The shape of luminance increments at the intersection alters the magnitude of the scintillating grid illusion

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Abstract

The scintillating grid illusion refers to an illusory perception of black spots on the luminance increments at the intersections of gray grids on a black background. In this study, we examined how the shape of luminance increments modulated the strength of the illusion. In Experiment 1, we concurrently controlled the size and shape of luminance increments, and found significant reduction of the illusory strength on the square, compared with circle and diamond, in the largest size condition. In Experiment 2, we controlled overall orientation of squared luminance increments, and confirmed the significant reduction of the illusion when the relative edge orientation of luminance increments and the grids was larger than 30 deg. This indicates that not the categorical difference of the shape, but the orientation difference between the grids and the luminance increments determines the strength of the illusion. We discussed about the contribution of orientation processing to scintillating grid illusion.

Illusory gray spots are observed on the intersections of white grids against a black background (Fig. 1). The well-known phenomenon is referred to as Hermann Grid Illusion (Brewster, 1844; Hermann, 1870). Previous studies designed several variations of the illusion and showed that the illusion existed even when the grids were sloped (Spillmann, 1994). Lateral inhibition is known as a convincing mechanism for the illusion (Baumgartner, 1960).

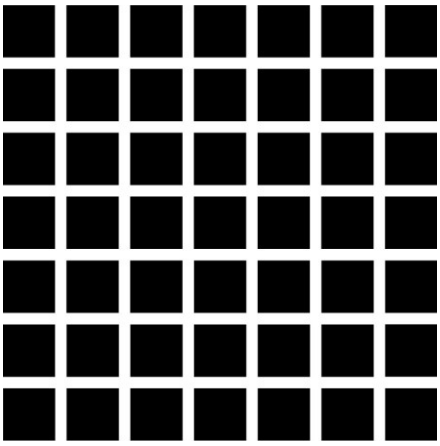

Figure 1. Hermann Grid Illusion

By adding circular luminance increments to the intersections of Figure 1 and reducing the luminance level of the intersections, illusory black spots are observed on the luminance increments (Fig. 2). This illusion is so called, scintillating grid illusion (Schrauf, Lingelbach, & Wist, 1997).

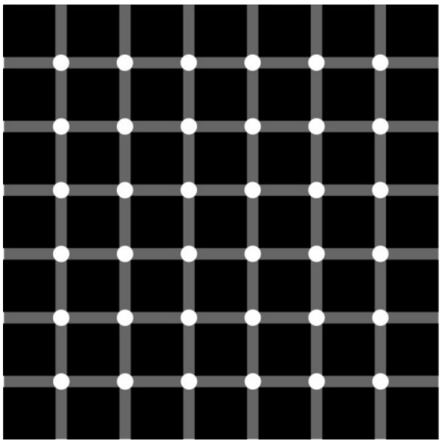

Figure 2. Scintillating Grid Illusion

The scintillating grid illusion is critically different from the Hermann grid illusion in that the illusory black spots are not constantly perceived, but momently scintillated. Why does the percept of scintillation occur? Schrauf and his colleagues conducted experiments on 3 different conditions, pursuit eye movement on stationary grids, smooth displacement of the grids with steady gaze, and brief exposure of the stationary grids, and found that not the eye movement itself but a transient stimulation caused by the eye movements or brief exposures is essential for generating scintillating grid illusion (Schrauf, Wist & Ehrenstein, 2000). They also showed that high stimulus speed or brief exposure less than 210 ms either reduced the strength of the illusion. This indicates that the spatial and temporal integration of the activity of visual neurons is important for generating the illusion. Recently, VanRullen & Dong (2003) reported that the distance between an attended location and intersections determined the strength of illusory spots at the intersections, and implied that the spatial distribution of covert attention affects the illusion. Perhaps, the slow temporal course of scintillating grid illusion may be related with attention shifts that seem to be required for the scintillation of illusory spots.

Furthermore, scintillating grid illusion likely stems from the different mechanism for Hermann grid illusion. As described above, Hermann grid illusion is explained with lateral inhibition (Baumgartner, 1960). However, because of the complexity of the intersections due to the luminance increments, the explanation with Hermann grid illusion cannot perfectly stand for scintillating grid illusion. Moreover, scintillating grid illusion is evidently affected by the diameters of luminance increments that do not exist in Hermann grid illusion.

In this study, we explored the underlying mechanism for the scintillating grid illusion by concurrently controlling the shapes and sizes of the luminance increments. Previous studies examined the effects of sizes and luminance on the illusion (Schrauf, Lingelbach, & Wist, 1997). However, the shape of the luminance increments was not examined: Only circle shape was introduced into luminance increments at the intersections. Thus, it was unclear whether the effect of sizes of luminance increments was common among variable shapes. We planned to test diamond and square shapes beside the original circle shape. Although the two new shapes have the same side length and interior angles, they are different in terms of their overall orientation. By using three kinds of shape, we tried to confirm the role of edge orientation of luminance increments in the illusion. By comparing the strength of the illusion among three shapes, we discuss the underlying mechanism for the illusion in terms of orientation processing.

