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# The scintillating grid illusion: Influence of size, shape, and orientation of the luminance patches

Kun Qian, Yuki Yamada, Takahiro Kawabe¶, Kayo Miura¶
Graduate School of Human-Environment Studies (¶ Faculty of Human-Environment Studies), Kyushu University, 6-19-1 Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan;
e-mail: kon@psycho.hes.kyushu-u.ac.jp
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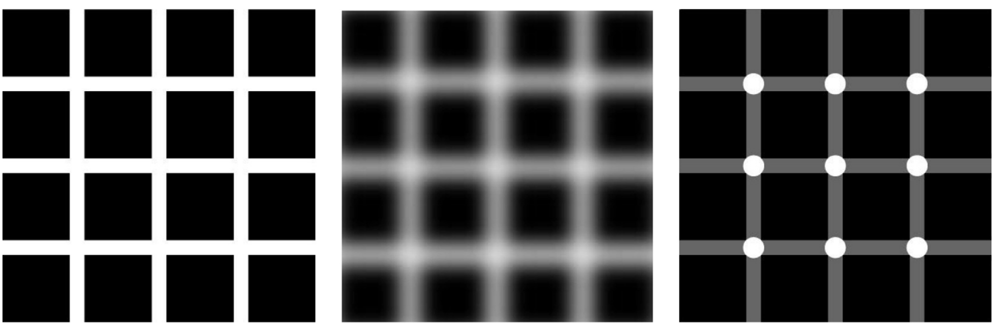
**Abstract.** The scintillating grid illusion refers to the illusory perception of black spots on luminance patches at the intersections of a grey grid on a black background. We examined how spatial parameters of luminance patches modulated the strength of the illusion. In experiment 1, we controlled the size and shape of the luminance patches. For the largest-size conditions tested, we found a significant reduction in the strength of the illusion with squares when compared to circles or diamonds. In experiment 2, we controlled the orientation of quadrangle patches and confirmed a significantly larger reduction in the strength of the illusion when the edge orientations of quadrangle patches were vertical and horizontal (square) than when they were oblique (diamond). To explore the relationship between orientation processing and scintillating grid illusion, we controlled, in experiment 3, the global orientation of the display; the strength of the illusion with diamonds was significantly weaker when it was rotated by 45° than when it was not rotated. These results indicate that it is not only the difference of edge orientation of luminance patches, but also the orientation with respect to the grid that determines the strength of the illusion.

## 1 Introduction

Illusory grey spots are observed at the intersections of a white grid against a black background (figure 1a). This well-known phenomenon is referred to as the Hermann grid illusion (Brewster 1844; Hermann 1870). The phenomenon was first explained as a simultaneous contrast between bright and dark areas (Hermann 1870; Hering 1920). Small eye movements in conjunction with afterimages were proposed as a possible cause of the illusion (Ehrenstein 1941), but this explanation proved unsatisfactory because the illusion was even observed at very brief exposure durations (Spillmann 1971). The most widely accepted explanation is the retinal-ganglion-cell theory proposing that stronger lateral inhibition at the crossings than elsewhere is the source of the illusion (Baumgartner 1960; Wolfe 1984; Spillmann 1994). However, several inconsistent findings related to the retinal ganglion theory have also been reported. For example, visual factors which are assumed to enhance lateral inhibition, such as size variations of stimuli and the addition of diagonal bars, did not effectively influence



(a) (b) (c)

**Figure 1.** (a) Hermann grid illusion; (b) Bergen's illusion; (c) scintillating grid illusion.

the magnitude of the illusion (Lingelbach et al 1985; Spillmann 1994; Schiller and Carvey 2005). On the other hand, visual factors that would not change the putative differential responses of ganglion cells, such as a 45° rotation of the image, serration of bar edges, spatial offset of bars, and the change of size ratio of square size to bar width, reduced the illusory effect (Spillmann 1971, 1994; Spillmann and Levine 1971; Levine et al 1980; Lingelbach and Ehrenstein 2002; Schiller and Carvey 2005). The influences of these visual factors proved the retinal-ganglion-cell theory untenable. A new theory was proposed positing that S1-type simple cells in the primary visual cortex respond to the grid orientation (Schiller and Carvey 2005). Later, an artificial neural network, after training for lightness constancy, was explored as a neural model of the Hermann grid illusion (Bizios et al 2007; Bach 2008). In summary, previous studies have put forward different hypotheses to explain the mechanism of the Hermann grid illusion; however, all these theories assumed that this illusion occurs in the primary visual cortex (Baumgartner 1960; Schiller et al 1976a, 1976b; Spillman 1994; MacEvoy and Paradiso 2001; Schiller and Carvey 2005).

