Eggs illusion: Local shape deformation generated by a grid pattern

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In this study, we report a new visual shape illusion, the eggs illusion, in which circular disks located at the midpoints between adjacent grid intersections are perceived as being deformed to ellipses. In Experiment 1, we examined the eggs illusion by using a matching method and found that grid luminance and patch size play a critical role in producing the illusory deformation. In Experiment 2, we employed several types of elliptic or circular patches to examine the conditions in which the illusory deformation was cancelled or weakened. We observed that the illusory deformation was dependent on local grid orientation. Based on these results, we found several common features between the eggs illusion and the scintillating grid illusion. This resemblance suggests a possibility that similar mechanisms underlie the two phenomena. In addition to the scintillating grid illusion, we also considered several known perceptual phenomena that might be related to the eggs illusion, i.e., the apparent size illusion, the shape-contrast effect, and the Orbison illusion. Finally, we discuss the role of orientation processing in generating the eggs illusion.

Introduction

Grid patterns are widely known to produce several illusory effects at the intersections of the grid. The Hermann grid illusion, in which illusory dark smudges are perceived at the intersections of a white grid within a black background, is the earliest grid illusion discovered (Brewster, 1844; Hermann, 1870). Bergen (1985) found that blurring the display of the Hermann grid illusion could enhance the illusory dark smudges to scintillating black spots (also referred to as the Bergen grid illusion). Such a scintillating effect was further developed by using a nonblurring presentation of white circular disks located at the intersections of a gray grid within a black background. In the scintillating grid illusion (Schrauf, Lingelbach, Lingelbach, & Wist, 1995; Schrauf, Lingelbach, & Wist, 1997), illusory scintillating dark spots are observed in circular patches. Psychophysical evidence suggests several common features between the Hermann grid illusion and the scintillating grid illusion. These features include: (a) luminance contrast among the geometrical elements (i.e., white disks, a bright grid consisting of orthogonal bars, and black background squares divided by the grid) affects the illusions (Hering, 1920; Hermann, 1870; Schrauf et al., 1997); (b) size relationship among the geometrical elements also affects the illusions (Schiller & Carvey, 2005; Schrauf et al., 1997); (c) both illusions occur in the periphery (Hering, 1920; Schrauf et al., 1997; VanRullen & Dong, 2003); (d) eye movements are essential in generating both illusions (Ehrenstein, 1941, 1954; Schrauf et al., 1997; Verheyen, 1961); (e) both illusions occur even with a brief presentation (Schrauf, Wist, & Ehrenstein, 2000; Spillmann, 1971); (f) orientation information is critical for generating both illusions (Geier, Bernáth, Hudák, & Séra, 2008; Qian, Yamada, Kawabe, & Miura, 2009). These common features indicate that the Hermann grid illusion and the scintillating grid illusion share a common underlying mechanism. Several hypotheses and ideas have been proposed to explain the Hermann grid illusion (Schiller & Carvey, 2005) and the scintillating grid illusion (Qian, Kawabe, Yamada, & Miura, 2012).

The grid illusions just introduced are all perceptual phenomena of brightness. This means that the intersections in these stimuli can be perceived as darker (or brighter in a contrast-reversed version of the patterns) than the other parts with the same luminance. In addition to these grid illusions on brightness, Kawabe, Qian, Yamada, and Miura (2010) reported that grid patterns also produce a
visual illusion on shape. In the pattern created by Kawabe et al., diamond-shaped patches located at the intersections of the grid are perceived as jaggy (Kawabe et al., 2010). The jaggy diamonds illusion also shares common features with the scintillating grid illusion as well as with the Hermann grid illusion. For example, the illusion is evident when the luminance contrast between the patches and background is higher, and is weakened by rotating the overall pattern by $45^\circ$.