Methods

Subjects

Five observers (2 males, 3 females; mean age: 26.4 years) served as subjects in Experiment 1 while other five observers (2 males, 3 females; mean age: 26.8 years) participated in Experiment 2. All of them had normal or corrected-to-normal visual acuity. They were naive as to the purpose of the experiments.

Apparatus and stimuli

Stimuli were generated by a computer (VAIO, SONY, Japan) and displayed on the screen of a 19 inch. CRT monitor (FlexScan T761, EIZO, Japan). The subject's head was fixated by a chin rest located 60 cm away from the monitor. The test stimulus was a 8 × 6 scintillating grid with 11.99 × 15.51 deg of visual angle. A bar of a grid had a luminance of 9.72 cd/m^2 and a width of 0.33 deg. The gap between bars was 1.7 deg. Luminance increments had a luminance of 99.5 cd/m^2 and variable sizes. They were presented against a background with a luminance of 2.21 cd/m^2).

In Experiment 1, we employed luminance increments with three shapes (circle, square, and diamond) and with five sizes (0.20, 0.26, 0.33, 0.46, and 0.59 deg). The sizes denote the side length for square and diamond while that of radius of circle. Fifteen stimuli (3 shapes × 5 sizes) were used in total. In Experiment 2, we used squares of luminance increments with the size of 0.59 deg and 6 different orientations (0, 15, 30, 45, 60, and 75°). Each of them appeared twice in a randomized order for each observer (Fig, 3).

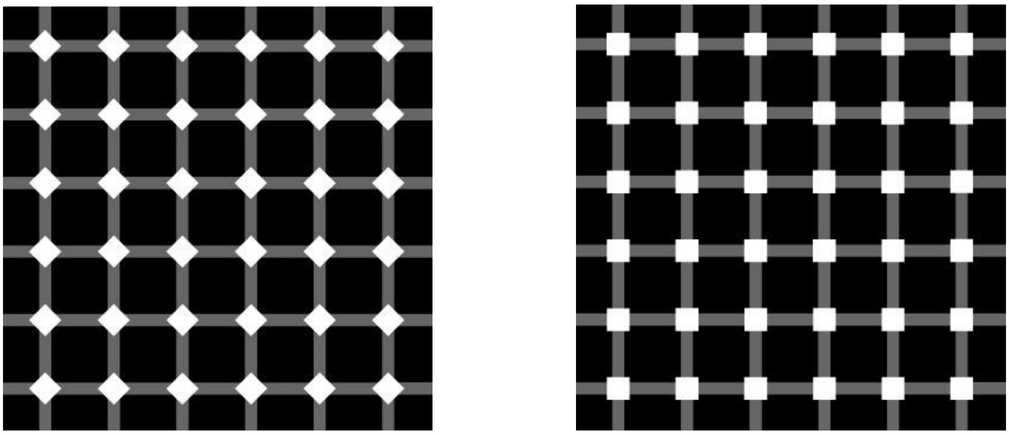
(Diamond, 0.46 deg) (Square, 0.46 deg)

Fig. 3. Stimuli used in Experiment 1

Procedure

For both the experiments, the subjects were asked to rate the strength of the illusion in 7 rating grades without time limits. They were asked for a pilot observation of all the stimuli before rating, to set the criterion for the rating. Before the presentation of each stimulus, the stimulus number was presented for 1 sec. The order of the stimuli for rating was identical to the pilot observation.

Results and Discussion

Experiment 1: the effects of shape and size of the luminance increments

Fig. 4 illustrates the mean rated strength in Experiment 1. A two-way ANOVA revealed the significant main effects of the shape [F (2, 8) = 8.604, p < .05] and the size [F (4, 16) = 3.931, p < .05]. The interaction between them was also significant [F (8, 32) = 3.508, p < .01]. A simple main effect of the shape was significant when the sizes were 0.46 deg (p < .05) and 0.59deg (p < .001), while that of size was significant in the circle (p < .005) and square (p < .005) conditions. Post hoc comparison showed that, in the 0.46 deg condition, the rated strength of circle was significantly greater than that of square (p< .05). In the 0.59 deg condition, the rated strengths of circle and diamond were significantly larger than that of square.

