6 was an image with white and black bands painted on the road with a band length of 0.6 m (Fig. 12). Stimulus 7 was a road image with black lines of 0.6 m width with a 4-m interval between lines (Fig. 13). Stimulus 8 was a road image with repeated gradient patterns of 4-m length, but with the gradient patterns painted in the opposite direction from the first stimulus (Fig. 14).
Figure 10  Road image with gradient patterns at 4-m intervals

Figure 11  Road image with gradient patterns at 2-m intervals

Figure 12  Road image with white and black lines

Figure 13  Road image with black lines at 4-m intervals

Figure 14  Road image with opposite gradient patterns at 4-m intervals

Figure 15  Experimental environment
2.3 Experimental Environment

Figure 15 shows a schematic diagram of the experimental environment. The stimulus was projected at 0.6-m width and 0.8-m height on a screen using a personal computer and a projector. The level of the subject’s eyes and the center of the projected image were adjusted to about 1.2 m in order to ensure consistency with the camera’s height in the simulated road. The distance to the screen from the subject’s eyes was adjusted to about 1.2 m.

2.4 Participants

Fifteen undergraduate and graduate students served as observers (aged 21–24 years; two females and 13 males). All were naive to the purpose of the study and had normal or corrected-to-normal vision.

2.5 Procedure

In random order, each stimulus was displayed on the screen for 5 s after presentation of the image of Fig. 16, which allowed fastening the observer’s gaze. The participants reported their observations about apparent movements or other weak brightness changes of the stimulus.

<table>
<thead>
<tr>
<th></th>
<th>Far to near</th>
<th>Near to far</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig 7</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Fig 8</td>
<td>0</td>
<td>0</td>
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<td>Fig 9</td>
<td>2</td>
<td>0</td>
<td>0</td>
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<td>Fig 10</td>
<td>3</td>
<td>0</td>
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<tr>
<td>Fig 11</td>
<td>2</td>
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<td>1</td>
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<td>Fig 12</td>
<td>1</td>
<td>0</td>
<td>7</td>
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<tr>
<td>Fig 13</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Fig 14</td>
<td>0</td>
<td>3</td>
<td>1</td>
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</table>

2.6 Results and Discussion

Table 1 shows the number of observers who perceived some sort of apparent movements with respect to each stimulus. “Far to near” and “near to far” indicate any movements from far to near side of the road and vice versa. “Others” indicates other movements or weak brightness changes of the gradient pattern.

60% of all participants reported perceiving some movements in the images with the gradient pattern. Figures 9, 10, 11, 12, and 14 induced some movements but these were reported only by a few participants.

In the Fraser-Wilcox illusion, a single gradient pattern hardly creates the illusion effect, but the repetition of these gradient patterns clearly generates the motion illusion. In this experiment, the perspective distorted the size of the gradient elements: smaller at a far distance and larger at a near distance. Thus, the motion illusion induced by the gradient pattern was expected to be perceived weakly.

The maximum number of reported movements was recorded for Figs. 10 and 14; they had the same gradient pattern with a 4-m interval. It can be assumed that this interval is optimal to effectively induce the motion illusion. Furthermore, using the image pattern for the optimized Fraser-Wilcox illusion, the direction of movement seems to be controlled.

Seven subjects perceived other changes when they observed Fig. 12; for example, “it
appeared to be waving along the longitudinal direction” or “the patterns were flickering.” We suggest that the participants perceived an effect such as the Op-Art illusion, because the white and black lines were very close in Fig. 12.

3 EXPERIMENT 2 (VEHICLE SPEED PERCEPTION)

3.1 Purpose of Experiment

The brightness gradient pattern with depth cues had a high likelihood to induce the motion illusion. However, painting the entire road with a gradient pattern would be very expensive in real road construction. In addition, there is the possibility of creating a sense of discomfort in the drivers.

We developed a road design with the brightness gradient pattern on the guardrail and the sideband of the lane. Thus, we conducted an experiment to confirm the effect of this road design on vehicle speed perception.

3.2 Stimulus

An image of a straight road (Fig. 17) was generated by using a computer graphic software (blender 2.69). According to a standard road design established in Japan, the inside of the white lines was 3.5 m, the width of the white line was 0.15 m, and the sideband was 0.75 m. The height of camera was 1.2 m and the angle of view was 60 degrees.

Using this road image, we created additional images: the proposed road with the brightness gradient pattern (4-m interval) painted on the guardrail and the sideband (Fig. 18) and a control road with black lines (4-m interval) painted on the guardrail and sideband (Fig. 19). These intervals were established from the results of Experiment 1. We termed these two types of roads as “gradient pattern road” (Fig. 18) and “black line road” (Fig. 19). Figure 20 shows the brightness gradient pattern used in this experiment.

We then created the driving simulation movies using these roads. We prepared various vehicle speeds. The details are described in section 3.5.

3.3 Experimental Environment

The environment was the same as in Experiment 1 except for the size of the projected image, which was 1.0 m in height and 1.4 m in width in order to ensure consistency with the camera angle in the projected image.

Figure 17 Normal road image

Figure 18 Road image with gradient patterns at 4-m intervals on the sideband and guardrail
3.4 Participants

Fifteen undergraduate and graduate students served as observers (aged 21–25 years; one female and 14 males). Each participant owned a car and used it on a daily basis. All participants were naïve to the purpose of the study and had normal or corrected-to-normal vision.