In this study, we report another type of shape deformation illusion generated by a grid. Figure 1 is an example of the pattern we created. In contrast to the grid illusions described already, we put small patches not at the grid intersection, but at the midpoints between the adjacent intersections. Circular disks located at the midpoint of the intersections seem to be perceived as being deformed to egg-like ellipses. In an attempt to examine this “egg-like” appearance formally, we conducted psychophysical experiments by using matching and cancellation methods. The purpose of the present study is to demonstrate the existence of the “eggs” illusion, and to explore which stimulus parameters affect the magnitude of the illusion. Based on the results of these experiments, we will discuss (a) the relationship between the eggs illusion and other known perceptual phenomena including the scintillating grid illusion and (b) several possible mechanisms underlying the eggs illusion.

**Experiment 1: The effect of grid luminance and patch size**

As this was the first exploration of the eggs illusion, we varied the luminance of the grid and the size of the circular patches, which are known to play a role in the scintillating grid illusion. To measure the magnitude of the illusion, we used a matching method in which observers choose the ellipse that is close to the perceived shape of the circular patches. We expected that, if the illusory deformation is stronger, the matched shape would be more elliptic.

**Methods**

**Observers**

Ten observers participated in Experiment 1 (seven males and three females; mean age: 26.9 years). All had normal or corrected-to-normal visual acuity and were naïve as to the purpose of the experiment. The experiment was conducted in accordance with the Declaration of Helsinki.

**Apparatus and stimuli**

Stimuli were generated by a computer (Apple, Mac Pro, MA356J/A, California) and displayed on a 22-inch CRT monitor (Mitsubishi, Diamondtron Flat, RDF221S, 1152 × 870 pixels, 75 Hz, Japan). The experiment was run by using MATLAB R2007a and Psychtoolbox (Brainard, 1997; Pelli, 1997). Observers binocularly viewed the screen with a chin-and-forehead rest. The viewing distance was 60 cm.

The test stimulus consisted of an $11 \times 11$ grid with a visual angle of $25^\circ \times 25^\circ$. The grid consisted of vertical and horizontal gray bars with a width of 35.4’. The distance between the centers of the bars was 1.73$^\circ$ across all conditions. Ten circular bright patches were positioned on each gray bar. Each patch was located just at the middle of two adjacent crosses. The luminance values of the circular patch and background were 94 cd/m$^2$ and 1.2 cd/m$^2$, respectively. All stimuli were drawn using the antialiasing method.

The luminance of the grid and the size of circular patches were varied as independent variables. The luminance of the grid was selected from 6 cd/m$^2$, 13 cd/m$^2$, 19 cd/m$^2$, and 26 cd/m$^2$, and the diameter of circular patches was selected from 35.4’ (same as the width of the gray bars), 39.6’, 44.4’, 49.2’, and 52.8’ (Figure 2). The diameter of the circular patches in all conditions was equal to or greater than the width of the gray bars. Circular patches with a smaller diameter were not used, because they might not be properly displayed on the monitor that we used (1152 × 870 pixels).

For the response display, a nine-point scale was presented on the black background after the test.
stimulus disappeared (Figure 3). Under the leftmost point of the scale, two circular patches with a diameter of 44.4' were displayed. Similarly, under the third, fifth, seventh, and ninth points of the scale, four sets of elliptic patches were displayed. In one set, two elliptic patches of the same size that differed in orientation (one was vertical and the other was horizontal) were located under the scale point. All eight ellipses had a minor-axis length of 44.4' (the same as the diameter of the circular patches). The major-axis lengths of the ellipses under the third, fifth, seventh, and ninth points were 48.0', 50.4', 54.0', and 57.6', respectively. Therefore, for the five sets of circular or elliptic patches, their aspect ratios were 1.00, 1.08, 1.14, 1.22, and 1.30.

