Perception, 2007, volume 36, pages 990 – 1002

DOI:10.1068/p5749

Perceived depth in the 'sieve effect' and exclusive binocular rivalry

Kazumichi Matsumiya
Department of Visual Cognition and Systems, Research Institute of Electrical Communication, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan; e-mail: kmat@riec.tohoku.ac.jp

Ian P Howard
Centre for Vision Research, York University, 4700 Keele Street, Toronto, Ontario M3J 1P3, Canada; e-mail: ihoward@cvr.yorku.ca

Hirohiko Kaneko
Imaging Science and Engineering Laboratory, Tokyo Institute of Technology, 4259-R2-60 Nagatsuta, Midori-ku, Yokohama 226-8503, Japan; e-mail: kaneko@isl.titech.ac.jp
Received 28 September 2005, in revised form 24 November 2006

Abstract. An impression of a surface seen through holes is created when one fuses dichoptic pairs of discs, with one member of each pair black and the other member white. This is referred to as the 'sieve effect'. The stimulus contains no positional disparities. Howard (1995, *Perception* **24** 67 – 74) noted qualitatively that the sieve effect occurs when the rivalrous regions are within the range of sizes, contrasts, and relative sizes where exclusive rivalry occurs, rather than binocular lustre, stimulus combination, or dominant rivalry. This suggests that perceived depth in the sieve effect should be at a maximum when exclusive rivalry is most prominent. We used a disparity depth probe to measure the magnitude of perceived depth in the sieve effect as a function of the sizes, contrasts, and relative sizes of the rivalrous regions. We also measured the rate of exclusive rivalry of the same stimuli under the same conditions. Perceived depth and the rate of exclusive rivalry were affected in the same way by each of the three variables. Furthermore, perceived depth and the rate of exclusive rivalry were affected in the same way by changes in vergence angle, although the configuration of the stimulus surface was held constant. These findings confirm the hypothesis that the sieve effect is correlated with the incidence of exclusive rivalry.

1 Introduction

Stereopsis and binocular rivalry are thought to be distinct processes in parallel channels (Kaufman 1964; Julesz and Miller 1975; Wolfe 1986). In stereopsis, similar images with disparities fuse to produce an impression of depth. In binocular rivalry, on the other hand, dissimilar dichoptic images spontaneously alternate (Wheatstone 1838; Breese 1899; Levelt 1965; see a review by Alais and Blake 2005). Kaufman (1964) found that colour rivalry and fusion stereopsis can occur simultaneously in the same location. This suggests that rivalry can occur in the chromatic channel while stereopsis occurs in the achromatic channel. Julesz and Miller (1975) found that depth was apparent in a random-dot stereogram even when random-dot noise with a spatial frequency higher than that of the stereogram was added to one eye. They argued that one spatial-frequency channel may code stereopsis while another spatial-frequency channel produces rivalry. Wolfe (1986) presented a theory that stereopsis and rivalry can coexist in the same location of the visual field because the stereopsis and rivalry information are processed in independent and parallel channels in early stages of visual processing.

Other evidence shows that stereopsis and rivalry interact. Shimojo and Nakayama (1990) showed that rivalry depends on information about monocular zones in stereoscopic displays. A monocular zone on the seeing-eye side of a vertical-disparity discontinuity (a valid zone) creates impressions of depth and escapes binocular rivalry. A monocular zone on the opposite side (an invalid zone) generates binocular rivalry. Thus, in the case of occlusion, stereopsis and rivalry do not coexist in the same location of the visual field.

On the other hand, Howard (1995) has shown a novel stereoscopic effect in which binocular rivalry can create a depth-percept field in the absence of binocular disparity. When one fuses dichoptic pairs of discs, with one member of each pair black and the other member white, as shown in figure 1a, the impression of a surface seen through holes is created (Howard 1995). The effect requires the presence of a visible rim around one of the rivalrous regions; without the rim, the impression of holes in a surface is lost. This is referred to as the sieve effect. In this stereogram, there are no spatial disparities of luminance edges and no monocular cues to depth. The only disparity is one that the visual system may infer from the rivalrous contents of the discs. That is, luminance rivalry is serving as a cue to depth. The sieve effect is not related to depth produced by disparity between thin lines with opposite luminance polarity as shown in figure 1b (Helmholtz 1867/1962) because opposite-polarity lines have a disparity between edges with the same sign of contrast. Nor is the sieve effect related to depth created by binocular combination of random-dot displays that are uncorrelated between the two eyes, as shown in figure 1c—an effect known as rivaldepth (O'Shea and Blake 1987). This effect occurs because misconvergence induces positional disparity into the non-rivalrous region in the central square on the O'Shea and Blake stereogram (figure 1c).