Stimulus modulations of the Hermann grid illusion produce a novel appearance of stimuli or scintillation. This scintillating effect was first produced by blurring the display for Hermann-grid illusion (Bergen 1985): scintillating black spots are seen on the intersections of the blurred grids (Bergen's illusion; figure 1b).

A strong version of the scintillating effect is obtained by adding circular white discs of high luminance to the intersections of the stimuli of the Hermann grid illusion and by reducing the luminance level of the white bars to grey (figure 1c). This phenomenon is called the 'scintillating grid illusion' (Schrauf et al 1995, 1997). The scintillating grid illusion is phenomenally different from the Hermann grid illusion in that the illusory black spots are not constantly perceived, but momentarily scintillate.

Why does the scintillating grid illusion occur? Researchers have examined temporal and spatial properties of this illusion. Regarding temporal properties, Schrauf and colleagues conducted experiments using three different conditions: pursuit eye movements over a stationary grid, smooth displacements of the grid with a steady gaze, and a brief exposure to a stationary grid. They found it was not the eye movement itself, but a transient retinal stimulation caused by eye movements or a brief exposure of the stimuli that was essential for generating the scintillating grid illusion (Schrauf et al 2000). They also showed that a high stimulus speed or a very brief exposure (less than 210 ms) reduced the strength of the illusion.

Spatial properties of the scintillating grid illusion have also been investigated. Schrauf et al (1997) examined the effect of the ratio of grid width to disk diameter on the strength of the illusion and identified an optimal ratio to elicit a strong illusion. Schrauf et al (1997) described that, inconsistent with the Hermann grid illusion, the spatial properties of the scintillating grid illusion are not well explained by simple lateral interactions. Recently, VanRullen and Dong (2003) reported that the distance from the attended location to the intersection was a critical parameter determining the strength of the illusory spots at the intersections, and implied that the spatial distribution of covert attention affects the strength of the illusion. Yu and Choe (2006) proposed a neural model that proves the scintillating grid illusion cannot be simply explained by lateral inhibition. Therefore, it is still unclear what type of spatial interaction in visual processing causes the scintillating grid illusion.

In this study, we explored the spatial mechanism underlying the scintillating grid illusion by controlling the shape, size, and orientation of the luminance patches at the grid intersections. Previous studies have examined only the effects of luminance and the ratio between grid width and disc diameter on the strength of the illusion (Schrauf et al 1997). However, it was unclear whether the size ratio effect could be extended to other shapes. Therefore, we tested the effects of diamonds and squares in addition to the original circle shape. Although the two new shapes (diamond and square) have the same side length and interior angles, they are different in terms of their overall orientation. By using three kinds of shapes, we attempted to confirm the role of edge orientation in the illusion. We also controlled the global orientation of the stimulus display, and examined the effect of relative orientation between grids and luminance patches on the illusion, in addition to the orientation of the luminance patches themselves. By comparing the strength of the illusion with these stimulus variations, we explored the underlying mechanism of the illusion in terms of orientation processing.