Procedure

The experiment was conducted in a darkened room. At the beginning of each trial, a black background was presented for 1 s, and followed by a 200-ms presentation of a fixation cross (1.1' x 1.1' ; 94 cd/m²). After the fixation cross disappeared, the test stimulus was presented for 1 s. We chose the exposure duration of the test stimulus (1 s) based on our preliminary observations, in an attempt to make it easy for the naive observers to judge the perceived shape of the patches. A previous study showed that the scintillating grid illusion occurs during a 1-s presentation (Schauf et al., 2000). Observers were instructed to view the stimulus without keeping their eyes on a particular position of the stimulus. After the test stimulus disappeared, the response display appeared. Observers’ task was to choose the patch whose perceived aspect ratio was the closest to the test disks among the nine alternatives. Speeded response was not required for their judgment. Observers were also instructed, in case that perceived patch shapes were different among different locations, that they should select the average shape. The next trial started 1 s after the observers’ response.

Twenty test conditions (4 grid luminance x 5 patch size) were tested in a randomized order. Each stimulus was tested six times, yielding 120 experimental trials. Ten practice trials were run before the experimental trials.

Results and discussion

Figure 4 shows the perceived aspect ratios averaged over the ten observers in Experiment 1. A two-way within-participant analysis of variance (ANOVA) was performed on the mean aspect ratios, with the factors of grid luminance and patch size. We found significant main effects of grid luminance \( F(3, 27) = 37.8, p < .0001 \) and patch size \( F(4, 36) = 69.2, p < .0001 \), and a significant interaction between the two factors \( F(12, 108) = 5.53, p < .0001 \). Tests of simple main effects revealed that the effect of grid luminance was significant for all patch sizes \( 35.4' : F(3, 135) = 34.1, p < .0001; 39.6' : F(3, 135) = 32.8, p < .0001; 44.4' : F(3,
135) = 13.9, p < .0001; 49.2: F(3, 135) = 9.60, p < .0001; 52.8: F(3, 135) = 5.04, p < .005; 19 cd/m²: F(4, 144) = 47.6, p < .0001; 26 cd/m²: F(4, 144) = 39.8, p < .0001. Multiple comparisons with Ryan’s method (Ryan, 1960) showed that perceived aspect ratios were significantly different for each pair of all grid-luminance combinations except for a pair of 19 and 26 cd/m² (ps < .05) and for each pair of all patch-size combinations of (ps < .05).

These results suggest that illusory deformation depended on both grid luminance and patch size. The brighter the grid was (i.e., a higher contrast between the grids and the background) or the smaller the patches were, the more the patches appeared elliptic. When the grid luminance decreased or the patch size increased, the illusion tended to disappear (i.e., the patches were perceived veridically—circular). At least for the patches whose widths were greater than the bar width, these influences of grid luminance and patch size on the eggs illusion are similar to the case of the scintillating grid illusion (Schrauf et al., 1997).

At each of the five positions in the response display used in Experiment 1, two elliptic patches whose orientation differed were presented. Thus, Experiment 1 is not sufficient to reveal the orientation of perceived deformations with respect to the grid bars. Based on our informal observations, patches located on horizontal bars appeared elongated vertically, whereas those located on vertical bars appeared elongated horizontally. This is consistent with subjective reports by several naive observers. To examine this point formally, we conducted Experiment 2.

**Experiment 2: Cancellation of the eggs illusion**

In this experiment, circular patches used in Experiment 1 were replaced by ellipses whose aspect ratio was systematically varied with respect to grid orientation. For a given test stimulus, the orientation of elliptic patches was consistent with or orthogonal to the local grid orientation. Observers’ task was to choose the patch whose aspect ratio was close to that of perceived patch shape in the test stimulus. If the illusory deformation is related to local grid orientation, it would be cancelled out or reduced by using elliptic patches that have a particular aspect ratio with respect to local grid orientation.

**Methods**

**Observers**

Ten observers participated in Experiment 2 (eight males and two females; mean age: 27.5 years; 5 of them also participated in Experiment 1). All had normal or corrected-to-normal visual acuity, and were naive as to the purpose of the experiment.