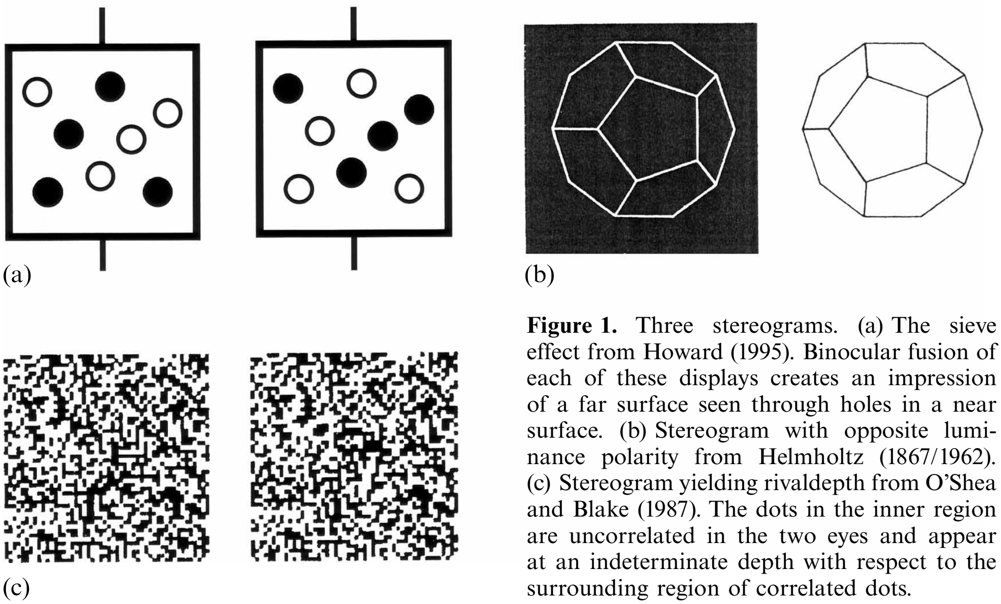


Figure 1. Three stereograms. (a) The sieve effect from Howard (1995). Binocular fusion of each of these displays creates an impression of a far surface seen through holes in a near surface. (b) Stereogram with opposite luminance polarity from Helmholtz (1867/1962). (c) Stereogram yielding rivaldepth from O'Shea and Blake (1987). The dots in the inner region are uncorrelated in the two eyes and appear at an indeterminate depth with respect to the surrounding region of correlated dots.

Howard (1995) noted that the impression of depth in the sieve effect occurred when the size and contrast of the rivalrous patterns were such as to produce exclusive rivalry. In exclusive rivalry, the whole of a stimulus in one eye alternates with the whole of a stimulus in the other eye (Blake et al 1992). Tsai and Victor (2000) found the depth judgments in the sieve effect were less precise than those produced by disparity, and found a dependence of perceived depth on the vertical extent of unmatched images in the sieve effect. They concluded that the mechanism responsible for the sieve effect is different from mechanisms responsible for depth from disparity and from occlusion zones. However, the previous studies did not quantitatively examine the relationship between perceived depth in the sieve effect and exclusive rivalry. If the depth percept in the sieve effect is linked with exclusive binocular rivalry, the stimulus factors that produce the largest incidence of exclusive rivalry should produce the largest magnitude of perceived depth in the sieve effect.

We designed the following experiments to test the hypothesis that the magnitude of perceived depth in the sieve effect is positively correlated with the rate of exclusive rivalry.

2 Experiment 1

In experiment 1, we varied (i) the luminance contrast between each pair of rivalrous squares, (ii) the size of squares, and (iii) the width of the rim around each pair of rivalrous squares. In each case, we measured the perceived depth of the sieve effect and the frequency of exclusive rivalry.

2.1 *Methods*

2.1.1 *Apparatus and stimuli.* Visual stimuli were presented on two monitors with a refresh rate of 75 Hz controlled by a Power Macintosh computer. The two displays were superimposed in a mirror stereoscope to create a single surface in the frontal plane of the subject at a distance of 100 cm. The two monitors were matched in luminance and contrast by calibrating the luminance of each monitor. The room lights were extinguished and all surfaces surrounding the display were painted black or covered by black cloth. The subject's head was fixed with a chin-rest.