## 2 Experiment 1. Shape and size of luminance patches

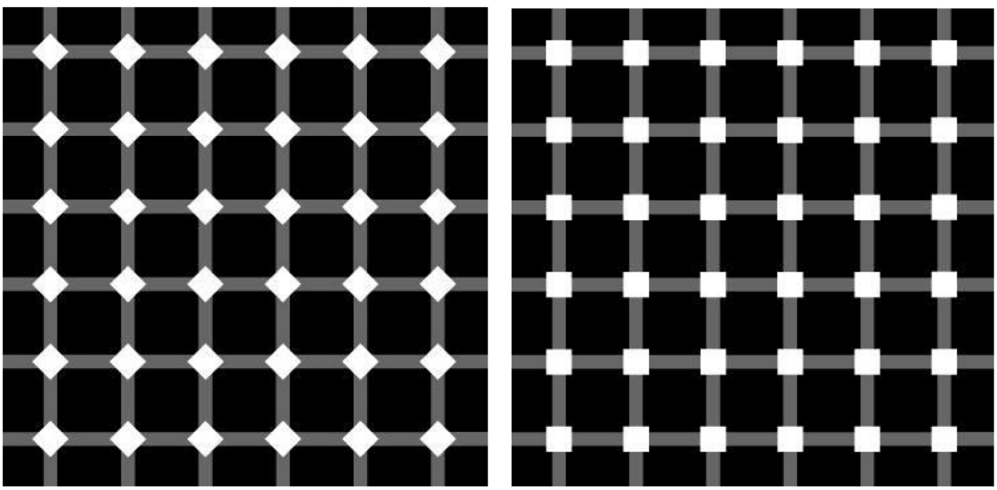
### 2.1 *Observers*

Five students at Kyushu University served as the observers (two males and three females; mean age: 26.4 years). All of them reported normal or corrected-to-normal visual acuity. They were naive as to the purpose of the experiments.

### 2.2 *Apparatus and stimuli*

Stimuli were generated by a computer (Vaio, Sony, Japan) and displayed on a 19-inch CRT monitor (FlexScan T761; Eizo, Japan). The chin head-rest was used to stabilise the visual field of the observers. The visual distance was 60 cm. The test stimulus was an $8 \times 6$ scintillating grid with a visual angle of 11.99 deg $\times$ 15.51 deg. The grey bars of the grid had a luminance of 9.72 cd $m^{-2}$ and a width of 0.33 deg. The distance between the bars was 1.7 deg. The luminance at the grid intersections was 99.5 cd $m^{-2}$, irrespective of shape and size. The black background had a luminance of 2.21 cd $m^{-2}$.

The three shapes (circle, square, or diamond) were presented in five sizes (0.20, 0.26, 0.33, 0.46, or 0.59 deg). The size refers to the side length for the square and diamond, and the diameter of the circle. 15 stimuli (3 shapes $\times$ 5 sizes) were used in total (figures 2a and 2b).



(a) (b)

**Figure 2.** Stimuli used in experiments 1 and 2. The shape of the luminance patches was (a) diamond (0° quadrangle), (b) square (45° quadrangle), or circle (see figure 1c; only used in experiment 1). Only parts of these figures are shown.

### 2.3 *Procedure*

Prior to the main experiment, observers performed a pilot observation of all the stimuli in order to establish the rating criterion. The observers viewed each stimulus without a time limit. In the main experiment, at the initial trial the stimulus number was presented for 1 s and followed by the stimulus display. With no time limit imposed, subjects were asked to rate the strength of the illusion for each stimulus by using a scale ranging from 1 (weak) to 7 (strong) and marking the rating score on the printed scale provided. The order of the test stimuli for the rating was identical to that of the pilot observation.

2.4 *Results and discussion*

Figure 3 illustrates the mean score for illusion strength in experiment 1. A two-way analysis of variance (ANOVA) revealed significant main effects of shape ($F_{2,8} = 8.604$, $p < 0.05$) and size ($F_{4,16} = 3.931$, $p < 0.05$) and a significant interaction between these factors ($F_{8,32} = 3.508$, $p < 0.01$). Tests of simple main effects revealed that the effect of shape was significant for the larger sizes (0.46 deg: $F_{2,40} = 4.853$, $p < 0.05$; 0.59 deg: $F_{2,40} = 14.773$, $p < 0.001$); the effect of size was significant for the circle ($F_{4,48} = 5.334$, $p < 0.005$) and the square ($F_{4,48} = 4.595$, $p < 0.005$). A posteriori comparison (Ryan's method—Ryan 1960) showed that, when the size was 0.46 deg, the strength of the illusion generated with circles was significantly greater than that with squares ($p < 0.05$). When the size was 0.59 deg, the strength of the illusions generated with circles and diamonds was significantly greater than that with squares ($p < 0.05$).