**Apparatus and stimuli**

The apparatus and stimuli were identical to those of Experiment 1, except for the following: because the results obtained in Experiment 1 were similar for grid luminance values of 19 cd/m² and 26 cd/m², we did not...
include a grid luminance of 19 cd/m² in Experiment 2. Therefore, three values of the grid luminance, 6 cd/m², 13 cd/m², and 26 cd/m², were used in Experiment 2.

Unlike in Experiment 1, the patch shape of the test stimulus was circular or elliptic. The aspect ratio of the patches was varied with respect to local grid orientation. The aspect ratios were 0.87, 0.91, 0.96, 1.00, 1.05, 1.09, and 1.14. The diameter of the circular patch was 39.8'. To control the patch size, the area of the patches was kept constant across different patches. For the elliptic patches, the lengths of the axis along the local grid orientation was 37.2', 38.0', 39.0', 40.8', 41.6', and 42.5', and those of the other axis were 42.7', 41.7', 40.7', 38.9', 38.1', and 37.4', respectively (Figure 5). For the same reason stated in Experiment 1, only elliptical patches whose axes were longer than the bar width were employed in Experiment 2.

For the response display, a six-point scale was used. A pair of two sample patches with the same aspect ratio was displayed under each of the six points on the scale. Sample patches at the leftmost point were two disks with a diameter of 39.8'. For each of the second to the sixth points from the left end, two ellipses with the same aspect ratio but with different orientations orthogonal to each other (vertical and horizontal) were located. The sizes of the five ellipses were 39.0' × 40.8', 38.0' × 41.6', 37.2' × 42.5', 36.4' × 43.4', and 35.4' × 44.3.' Consequently, the aspect ratios of the sample patches were 1.00, 0.96, 0.91, 0.88, 0.84, and 0.80.

Procedure

The procedure was the same as that of Experiment 1, except for the following: in each trial, observers were asked to choose one of the six alternative sample patches that was the closest to the one they perceived in the test stimulus. No feedback on response accuracy was provided.

Each block consisted of 21 trials (7 patch shapes × 3 repetitions). Grid luminance was varied across blocks. Each observer completed 15 experimental blocks (3 grid luminance × 5 repetitions). Block order was counterbalanced across blocks and observers. For each observer, 315 experimental trials (21 trials × 15 blocks) were tested in total. Before the experimental trials, each stimulus condition was tested twice, yielding 42 practice trials.

Results and discussion

Figure 6 shows the perceived aspect ratios averaged over the ten observers in Experiment 2. A two-way within-participant ANOVA was performed on the mean perceived aspect ratios, with the factors of grid luminance and patch aspect ratio. We found
significant main effects of grid luminance \( F(2, 18) = 29.2, p < .0001 \) and patch aspect ratio \( F(6, 54) = 54.7, p < .0001 \), as well as a significant interaction between these two factors \( F(12, 108) = 10.1, p < .0001 \). Tests of simple main effects revealed that the effect of grid luminance was significant for all patch aspect ratios except for an aspect ratio of 0.91 [0.87 aspect ratio: \( F(2, 126) = 6.30, p < .005; 0.91 \) aspect ratio: \( F(2, 126) = 2.21, p = .11; 0.96 \) aspect ratio: \( F(2, 126) = 15.5, p < .0001; 1.00 \) aspect ratio (circular patches): \( F(2, 126) = 27.0, p < .0001; 1.05 \) aspect ratio: \( F(2, 126) = 29.2, p < .0001; 1.09 \) aspect ratio: \( F(2, 126) = 12.5, p < .0001; 1.14 \) aspect ratio: \( F(2, 126) = 7.28, p < .005 \); the simple main effect of patch aspect ratio was significant for all grid luminance conditions [6 cd/m\(^2\): \( F(6, 162) = 49.6, p < .0001; 13 \) cd/m\(^2\): \( F(6, 162) = 42.6, p < .0001; 26 \) cd/m\(^2\): \( F(6, 162) = 41.3, p < .0001 \].