The binocularly combined stimulus consisted of an array of rivalrous black and white squares on a random-dot textured background, as shown in figure 2a. In the basic stimulus, each square had a black rim 3 min of arc thick that was visible only around the white squares—the sieve effect requires the presence of a rim (Howard 1995). Unless stated otherwise, the luminance of the white squares was 12 cd m^{-2}. The random-dot textured background subtended 6 deg in width and 6 deg in height and was the same in the two eyes. In all conditions, nonius lines 3 min of arc wide and 22 min of arc long were presented in the centre of the display to avoid possible artifacts related to misconvergence.

The experiment involved three conditions. In the 'size-change' condition we varied the side of the inner squares over values of 4, 8, 12, 17, 27, 44, and 70 min of arc, keeping the thickness of the rim constant at 3 min of arc, as illustrated in figure 2b. In the 'contrast-change' condition we varied the luminance contrast between each pair of rivalrous squares over values of 0.06, 0.1, 0.16, 0.25, 0.4, 0.63, and 1.0 (figure 2c). The contrast of 1.0 was defined as the contrast between the brightest white in the CRT display and the darkest black in the CRT display. The side of each inner square subtended 21 min of arc, which was the size giving the greatest depth in condition (i). The rim was 3 min of arc thick. In the 'relative-size-change' condition each square subtended 12 min of arc but the thickness of the rim was varied over values of 0, 2, 4, 6, 8, 10, 12, and 14 min of arc. Thus, the black squares became larger while the white squares remained the same size but with a larger rim, as shown in figure 2d.

2.1.2 *Procedures.* We measured the perceived depth of the sieve effect and the frequency of exclusive rivalry. For depth measurements, subjects used a trackball to adjust the horizontal disparity in nine square regions within the random-dot background until these regions appeared at the same depth as the surface perceived through the rivalrous squares. All nine square regions within the random-dot background had the same horizontal disparity. When all regions had an uncrossed disparity, subjects perceived a textured plane through the nine holes. Before starting the experiment, subjects were instructed how to adjust the perceived depth of the probe plane until it appeared at the same depth as that created by the sieve effect. The starting value of the probe plane was zero disparity. The order of stimulus values was randomised in each of the three conditions. Each stimulus value was repeated five times in a session. Subjects performed three sessions for each condition.