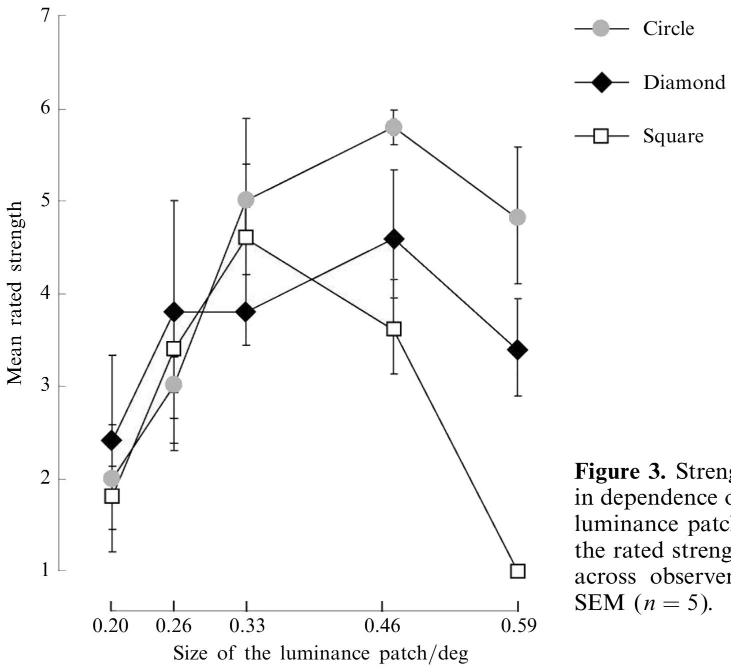



**Figure 3.** Strength of illusory black spots in dependence of the shape and size of the luminance patches. Data points represent the rated strength of the illusion averaged across observers. Error bars denote ±1 SEM ($n = 5$).

The results of experiment 1 suggest that the scintillating grid illusion was weakened or disappeared when the luminance patches were square in shape. The results indicated that the initial increase of the illusion strength with size increments of patches is fairly independent of their shape. For small sizes there was no significant difference among shapes. We considered that these findings might have resulted simply from the size ratio of bar to luminance patch without the contribution of the patch shape. However, the strength of the illusion with the square patches was drastically decreased when the patch sizes were 0.46 and 0.59 deg, whereas the strength of the illusion with the diamond patches was then only moderately decreased. These results are counterintuitive because the square and the diamond had the same area, side length, and internal angles. We reasoned that the results were dependent on the edge orientation of luminance patches. Hence, in the next experiment, we examined whether the strength of the illusion was dependent on the rotation of the quadrangle patches from square to diamond, systematically altering the edge orientation of patches from cardinal (horizontal and vertical) to oblique.

## 3 Experiment 2. Orientation of the quadrangle

### 3.1 *Observers*

Five students at Kyushu University served as observers (two males and three females; mean age: 26.8 years; three of them also participated in experiment 1). All had normal or corrected-to-normal visual acuity. They were naive as to the purpose of the experiments.

### 3.2 *Apparatus, stimuli, and procedure*

The apparatus, stimuli, and procedure for experiment 2 were similar to those used in experiment 1. We used quadrangle patches with a size of 0.59 deg and one of six different orientations (0°, 15°, 30°, 45°, 60°, and 75°) relative to the grey bars of the grid. The patch with 0° orientation corresponded to the square, and the patch with 45° orientation corresponded to the diamond. Thus, the former had vertical and horizontal edges, and the latter had oblique edges. Each stimulus appeared twice in randomised order for each observer, and 12 trials were conducted per observer.

### 3.3 *Results and discussion*

Figure 4 shows the results of experiment 2. The illusion was most prominent when the orientation of the quadrangle was 45° (diamond), and the illusion strength decreased as the orientation was reduced to 0° (square). A one-way ANOVA with orientation as a factor revealed a significant main effect ($F_{5,20} = 56.432$, $p < 0.0001$). Multiple comparison tests (Ryan's method) showed that pairs of 0° – 30°, 0° – 45°, 0° – 60°, 0° – 75°, 15° – 30°, 15° – 45°, 15° – 60°, 30° – 45°, 30° – 75°, 45° – 75°, 60° – 75° were significantly different ($p < 0.05$).

The results of experiment 2 suggest that the edge orientation of the luminance patches is a critical parameter for the scintillating grid illusion. The strength of the illusion increased when the edge orientation of the patches became oblique[(1)] and decreased when the edge orientation of the patches approached cardinal (vertical and horizontal). These results imply that orientation of the patch may underlie the scintillating grid illusion. Results of both experiments 1 and 2 indicate that the scintillating grid illusion

[(1)] In experiments 1 and 2, the strength of the illusion was rated differently even though the stimulus was the same. For example, the rating of the stimulus with 0.59 deg size diamonds was approximately 4 in experiment 1 but was rated 6 in experiment 2. There are several possibilities to explain these differences. First, the difference of observers between the experiments might explain the different results. Second, different rating criteria might be established in the pilot experiment of each experiment with different stimulus sets, and this might lead to the different results between experiments. Specifically, the stimulus set used in experiment 2 did not include the stimulus with circular patches; the stimulus eliciting the maximum strength of the illusion was the one with diamonds in experiment 2. The difference in stimulus sets might affect the difference of relative strength of the illusion between experiments, resulting in the rating difference between experiments.

