

Effects of Support Ratio on the Perception of Illusory Contours, Brightness Enhancement, and Depth Stratification in Illusory Figures

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For the stimulus inducing illusory figures support ratio is defined as the ratio of the diameter of an inducing element to the separation distance between the centers of the two nearest inducing elements. Shipley and Kellman (1992) reported that perceived magnitude of illusory contours for the stimuli of equal support ratio did not differ from the other even though the stimuli differed from one another in retinal size at support ratios of 0.5 and 0.8 and that it was larger for larger retinal size of the stimulus at support ratio of 0.3. This result suggests that perceived magnitude of illusory contours is scale invariant at higher support ratios and that it depends on retinal size of the stimulus at lower support ratios. In the present study we investigated the effects of retinal size of the stimulus of fixed support ratio on perceived magnitude of illusory contours, brightness enhancement, and depth stratification in illusory figures using families of congruent figures as stimuli. We found that perceived magnitude of them was independent of retinal size of the stimulus of fixed support ratio of 0.80 and that it was larger for larger retinal size of the stimulus at support ratios of 0.20 and 0.40. These results suggest that not only illusory contour formation but also illusory surface formation are scale invariant at higher support ratios and that they are facilitated by larger retinal size of the stimulus at lower support ratios.

Key words: illusory figures, scale invariance, support ratio

Introduction

Perception of illusory figures² is known to be affected by spatial parameters of a stimulus. For example, perceived magnitude of illusory contours, which is one of the attributes of illusory figures, is decreased by the increase of the separation length between the centers of the two nearest inducing elements when the diameter of an inducing element is fixed (Banton & Levi, 1992; Kellman & Shipley, 1991; Liinasuo, Rovamo, & Kojo, 1997; Pughé & Russo, 1999; Shipley & Kellman, 1992, Tanaka, 1985; Watanabe & Oyama). It is increased by the increase of the diameter of an inducing element when the separation length between the centers of the two nearest inducing elements is fixed (Banton & Levi, 1992; Kellman & Shipley, 1991; Pillow & Rubin, 2002; Shipley & Kellman, 1992, Tanaka, 1985).

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 2. We restrict the term *illusory contours* to refer to the bounding contours and not to entire illusion, which we call *illusory figures*. The latter are closed region and are far more complex entities than the former (Gurnsey, Poirier, & Gascon, 1996).

Shipley and Kellman (1992) unified these two spatial parameters into one, which was later referred to as *support ratio* by Leshner and Mingolla (1993). Support ratio is defined as the ratio of the diameter of an inducing element to the separation distance between the centers of the two nearest inducing elements. More generally, it is defined as the ratio between the physically specified contour, that is, the contour specified by luminance gradient, to the total length of the contour. Note that support ratio is independent of retinal size of the stimulus.

Kellman and Shipley (1991) and Shipley and Kellman (1992, Experiment 1) found that perceived magnitude of illusory contours for the stimuli of approximately equal support ratio was quite similar to one another even though the stimuli differed from one another in both the separation length between the centers of the two nearest inducing elements and the diameter of an inducing element. They claimed that not the absolute retinal size but support ratio of the stimulus was the main spatial determinant of perceived magnitude of illusory contours. Scale invariance of illusory contours held over the range of support ratio from 0.29 to 0.80.

Shipley and Kellman (1992), however, obtained different results in their Experiments 2 and 3. They presented the observers families of congruent figures with various support ratios as stimuli. They found that perceived magnitude of illusory contours was scale invariant at support ratios of 0.5 and 0.8 and that it was larger for larger retinal size of the stimulus at support ratio of 0.3. This result was, however, inconsistent with the results of two studies using stimuli of lower support ratios. Dumais and Bradley (1976) reported that perceived magnitude of illusory contours was larger for smaller retinal size of the stimulus of support ratio fixed at 0.38. Ringach and Shapley (1996) reported that scale invariance held for illusory contours at support ratio of 0.25.