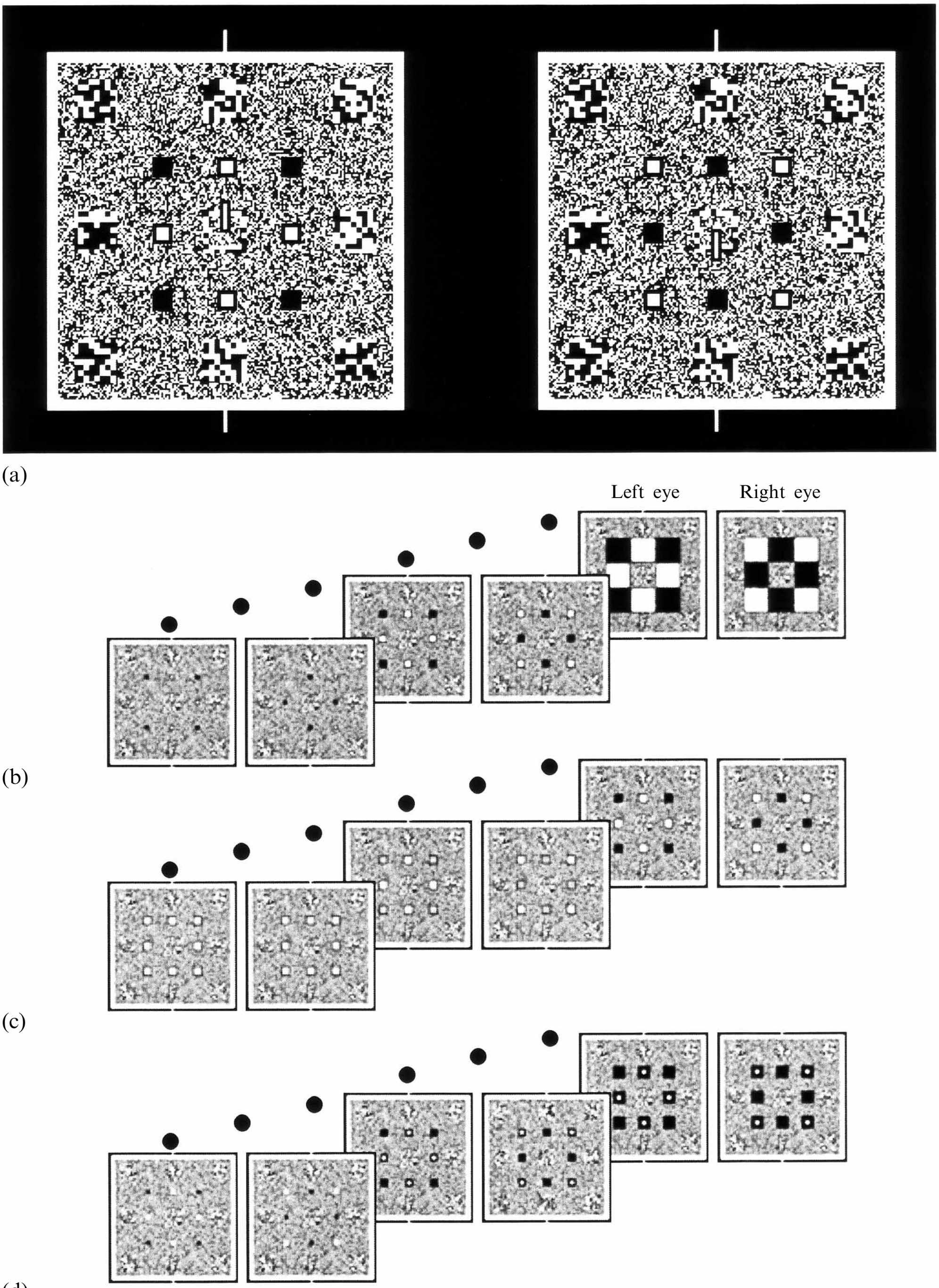


Figure 2. Visual stimuli and stimulus parameters used in experiment 1. (a) Arrangement of the visual stimuli. The left, right, upper, and lower squares were 3 deg from the display centre in each image. The centre-to-centre separation between the black and white squares in each display was 3 deg. The nonius lines were 22 min of arc high and 3 min of arc wide. The horizontal disparity of the nine random-dot squares on the background was adjusted by the subject. The side of each random-dot square subtended 46 min of arc. (b) Size of rivalrous squares. (c) Luminance contrast between each pair of rivalrous squares. (d) Thickness of rims around each pair of rivalrous squares.

For measuring the frequency of rivalry, subjects attended to a selected rivalrous square while fixating the centre of the display. When subjects saw the black square in the target square, they pressed a button to start a trial. After that, they pressed the same button when they perceived the black square, and another button when they perceived the white square. The frequency of exclusive rivalry was defined as the number of changes from black squares to white squares over a period of 30 s. However, the last interval of black squares to white squares was not counted because its interval could be incomplete. The target square was randomly selected from upper, lower, left, and right positions and was the same throughout one session. Subjects were instructed to press a button when they saw only a black square and to press another button when they saw only a white square. This instruction ensured that the subjects were reporting exclusive rivalry. After the subjects performed all trials in a session, they were asked to report verbally how the target square was perceived throughout a session. Each stimulus value was repeated twice for each selected target square in a session. The rivalry frequencies of the four target squares were averaged. Subjects performed two sessions for each target square.

Depth judgments were based on the global impression of depth over the whole display, whereas judgments of rivalry had to be based on one region of the display because subjects could not track rivalry over all the rivalrous squares at the same time. However, the comparison between these two measures is valid because the impression of depth is the same in each hole. Subjects saw a single surface at one depth through the set of apparent holes. Also, the rivalry percept was piecemeal when considered over all the rivalrous squares.

The nonius lines presented in the centre of the displays were used to help subjects control convergence of the eyes. The subjects were instructed to keep the nonius lines aligned throughout a trial. If the subject could not keep the nonius lines aligned, data from that trial were excluded from analysis.

2.1.3 *Subjects.* Two female and two male subjects between the ages of 29 and 41 years, with corrected-to-normal vision, participated in this study. All the subjects were right-handed, and were volunteers. Subjects HJ and JZ were experienced in other psychophysical experiments, but were naive with respect to the purpose of this study. Subject SM had no experience with experiments on depth perception. Subject KM was one of the authors. Three of the four subjects participated for each stimulus condition. Subject HJ participated only in the size-change condition. Subject JZ participated only in the contrast-change and rim-change conditions. Subjects SM and KM participated in all conditions.