To confirm the first possibility, we extracted the data of three subjects that participated in both experiments, and checked whether the difference of observers resulted in the inconsistency of results between experiments. If this had been the case, the data from identical observers should not have been different from one another. We ran a two-way ANOVA with factors of experiment (1 and 2) and shape (diamond and square). The result revealed a significant interaction between these two factors ($F_{1,2} = 100.000$, $p < 0.01$). The simple main effect of experiment was significant when the shape was diamond ($F_{1,4} = 48.400$, $p < 0.005$). In other words, subjects rated different strengths for the same stimulus with diamond patches in different experiments. So we suggest that the difference of observers did not involve the difference of results between experiments in the diamond-patch condition. It therefore implies that the inconsistent results originate in the second possibility, namely different rating criteria.

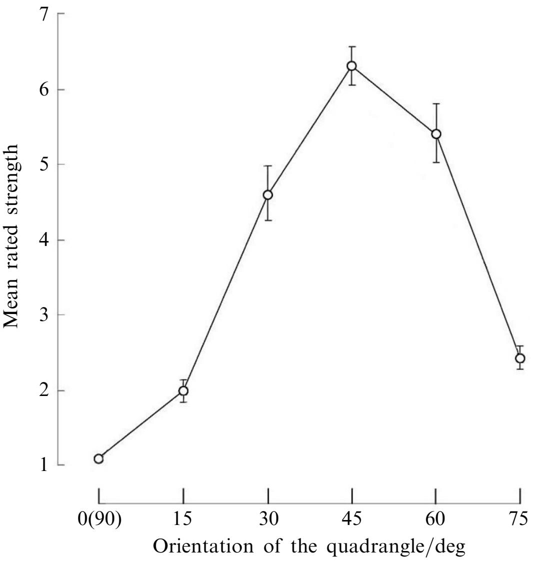



**Figure 4.** Strength of illusory black spots: the effect of edge orientation of a quadrangle with respect to the grey bars of the grid. Data points represent the rated strength of the illusion averaged across observers. Error bars denote $\pm 1$ SEM ($n = 5$).

seems to occur when luminance patches with an orientation other than cardinal are placed at the intersection of the grids.

However, before we reach a firm conclusion we ought to assess the role of orientation interaction between luminance patches and grids in the scintillating grid illusion. In the stimuli used in experiment 2, rotation of quadrangle patches clearly changed the relationship between the edge orientation of the patches and grid orientation. Hereafter, the edge orientation of a luminance patch will be designated as 'absolute orientation' whereas the orientation difference between the grids and the edge of patches will be designated as 'relative orientation'. Although the results in experiment 2 clearly showed the orientation dependence of the illusion, it was unclear whether the orientation dependence stemmed from absolute or relative orientations. To separate the contribution of these two kinds of orientation, we performed the next experiment.