Depth stratification and brightness enhancement are also the attributes of illusory figures (Kanizsa, 1979; Leshner, 1995). To our knowledge, only Bradley and Dumais (1984) investigated the effect of support ratio on the perceived magnitude of depth stratification using families of congruent figures with various support ratios as stimuli. They reported that at support ratio of 0.38 perceived magnitude of depth stratification was larger for the stimulus of smaller retinal size. No authors investigated the effect of support ratio on perceived magnitude of brightness enhancement using families of congruent figures with various support ratios as stimuli. So further investigation is needed to know whether the perception of illusory figures is scale invariant.

The aim of the present study was to investigate the effects of retinal size of the stimulus of fixed support ratio on perceived magnitude of illusory contours, brightness enhancement, and depth stratification in illusory figures to know whether the perception of illusory figures is scale invariant. In the present study, we measured perceived magnitude of contour clarity, apparent brightness, and apparent depth by the method of magnitude estimation using families of congruent figures at support ratios of 0.20, 0.40, and 0.80 as stimuli.

Method

Observers

Seventy-eight undergraduates (15 male and 63 female) with a mean age of 21.4 ($SD = 2.23$) years participated in the experiment as observers. They were familiar with illusory figures but were not aware of the purpose of the experiment. All had normal or corrected-to-normal visual acuity. Informed consent was received from each observer after the procedure of the experiment had been explained.

Apparatus and stimuli

The stimuli were presented on a 17-inch CRT monitor (Nanao FlexScan E53F). The observers viewed the stimuli binocularly and freely at a distance of 57.3 cm.

The stimulus was the Kanizsa figure. It consisted of four notched black disks, that is, the inducing elements, which were placed in order for the area cornered by them to form an imaginary square.

For the reference stimulus, the separation length between the centers of the two nearest inducing elements and the diameter of an inducing element were fixed at 2.30 deg and 1.40 deg, respectively.

Figure 1 shows the two sets of the test stimulus used in the present experiment. In the variable separation set, the diameter of an inducing element of the stimulus was fixed at 1.40 deg, and the separation length between the centers of the two nearest inducing elements was set at 1.75, 3.50, and 7.00 deg, at which the support ratios were 0.80, 0.40, and 0.20,

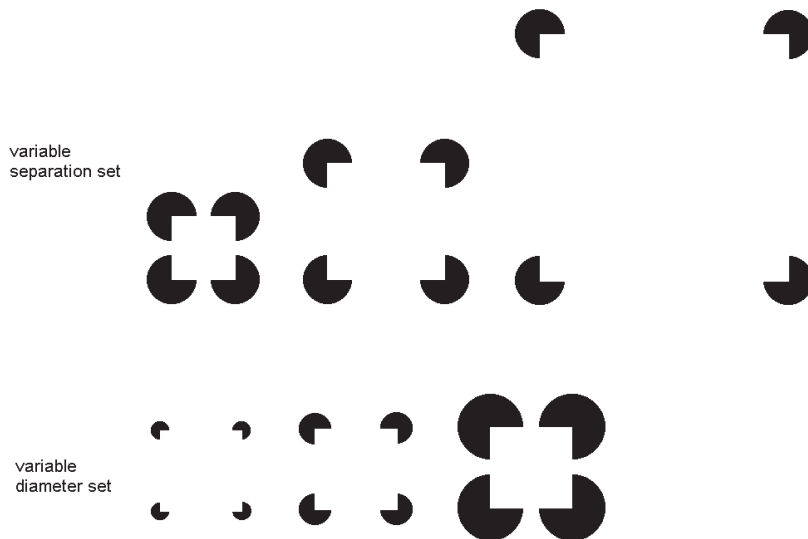


Figure 1. Two sets of the test stimulus in the present experiment. The upper row shows the variable separation set and the lower row shows the variable diameter set.

respectively. In the variable diameter set, the separation length between the centers of the two nearest inducing elements of the stimulus was fixed at 2.30 deg, and the diameter of an inducing element was set at 0.46, 0.92, and 1.84 deg, at which the support ratios were 0.20, 0.40, and 0.80, respectively.