2.2 *Results and discussion*

Figure 3a shows the mean perceived depth of the sieve effect for each of three subjects as a function of the size of the squares. Figure 3b shows the mean frequency of exclusive rivalry as a function of the size of the squares for the same subjects. In figures 3a and 3b each symbol represents a different subject. Figure 3c shows a significant correlation between the normalised sieve-effect depth and the normalised frequency of rivalry from the data of the three subjects ($r = 0.620$, $N = 21$, $p < 0.01$). For subjects KM and SM, there were significant correlations between the normalised sieve-effect depth and the normalised frequency of rivalry ($r = 0.546$, $N = 105$, $p < 0.05$ for KM; $r = 0.816$, $N = 105$, $p < 0.05$ for SM). For subject HJ, however, there was no significant correlation ($r = 0.175$, $N = 105$, $p > 0.05$, ns). The normalisation was carried out for each subject. In figures 3a and 3b it can be seen that, with increasing size of the squares, perceived depth increased to a maximum value and then declined to zero. The frequency of exclusive rivalry varied in a similar way. A comparison of figures 3a and 3b shows that the maximum magnitude of perceived depth occurred

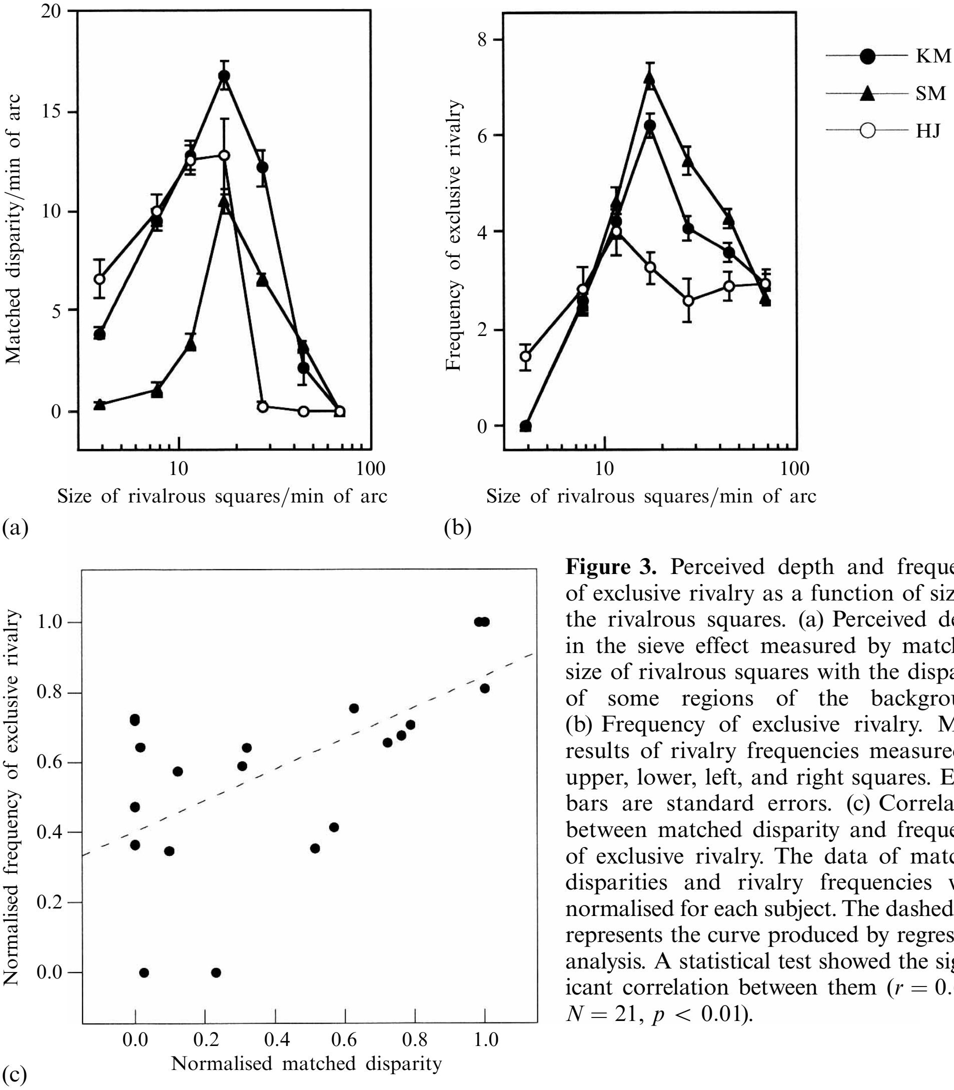


Figure 3. Perceived depth and frequency of exclusive rivalry as a function of size of the rivalrous squares. (a) Perceived depth in the sieve effect measured by matching size of rivalrous squares with the disparity of some regions of the background. (b) Frequency of exclusive rivalry. Mean results of rivalry frequencies measured at upper, lower, left, and right squares. Error bars are standard errors. (c) Correlation between matched disparity and frequency of exclusive rivalry. The data of matched disparities and rivalry frequencies were normalised for each subject. The dashed line represents the curve produced by regression analysis. A statistical test showed the significant correlation between them ($r = 0.620$, $N = 21$, $p < 0.01$).