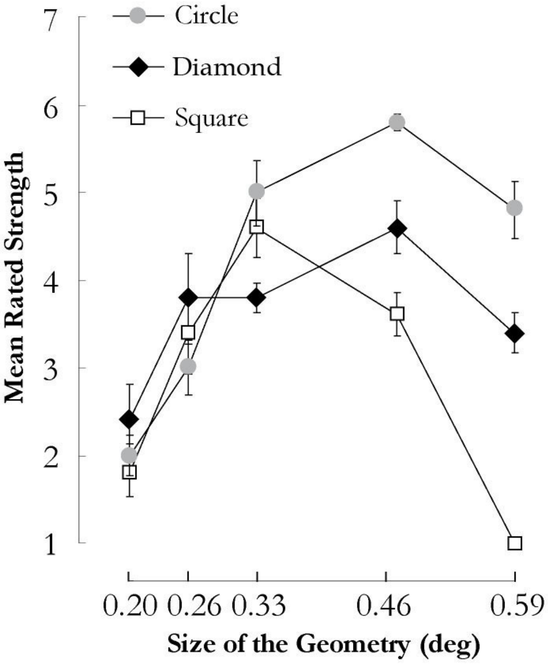

Fig. 4. Strength of illusory black spots in Experiment 1 (N = 5, Error Bar: SEM)

The results of Experiment 1 suggested that the scintillating grid illusion was weakened or disappeared when the luminance increments had square shape. In particular, the rated values drastically decreased in the 0.46 deg and 0.59 deg conditions only when the square condition, even though square and diamond had the same area, side length, and internal angles. This indicates that the mechanism of the scintillating grid illusion involves edge orientation of the luminance increments. We further examined this factor in experiment 2.

Experiment 2: Orientations of the quadrangles

Fig. 5 showed the results of Experiment 2. An ANOVA with orientation as factor revealed the significant main effect of the orientation [F (5, 20) = 56.432, p < .0001]. Multiple comparison tests showed that a pairs of quadrangles which differs more than 30° from 45° were significantly different. The illusion is most prominent when the orientation of quadrangle was 45°, and correspondingly decreased as the orientation changed towards 0°. The results of Experiment 2 also implied that the edge orientation of the luminance increments is concerned in the mechanism of scintillating grid illusion.

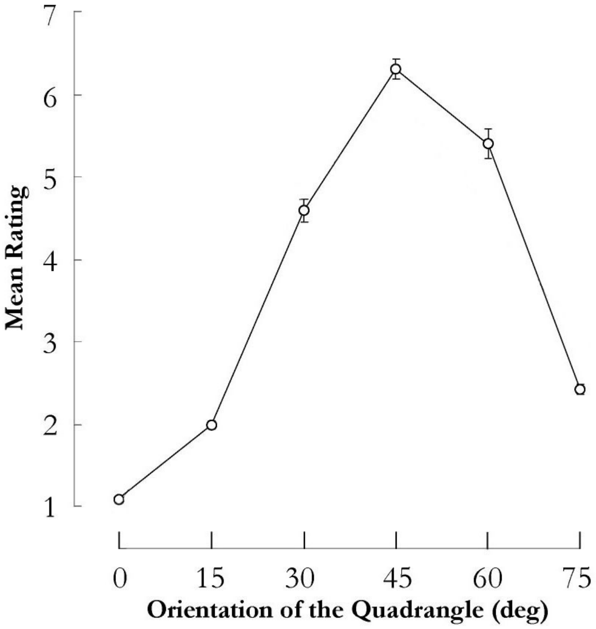

Fig. 5. Strength of illusory black spots in Experiment 2 (N = 5, Error Bar: SEM)

General Discussion

In this study, we examined whether the edge orientation of the luminance increments affected the strength of scintillating grid illusion. In previous researches, only circle shape was introduced into luminance increments in order to investigate the illusion. Meanwhile, the present study used circle, diamond, and square and demonstrated the scintillating effect. However, the strength of the illusion varied with the shapes as well as size. Overall, the variations of size and strength of the illusion in the circle and diamond conditions appeared similar but significantly differed from those of the square condition (Experiment 1). Although the diamond which rotated by 45° consisted with the square, the rated strength in the former shape was significantly greater than the latter shape (Experiment 2). These results indicate that edge orientation of luminance increments affected the illusion.

We consider that the mechanism of the scintillating grid illusion has an orientation tuning. The large population of neurons in the primary visual cortex has an orientation tuning with a bandwidth ranging from 20° to 40° (DeValois & DeValois, 1990). In the present study, the rated strength of the illusion was strongest with 45 deg condition, and was significantly reduced with less than 15 deg and more than 75 deg conditions, in other words, with the overall orientation differences more than 30° from 45 deg conditions. The results are consistent with the orientation tuning found in V1. Therefore, we suggest that orientation processing for luminance increments is one of underlying factors of the scintillating grid illusion.

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