The reference stimulus and the test stimulus were presented 16 deg horizontally apart between the centers of the imaginary square on the gray background of 32×20 deg. The test stimulus was presented right to or left to the reference stimulus at random between observers. The luminance of the inducing elements was 18.1 cd/m^2 and that of the background was 81.5 cd/m^2 .

Procedure

Twenty-six observers were randomly assigned to one of three groups. In each group, measurements were made with only one attribute of illusory figures.

Perceived magnitude of illusory contours, brightness enhancement, and depth stratification was measured as magnitude of contour clarity, apparent brightness, and apparent depth, respectively. They were measured by the method of magnitude estimation. Perceived magnitude of the attributes of illusory figures for the reference stimulus was called 100. The observer was asked to report perceived magnitude of the attribute by assigning a number to the test stimulus relative to that for the reference stimulus.

Test stimuli in the variable separation set and in the variable diameter set were intermixed, and each test stimulus was presented three times in a random order in a session. The session was repeated twice for each observer. So a total of six ratings were made at each combination of attribute and support ratio in each test stimulus set per observer, the mean of which was used for the data analysis. Practice trials were given to each observer before the measurements.

Results

Figure 2 shows the mean rating of perceived magnitude of the attributes of illusory figures as a function of support ratio. The open symbols and the filled ones show the results for the variable separation set and for the variable diameter set, respectively.

A three-way ANOVA showed that there was a significant two-way interaction between support ratio and test stimulus set, $F(2, 150) = 31.23, p < .001$. The analysis of simple main effects and multiple comparisons using Ryan's method showed that the variable separation set was larger than the variable diameter set in mean rating at support ratios of 0.20 and 0.40. At support ratios of 0.20 and 0.40 mean ratings for the variable diameter set were as low as on average 49.2 % of those for the variable separation set.

There was also a significant two-way interaction between attribute and test stimulus set, $F(2, 75) = 7.25, p = .001$. The analysis of simple main effects showed that the variable separation set was larger than the variable diameter set in mean rating for all the attributes.

These results show that the scale invariance holds at support ratio of as high as 0.80 and

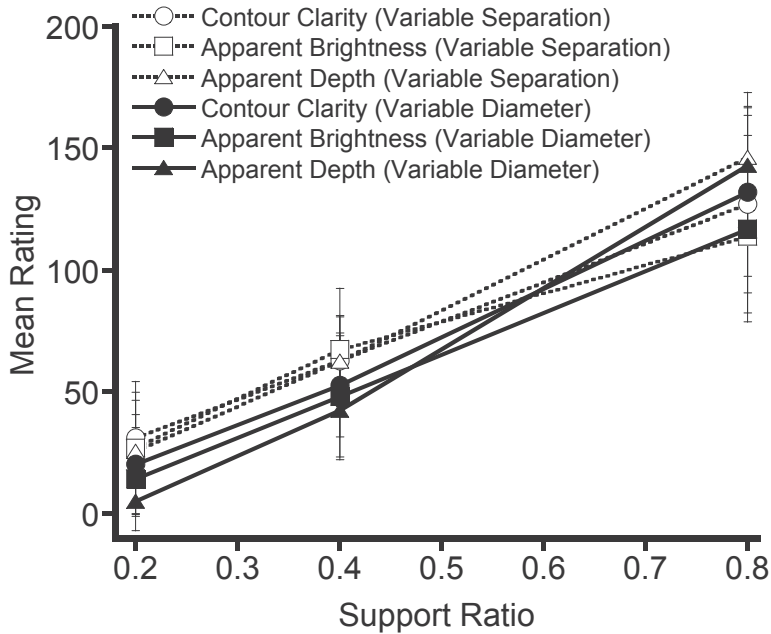


Figure 2. The mean rating of perceived magnitude of the attributes of illusory figures as a function of support ratio.

that it collapses at support ratios of 0.20 and 0.40 for all the attributes.