To examine the orientation of the illusory deformation quantitatively, we fitted a Gaussian function to the perceived aspect ratios. The Gaussian function had three free parameters: the mean, standard deviation (SD), and peak amplitude. The Gaussian curve was assumed to have an asymptote of 0.8, corresponding to the leftmost of the response scale. The fitting curves are also shown in Figure 6. \( R^2 \) values were 0.97, 0.94, and 0.98 for grid luminance values of 6 cd/m\(^2\), 13 cd/m\(^2\), and 26 cd/m\(^2\), respectively. One-way ANOVA with the factor of grid luminance was performed on the best-fit values of amplitude, mean, and SD. Significant main effects were found in all three analyses [Amplitude: \( F(2, 18) = 25.4, p < .0001 \); Mean: \( F(2, 18) = 17.2, p < .0005 \); SD: \( F(2, 18) = 3.76, p < .05 \)]. These analyses are consistent with the results in Experiment 1, showing the effects of grid luminance on illusory deformation.

The best-fit values of the mean of the Gaussians calculated from the averaged data of 10 observers were 0.982, 0.964, and 0.947 for grid luminance values of 6 cd/m\(^2\), 13 cd/m\(^2\), and 26 cd/m\(^2\), respectively. We marked these values in Figure 6. These values represent the conditions in which patch shape was mostly perceived as circular. As shown by the gaps between these values and the veridical one (i.e., aspect ratio = 1.00), when the grid was brighter, more elongated ellipses were needed to counteract illusory deformation effects. Consistent with the discussion in Experiment 1, these results suggest that brighter grids generated a greater illusory deformation.

The averaged best-fit values of amplitude among the ten observers were 0.965, 0.954, and 0.941 for grid luminance values of 6 cd/m\(^2\), 13 cd/m\(^2\), and 26 cd/m\(^2\), respectively. These results imply that the proportion of “circular” responses became higher as the grid was darker. Higher amplitude values mean a tendency toward “circular” responses (aspect ratio = 1.00), which suggests a weakening of the illusion under darker grid conditions.

Figure 7. Illusory deformations occur even when the circular patches are replaced by diamond-shaped patches. The orientation of deformation seems to be the same as that observed with circular patches. Diamond patches are perceptually elongated in the orientation orthogonal to the local grid orientation.

**General discussion**

The present study examined the illusory deformation in which white circular patches located on a gray grid are perceived as elliptic patches. In Experiment 1, we used a matching method to ascertain the existence of the illusion, and demonstrated the effect of patch size and grid luminance on perceived patch deformation. In Experiment 2, we employed a cancellation method with elliptic patches to show that the illusory deformation occurs in the orientation orthogonal to local grid orientation, and provided further evidence for the importance of grid luminance in generating the eggs illusion.

**Related perceptual phenomena including previously-reported illusions**

Are some known geometrical illusions related to this illusion? There are four potentially related perceptual phenomena: the scintillating grid illusion, the illusion of apparent size, the shape-contrast effect, and the Orbison illusion. In an attempt to argue that the eggs illusion is different from these illusions and discuss possible underlying mechanisms, we will analyze the similarities and the differences between the eggs illusion and previously reported illusions in detail.
It is clear that stimulus configurations for grid illusions on brightness such as the scintillating grid illusion and the Hermann grid illusion are similar to those of the eggs illusion. How do these illusions depend on stimulus parameters? Taking the scintillating grid illusion as an example, there are four common features between the scintillating grid illusion and the eggs illusion.