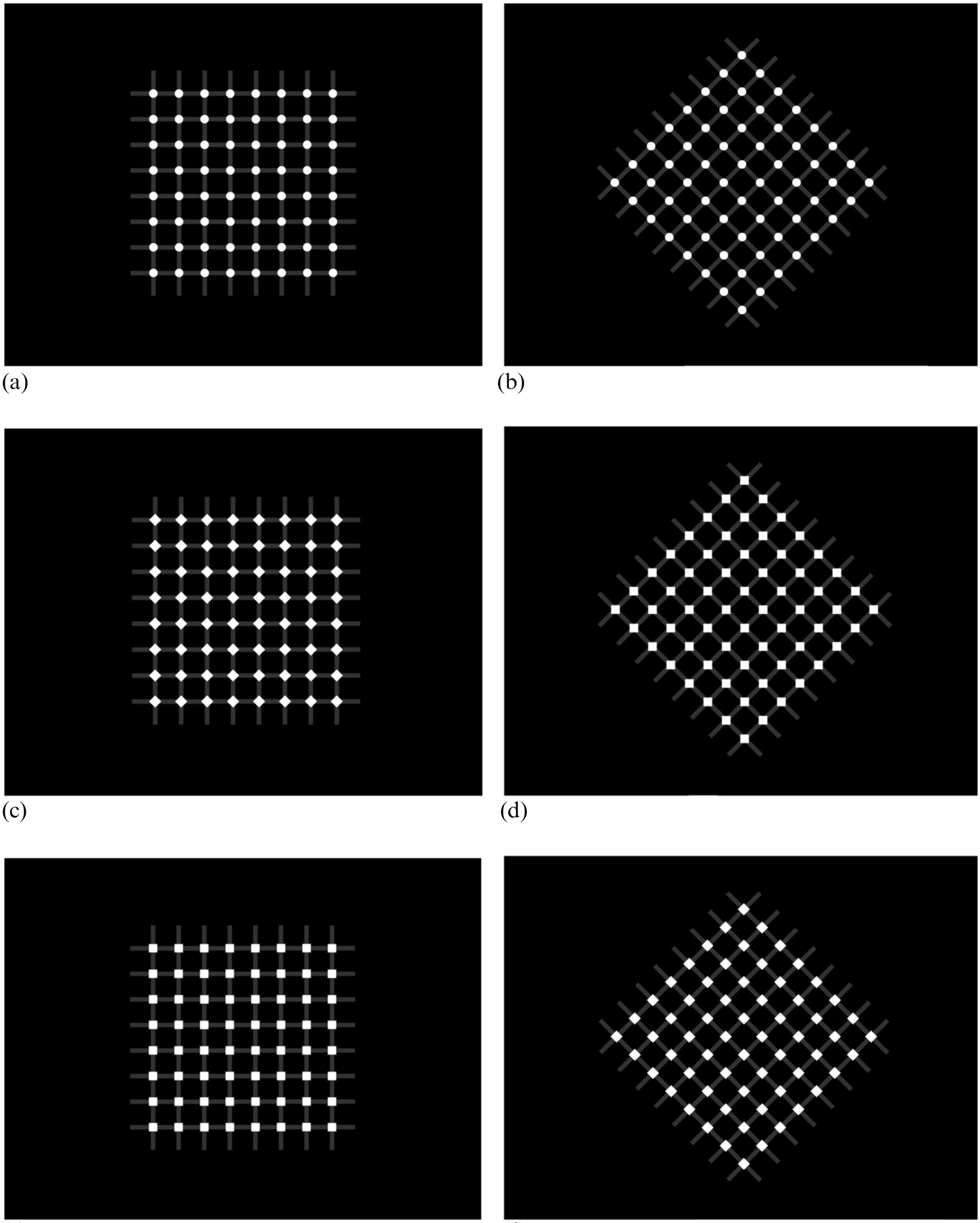
## 4 Experiment 3. Absolute orientation, relative orientation, or both orientations

### 4.1 *Observers*

Five students at Kyushu University served as observers (four males and one female; mean age: 25.8 years; four of them also participated in the previous experiments). All participants reported normal or corrected-to-normal visual acuity. They were naive as to the purpose of the experiments.

### 4.2 *Apparatus, stimuli, and procedure*

The apparatus, stimuli, and procedure were the same as those for experiment 1, except for the following: the test stimulus was an $8 \times 8$ scintillating grid (figure 5) with a visual angle of 15.51 deg $\times$ 15.51 deg. The three shapes (circle, square, or diamond) with a size of 0.59 deg were again employed. In this experiment two kinds of display orientation were used: upright and rotated. The upright display was the original stimulus used in experiments 1 and 2. In contrast, the rotated display was the original version of the display rotated by 45°. Thus, 6 stimuli (3 shapes $\times$ 2 displays) in total were used. The order of stimulus presentation was randomised across observers. We changed rating scales from $1-7$ to $0-6$, with the value of 0 meaning that no illusory spots were observed on the luminance patches. In several trials in experiment 2, some observers reported that no illusion was perceived.



(a) (b) (c) (d) (e) (f)

**Figure 5.** Stimuli used in experiment 3: (a) upright – circle; (b) rotated – circle; (c) upright – diamond; (d) rotated – diamond; (e) upright – square; (f) rotated – square. Note that diamonds become squares when they are rotated by 45°, but they are still labeled as diamonds in accordance with their original shapes.

### 4.3 *Results and discussion*

Figure 6 shows the results of experiment 3. A two-way ANOVA revealed a significant main effect of shape ($F_{2,8} = 139.182$, $p < 0.001$) and display orientation ($F_{1,4} = 45.375$, $p < 0.005$) and a significant interaction between these factors ($F_{2,8} = 8.432$, $p < 0.05$). Tests of simple main effect revealed that the effect of shape was significant for both displays (upright: $F_{2,16} = 71.437$, $p < 0.001$; rotated: $F_{2,16} = 61.065$, $p < 0.001$). In the following statistical description, we labeled circle as ‘C’, diamond as ‘D’, and square as ‘S’.