for the size of square for which exclusive rivalry was most in evidence. All subjects verbally reported that the square size of 70 min of arc gave the impression of mosaic rivalry and lustre but no impression of depth in figures 3a and 3b. In addition, all subjects verbally reported that the square size of 4 min of arc gave the impression of an exclusive white square in figures 3a and 3b. In this case, subject SM saw no depth and subjects KM and HJ saw a small magnitude of depth, as shown in figure 3a. In particular, subject KM obtained a small amount of depth but reported no rivalry in the 30 s test period. He may have experienced rivalry if tested over a longer period.

Figures 4a and 4b show the mean sieve-effect depth and the frequency of exclusive rivalry as a function of the luminance contrast between each pair of rivalrous squares (each symbol represents a different subject). Figure 4c shows the significant correlation between the normalised sieve-effect depth and the normalised frequency of exclusive rivalry from the data of the three subjects ($r = 0.874$, $N = 21$, $p < 0.01$). For each of the three subjects, there was a significant correlation between the normalised sieve-effect depth and the normalised frequency of rivalry ($r = 0.944$, $N = 105$, $p < 0.05$ for KM; $r = 0.953$, $N = 105$, $p < 0.05$ for SM; $r = 0.721$, $N = 105$, $p < 0.05$ for JZ).

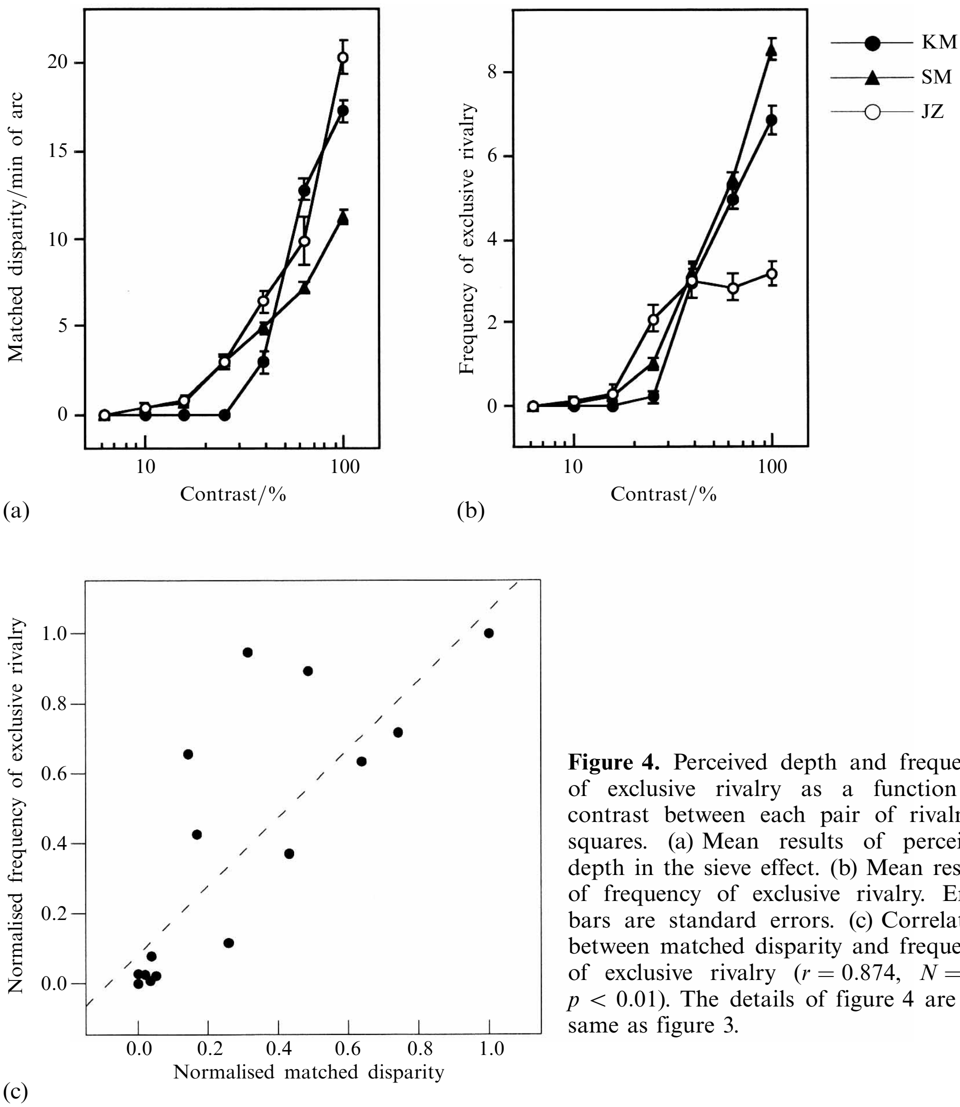


Figure 4. Perceived depth and frequency of exclusive rivalry as a function of contrast between each pair of rivalrous squares. (a) Mean results of perceived depth in the sieve effect. (b) Mean results of frequency of exclusive rivalry. Error bars are standard errors. (c) Correlation between matched disparity and frequency of exclusive rivalry ($r = 0.874$, $N = 21$, $p < 0.01$). The details of figure 4 are the same as figure 3.

These results indicate that increasing the contrast between each pair of rivalrous squares increases both sieve-effect depth and the frequency of exclusive rivalry. At low contrast, rivalry is replaced by an impression of intermediate gray squares. It is known that rivalry between orthogonal gratings gives way to an impression of a plaid as contrast is reduced (Liu et al 1992). In fact, all subjects verbally reported that the low-contrast squares gave the impression of stimulus mixture such as gray, suggesting that the sieve effect breaks down when exclusive rivalry is replaced by stimulus mixture. Alternatively, rivalry may still occur but may not be noticeable at low contrast.

Figures 5a and 5b show the mean sieve-effect depth and the frequency of exclusive rivalry as a function of the thickness of the rims around the rivalrous squares which define the relative sizes of the rivalrous regions (each symbol represents a different subject). Figure 5c shows the significant correlation between the normalised sieve-effect depth and the normalised frequency of exclusive rivalry from the data of the three subjects ($r = 0.903$, $N = 24$, $p < 0.01$). For each of the three subjects, there was a significant correlation between the normalised sieve-effect depth and the normalised