First, the size of white patches and the luminance of a grid are important in generating the scintillating grid illusion (Schrauf et al., 1997). These two factors have also been demonstrated as important in producing the eggs illusion in this study. Second, a previous study found that the scintillating grid illusion occurs not only with circular patches, but also with diamond patches (Qian et al., 2009). Similarly, if we change circular patches in the eggs illusion into tilted square patches, the patches are also perceived as rhombi with non-right angles (Figure 7). Third, Qian et al. (2009, 2012) showed that processing of orientation information provided by grid bars is essential for generating the scintillating grid illusion. For example, Qian et al. (2012) demonstrated that discontinuous bars attenuate the scintillating grid illusion. Similarly, when straight continuous bars are replaced by discontinuous bars (Figure 8), the eggs illusion seems to disappear. Fourth, Qian et al. (2012) reported that the scintillating grid illusion only occurs in the periphery. Likewise, based on our informal observations, the eggs illusion is also likely to occur in the periphery. When the circular patch is viewed in the fovea, it appears circular, as it physically is.

Even though there are such considerable common features, the scintillating grid illusion and the eggs illusion are essentially distinguishable from each other because the visual attributes of the illusions are totally different. Whereas the scintillating grid illusion involves a perception of brightness, the eggs illusion involves a perception of shape.

Another possibly related phenomenon is the illusion of apparent size, also called the irradiation illusion (Helmholtz, 1867; van Erning, Gerrits, & Eijkman, 1988). A greater luminance contrast makes a white square surrounded by a brighter background perceived bigger than that surrounded by a darker background. This phenomenon might also occur around the patches in the eggs illusion. The apparent size of the arc bounded on the gray area (grid, Figure 9a) might be smaller than that of the arc bounded on the black area (background, Figure 9b). The illusion of apparent size might result in a perception of deformed disks and also account for the orientation of perceived deformation in the eggs illusion.

Changes in apparent size can account for the orientation dependency of the illusory deformation, but not for the other features of the eggs illusion. Here we discuss three points. First, as in the case of the scintillating grid illusion, the deformed patches are also “leaping,” which means that they are briefly and randomly generated in the periphery. Obviously, this leaping appearance cannot be explained by apparent size changes. Second, under conditions of a bigger patch size (Figure 9b), the portion of arcs abutting to the black background increases. A lower contrast with the arcs in Figure 9a should increase the illusory deformation. However, as shown in the results of Experiment 1, the use of bigger patches actually reduced the perceived deformation. Third, an anony-
mous reviewer pointed out that disks located at the intersections of grids or checkerboard patterns may also deform in some cases, depending on their contrast relative to the local background. One such illusion is similar to that reported on a website (Kitaoka, 2015), where lower-contrast edges appear to expand (Figure 10). This is very interesting, as the orientation of the deformation appears to be opposite to that observed in the eggs illusion. Although we have no clear explanations for these phenomena, the differences in appearance may also be related to differences in local orientation information. That is, in the eggs illusion, patches are locally surrounded by edges parallel to each other, whereas in the phenomena discussed by the anonymous reviewer, the patches are surrounded by edges orthogonal to each other.

**Shape-contrast effect**

The third noteworthy phenomenon is the shape-contrast effect under a condition of brief stimulus presentation. Briefly displayed circle preceded by a flashed line is perceived as an ellipse elongated in the direction orthogonal to the line (Suzuki & Cavanagh, 1998). The orientation of this deformation is the same as that of the deformation in the eggs illusion, which indicates that these two phenomena might be similar. In the shape-contrast effect, the perceived shape of a circle is affected by flashed line, which provides clear orientation information.

However, two points should be noted in which the shape-contrast effect is different from the eggs illusion. First, the shape-contrast effect occurs when the line is longer than the diameter of the circle and intersects the circle. However, the eggs illusion occurs even when patches are not intersected by the grid edges. Indeed, the results of Experiment 1 showed that the illusion was evident when the patch edges did not intersect the bar edges (i.e., the diameter of patches was the same as the width of grid bars). In this case, the two lines (edges between the bar and background) are almost tangent to the circular patch, but do not go through it. Second, the shape-contrast effect is strong when the stimulus is presented briefly (typically <100 ms), and is reduced in magnitude when the stimulus is presented for 1 s (Suzuki & Cavanagh, 1998). In contrast, based on our informal observations, the eggs illusion is likely to be sufficiently strong when observers perform a free scan during a relatively long, 1-s continuous presentation. Therefore, the temporal properties of these two phenomena seem different.