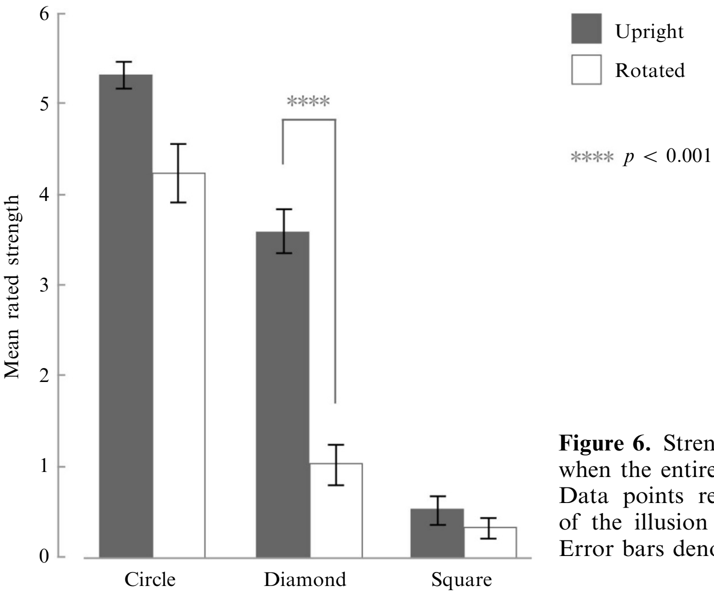



**Figure 6.** Strength of illusory black spots when the entire figures are rotated by 45°. Data points represent the rated strength of the illusion averaged across observers. Error bars denote $\pm 1$ SEM ($n = 5$).

A posteriori comparison (Ryan's method) showed that, for the upright display, the three shape pairs, C–D, D–S, and C–S, were significantly different ($p < 0.05$). On the other hand, for the rotated display, D–S was not significantly different, whereas C–D and C–S were significantly different ($p < 0.05$).

As observed in experiment 1, in the upright display the illusions were strongest in the circle condition and weakest in the square condition. In this experiment we found, for the first time, that this tendency to see illusion with both shapes was preserved irrespective of the display orientation.

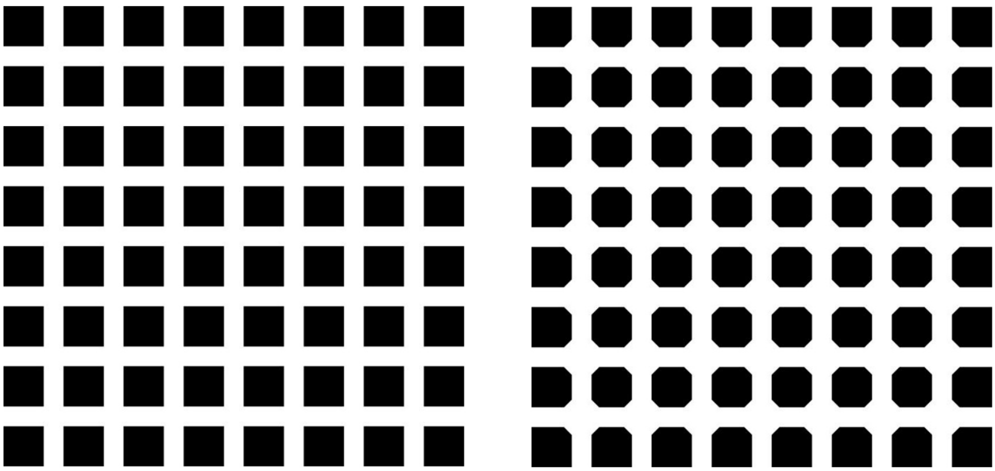
However, in the diamond condition, remarkable changes occurred across display rotations. The illusion became significantly weaker when the display was rotated; that is, the shape of the luminance patches changed from diamond to square, whereas in the square condition the illusion did not become strong when the luminance patches were changed from squares to diamonds. In both diamond and square conditions of the rotated display, either the absolute orientation or the relative orientation was 0°. In these situations the illusion was weak.