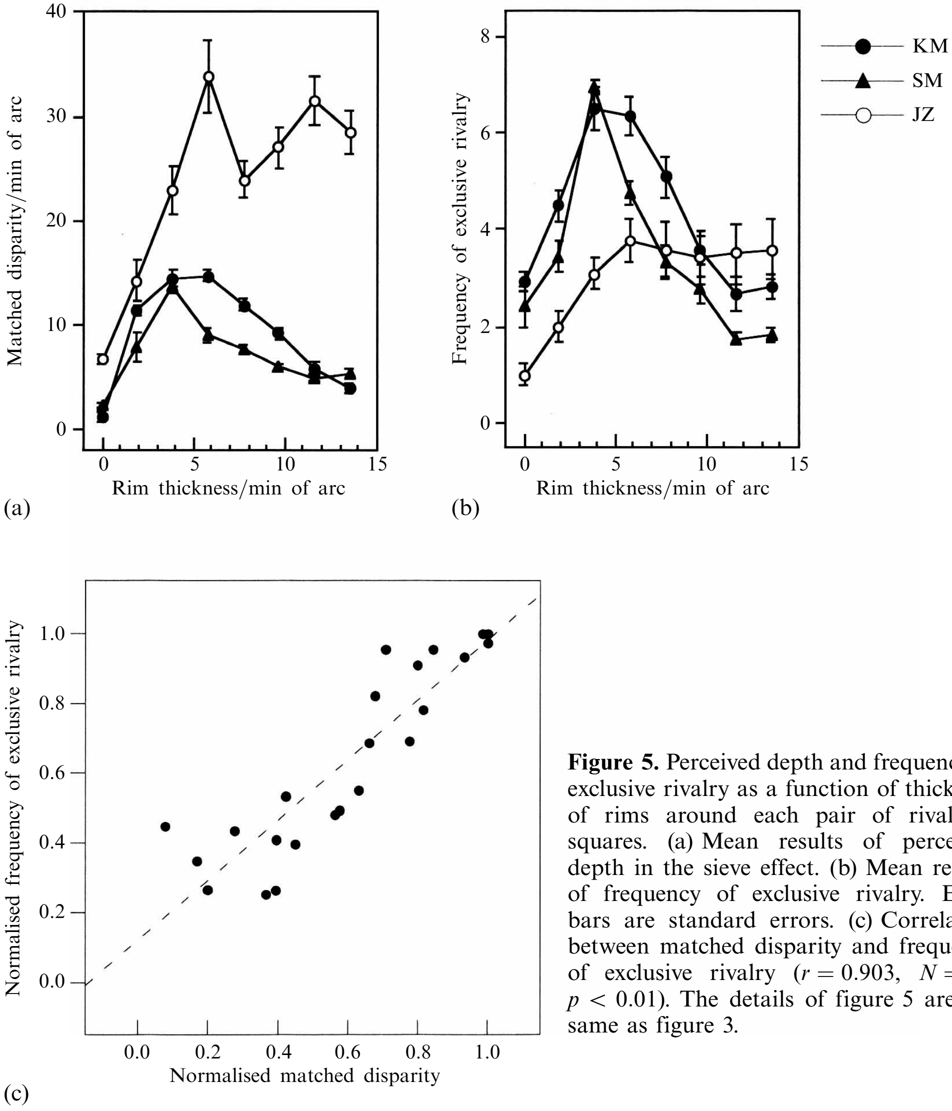


Figure 5. Perceived depth and frequency of exclusive rivalry as a function of thickness of rims around each pair of rivalrous squares. (a) Mean results of perceived depth in the sieve effect. (b) Mean results of frequency of exclusive rivalry. Error bars are standard errors. (c) Correlation between matched disparity and frequency of exclusive rivalry ($r = 0.903$, $N = 24$, $p < 0.01$). The details of figure 5 are the same as figure 3.

frequency of rivalry ($r = 0.635$, $N = 120$, $p < 0.05$ for KM; $r = 0.696$, $N = 120$, $p < 0.05$ for SM; $r = 0.459$, $N = 116$, $p < 0.05$ for JZ). Both the sieve-effect depth and the frequency of exclusive rivalry were maximal when rim thickness was within 4 to 6 min of arc. For subjects SM and KM, sieve-effect depth and the frequency of exclusive rivalry declined beyond the critical range. As the rim became wider, the black squares became larger so that the edges of each white square became more distant from the edges of the black squares. Under these conditions the edges of the squares did not rival and each white square persistently dominated the blank black region in the other eye—it showed dominant rivalry. For two subjects there was no consistent impression of depth when the black square was large. For