There was also a significant two-way interaction between support ratio and attribute, $F(4, 150) = 4.65, p = .001$. The analysis of simple main effects and multiple comparisons using Ryan's method showed that perceived magnitude of illusory contours, brightness enhancement, and depth stratification was increased by the increase of support ratio, and that depth stratification was larger than illusory contours and brightness enhancement in mean rating at support ratio of 0.80. The result that perceived magnitude of illusory contours was increased by the increase of support ratio is consistent with the results of previous studies (Banton & Levi, 1992; Kellman & Shipley, 1991; Liinasuo et al., 1997; Pillow & Rubin, 2002; Purghé & Russo, 1999; Shipley & Kellman, 1992; Tanaka, 1985; Watanabe & Oyama, 1988).

Discussion

The aim of the present study was to investigate the effects of retinal size of the stimulus of fixed support ratio on perceived magnitude of the three attributes of illusory figures, that is, illusory contours, brightness enhancement, and depth stratification, to know whether the perception of illusory figures is scale invariant. We found that at support ratio of 0.80 perceived magnitude of all the attributes was independent of retinal size of the stimulus, and that at support ratios of 0.20 and 0.40 it was larger for the variable separation set than for

the variable diameter set. This result indicates that the perception of illusory figures is scale invariant only at higher support ratios such as 0.80, and that it is facilitated by larger retinal size of the stimulus at lower support ratios such as 0.2 or 0.4.

This result is consistent with the results of Experiments 2 and 3 of Shipley and Kellman (1992) that when support ratio of the stimulus was held constant perceived magnitude of illusory contours was determined solely by support ratio at and higher than 0.5 and that it was larger for larger retinal size of the stimulus at support ratios lower than 0.5. Ringach and Shapley (1996), however, reported that scale invariance held for illusory contours at support ratio of as low as 0.25. The inconsistency in result at lower support ratios between Shipley and Kellman (1992)'s Experiments 2 and 3 as well as the present study and Ringach and Shapley (1996) seems to be attributed to the difference in observer's task. In order to estimate the magnitude of illusory contours, rating task was used in the present study and Shipley and Kellman (1992), whereas shape-discrimination task in Ringach and Shapley (1996). Illusory contour interpolation reported in Ringach and Shapley (1996) occurred with no reduction in strength over retinal distances of at least 13.2 deg, which is much longer than that predicted from the results of experiments using rating task (Purghé & Russo, 1999; Tanaka, 1985; Watanabe & Oyama, 1998). These two tasks might tap different visual interpolation processes, and so might have given inconsistent results.

Mendola et al. (1999) showed that the activation patterns in the lateral occipital complex in human cortex, which is thought to contain neurons with size-invariant receptive fields (Tootell, Mendola, Hadjikhani, Liu, & Dale, 1998), were remarkably consistent across a wide variation in retinal size of the stimulus inducing illusory figures of fixed support ratio of 0.5. This finding provides a neurophysiological support for scale invariance of illusory figure perception at higher support ratios.

Dumais and Bradley (1976) reported that at support ratio of as low as 0.38 perceived magnitude of illusory contours was larger for smaller retinal size of the stimulus, which is inconsistent with the results of the present study and Shipley and Kellman (1992). Shipley and Kellman (1992) speculated that the result of Dumais and Bradley (1976) might have been an artifact due to textured surface, which interfered with illusory contour formation, on the hand-drawn stimulus display that became more noticeable with the stimuli of larger retinal size.

Bradley and Dumais (1984) reported similar result to those of Dumais and Bradley (1976) for perceived magnitude of depth stratification, which is also inconsistent with the result of the present study. Illusory contour formation seems to be a cause of the emergence of depth stratification (Takiura, 2006; Watanabe & Oyama, 1988) so that one can speculate the result of Bradley and Dumais (1984) was also an artifact due to textured surface on the hand-drawn stimulus display.

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