Therefore, we suggest that not only the orientation of the luminance patches but also the relative orientation between grids and edges of luminance patches influence the scintillating grid illusion. Specifically, the illusion was reduced in either of the following two cases: (i) when the edge orientations of patches were vertical and horizontal or (ii) when the edge orientations of patches were parallel and orthogonal to the grid. In the circular patch condition, no change in the strength of the illusion was observed. We propose that this is because the edge orientation of the circular patches was neither vertical nor horizontal and because the edge orientation of the patches was neither parallel nor orthogonal. The upright display with the diamond patches elicited a relatively strong illusion. We posit that this is because the edge orientation of the diamond was oblique and diagonal with respect to the grid. It should be noted that the diamond patches in both the upright and rotated displays produced equal sampling properties of receptive field in the retina while the strength of illusion was different for these two displays. These results support the previous suggestion that lateral interaction does not involve the scintillating grid illusion (Schrauf et al 1997; Yu and Choe 2006).

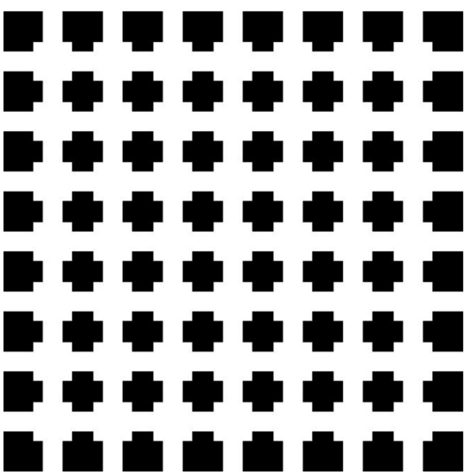
## 5 General discussion

In this study, we examined whether the size, shape, and orientation of luminance patches affect the strength of the scintillating grid illusion. In previous studies of this illusion, only the parameters of white circular disks were investigated. The present study used luminance patches of circles, diamonds, and squares to examine whether the scintillating grid illusion was affected by the shape as well as size of the patches. The illusion in the circle and diamond conditions was stronger than the one in the square condition when the patch size was large (experiment 1). The patches with oblique edge orientation caused a stronger illusion than those with vertical and horizontal edge orientation (experiment 2). Furthermore, besides the orientation of the luminance patches per se, the relative orientation between the patches and grids was also a parameter modulating the strength of the illusion (experiment 3). These results validate the importance of orientation processing for the scintillating grid illusion.

How can we explain the interaction between the shape and size of luminance patches in experiment 1? Given that the effect of shape was observed when the size of the patches was more than 0.46 deg but not when it was below 0.46 deg, we suggest that when patch size is below 0.46 deg, the visual detectors not sensitive to shape/orientation may be involved in the illusion. As patch size increases, the scale information (spatial



(a) (b)



(c)

**Figure 7.** An original Hermann grid illusion (a) in comparison with illusions resulting from shapes added to luminance patches at the intersections of the grid: diamonds (b) and squares (c).

frequency components) of the patches gradually approaches that of the grids and likely causes the orientation interaction between the patches and the grids. This interpretation is supported by previous studies showing that orientation integration across scales is more difficult than the integration within a scale (Dakin and Hess, 1999a, 1999b). Thus, our results indicate that the scintillating grid illusion is based on spatial integration of orientation information in addition to scale-sensitive processing as shown in Schrauf et al (1997).

However, clarification is still needed to determine why the cardinal orientation of the patch inhibited the scintillating grid illusion. As a speculation, we propose that figural organisation that is induced by the addition of luminance patches at the intersections alters the strength of the illusion. Figure 7 shows the Hermann grid illusion with and without luminance patches at the intersections of the grid. In our preliminary observation, the Hermann grid illusion was reduced when squares were added to the intersections (figure 7c). Moreover, the addition of squares at the intersections produced a cross-like shape on the grid. This cross-like shape did not occur when diamonds were added (figure 7b), and in this case the Hermann grid illusion was to an extent retained. We suggest that figural organisation involving the generation of a cross-like shape inhibits the orientation interaction across space, resulting in the reduction of the Hermann grid illusion. In the present study, the spatial interaction of orientation processing was the key mechanism for the scintillating grid illusion. If the scintillating grid illusion shares a common mechanism with the Hermann grid illusion, the figural organisation involving the cross-like figure might also induce the reduction of the scintillating grid illusion. Further investigations of this issue are warranted to clarify the mechanism underlying the scintillating grid illusion as well as the Hermann grid illusion.

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