3.5 Procedure

A paired comparison test was used. Each participant compared the following 72 combinations and selected the movie that induced the faster vehicle speed in each combination.

(1) Gradient pattern road at 40 km/h and normal road at 30, 35, 40, 45, 50, 55, 60, 65, and 70 km/h.
(2) Gradient pattern road at 60 km/h and normal road at 50, 55, 60, 65, 70, 75, 80, 85, and 90 km/h.
(3) Gradient pattern road at 80 km/h and normal road at 70, 75, 80, 85, 90, 95, 100, 105, and 110 km/h.
(4) Gradient pattern road at 100 km/h and normal road at 90, 95, 100, 105, 110, 115, 120, 125, and 130 km/h.
(5) Black line road at 40 km/h and normal road at 30, 35, 40, 45, 50, 55, 60, 65, and 70 km/h.
(6) Black line road at 60 km/h and normal road at 50, 55, 60, 65, 70, 75, 80, 85, and 90 km/h.
(7) Black line road at 80 km/h and normal road at 70, 75, 80, 85, 90, 95, 100, 105, and 110 km/h.
(8) Black line road at 100 km/h and normal road at 90, 95, 100, 105, 110, 115, 120, 125, and 130 km/h.

In random order, each combination of movies was used. Each movie was displayed on the screen after the image of Fig. 21 was shown for fastening the observer’s gaze. When the participants wanted to watch the movie again, the same combination was displayed any number of times until they could decide which movie induced the faster vehicle speed.

3.6 Results and Discussion

We calculated the ratios from the result of the paired comparison that calculated when the gradient pattern and black line road at each vehicle speed induced the faster speed impression than the normal road at each vehicle speed. Figures 22–25 show the ratios between each vehicle speed for the normal and gradient pattern road. Figures 26–29 show the ratios of each vehicle speed for the normal and black line road.

All curves in these figures were obtained by Probit analysis. We defined a ratio of 50% as
equal vehicle speed of normal and gradient pattern or black line road. Table 2 shows the equal vehicle speeds obtained from each graph.

In Table 2, the results of the gradient pattern road show the overestimation of vehicle speed at all generated speeds. The results of the black line road also show the overestimation at a range of 40–80 km/h. Okuno et al. [7] and Kuriyagawa et al. [8] reported that perception of optical flow in peripheral view was important to perceive vehicle speed. We think that this overestimation was caused by the increase of cues to perceive optical flow by the repetitive elements of the gradient pattern or the black lines.

On the other hand, at all vehicle speeds, the gradient pattern road produced higher speed sensitivity than the black line road. Moreover, with increasing vehicle speed, this difference became greater. In particular, at a speed of 100 km/h, the black line road did not create the overestimation but the gradient pattern road did. Therefore, we propose that the gradient pattern creates additional effects for vehicle speed perception. The gradient pattern also has the property to generate motion illusion. It was not clear whether the gradient pattern produced the motion illusion in the road movie or not, but we confirmed the effect of the overestimation.

Both the gradient pattern and black line road produced the highest sensitivity at vehicle speeds of 60 km/h. The interval between repetitive pattern elements was 4 m; thus, we suggest that this high sensitivity is critically dependent on the interval.
Figure 25  Selected ratio of the gradient pattern road at 100 km/h

Figure 26  Selected ratio of the black line road at 40 km/h

Figure 27  Selected ratio of the black line road at 60 km/h

Figure 28  Selected ratio of the black line road at 80 km/h

Figure 29  Selected ratio of the black line road at 100 km/h

Table 2  Perceived equal speed and percentage of overestimation at each vehicle speed

<table>
<thead>
<tr>
<th>Vehicle speed set in movie</th>
<th>Equal vehicle speed of the gradient pattern road</th>
<th>Equal vehicle speed of the black line road</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 km/h</td>
<td>45 km/h (+13%)</td>
<td>43 km/h (+8%)</td>
</tr>
<tr>
<td>60 km/h</td>
<td>71 km/h (+19%)</td>
<td>65 km/h (+9%)</td>
</tr>
<tr>
<td>80 km/h</td>
<td>94 km/h (+18%)</td>
<td>82 km/h (+3%)</td>
</tr>
<tr>
<td>100 km/h</td>
<td>115 km/h (+15%)</td>
<td>98 km/h (-2%)</td>
</tr>
</tbody>
</table>
4 CONCLUSIONS

The purpose of this study was to reveal the effects of gradient patterns on the driver’s speed perception. The first experiment showed that a brightness gradation pattern induced a weak motion illusion in images with pictorial depth cues. Subsequently, we selected the most effective pattern. In the second experiment, results showed strong effects of the gradient pattern on vehicle speed perception. The participants observing the gradient pattern road overestimated the speed by +13–19% compared to the normal road. The effect of the gradient pattern was likely caused by optical flow, which increased with the number of repetitive pattern elements, and by other effects such as motion illusion. The effect of the repetitive elements decreased at higher vehicle speeds while other effects increased. These findings suggest that one possibility of vehicle speed suppression consists of adding gradient patterns to the road design.

REFERENCES