**Orbison illusion**

The last perceptual phenomenon that should be considered is the Orbison illusion (Orbison, 1939), known as a classical one of geometrical shape illusions on tilt (e.g., Khuu, 2012). In the Orbison illusion, the arc of a circle is perceived as being expanded by radial lines (Figure 11a). The partial expansion of a circle is considered as a deformation of the arc perceived flatter than it physically is when intersected by orthogonal straight lines. In the eggs illusion, the bar edges go through the circular patches, and make the patches flatter (Figure 11b). Consistent with this idea, the eggs illusion seems to persist even when all the luminance-defined edges are replaced with outlines.

However, there are two pieces of evidence showing that the Orbison illusion and the eggs illusion are different phenomena. First, in the Orbison illusion, all lines are radial from one point, thus they are different in orientation. Based on our informal observations, the Orbison illusion does not occur any more if radial lines are replaced by parallel ones. Gregory (1963) also reported that manipulating line orientation in illusions of spatial distortions changed the strength of the illusions. In the eggs illusion, the lines (i.e., two edges of a bar) going through one circular patch are just parallel. Second, as described in the previous subsection, the bar edges which are almost tangent to the circle produced the strongest eggs illusion. Thus, the eggs illusion is different from the Orbison illusion.
Orientation processing in the eggs illusion

Although the eggs illusion should be distinguished from the four related perceptual phenomena, orientation information also seems important for these phenomena. In the scintillating grid illusion, orientation information provided by bars and patches can affect the strength of the illusion. In the shape-contrast effect and the Orbison illusion, deformation depends on line orientation. The relation between these phenomena and the eggs illusion implies that orientation information also plays an important role in generating the eggs illusion. Several studies suggest that orientation information is processed by simple cells in V1, such as bar detectors, edge detectors, and S1-type simple cells (Hubel & Wiesel, 1962; Mullikin, Jones, & Palmer, 1984; Schiller, Finlay, & Volman, 1976). If orientation information is essential for the eggs illusion, it is conceivable that activities of simple cells are related to the generation of the eggs illusion. The effects of orientation information also account for the present finding that brighter grids produce stronger illusions. Brighter grids made their contrast with a black background stronger and, finally, led to an easier detection of orientation information.

In several types of simple cells in V1, here we focus on S1-type simple cells (Schiller & Malpeli, 1978; Schiller et al., 1976). In contrast to other types of simple cells, S1-type simple cells can not only encode the luminance and contrast information, but also output luminance signals. This feature of S1-type simple cells is consistent with the generation of the scintillating grid illusion. Qian et al. (2012) suggested that the activity of S1-type simple cell plays an important role in generating the scintillating grid illusion. To explain the eggs illusion by S1-type simple cells, we need to assume that outputs of S1-type simple cells are also used to perceive shape (i.e., circular or elliptic). To examine this assumption, further neurophysiological as well as psychophysical studies are necessary.

The results of ANOVAs in the present experiments demonstrated a significant interaction between grid luminance and patch shape (size and aspect ratio in Experiments 1 and 2, respectively). A similar kind of interaction was also reported in the scintillating grid illusion (Qian et al., 2012). The two illusions may reflect an interaction between luminance and shape information, which are used to interpret both the brightness and the shape of a pattern. The results of the present study suggest that not only luminance illusions, but also deformation illusions such as the eggs illusion may be produced by the interactions between orientation and luminance.

**Keywords:** visual illusion, shape perception, orientation processing

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