subject JZ, however, both the sieve-effect depth and the frequency of exclusive rivalry did not decline as the size of the black square increased. Howard (1995) showed that small white discs superimposed on large black discs sometimes appeared in front of the black discs and sometimes beyond them. The depth order depended on whether the vergence state of the eyes brought the white discs closer to one or the other side of the black discs.

Subject JZ may have maintained an angle of vergence that brought the small white squares near to the edges of the black squares, where the juxtaposition of their edges would create an impression of depth.

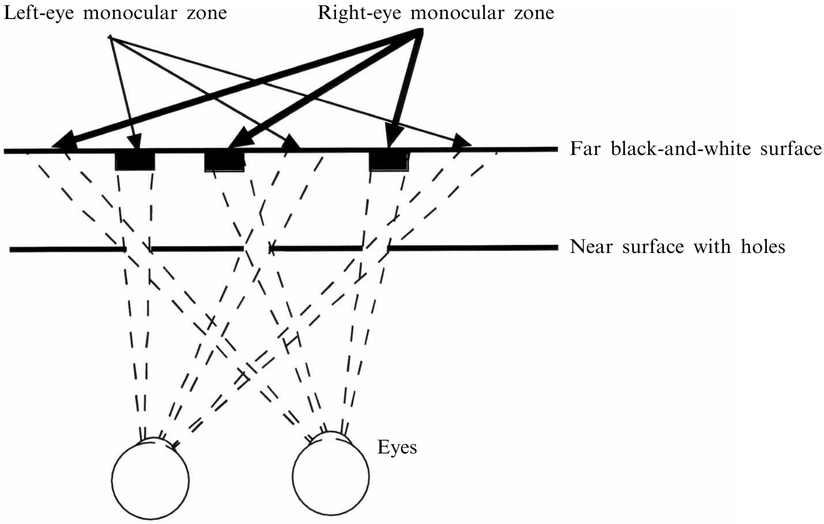
Our findings have confirmed that the rate of exclusive rivalry and the magnitude of perceived depth in the sieve effect are affected in the same way by changes in the size, contrast, and rim thickness of rivalrous squares. This suggests that the rate of exclusive rivalry is correlated with the magnitude of perceived depth in the sieve effect. However, it is possible that change in the rate of exclusive rivalry can simply be attributed to change of the configuration of the stimulus surface, rather than to the magnitude of perceived depth in the sieve effect. In experiment 2 we tested this possibility.

3 Experiment 2

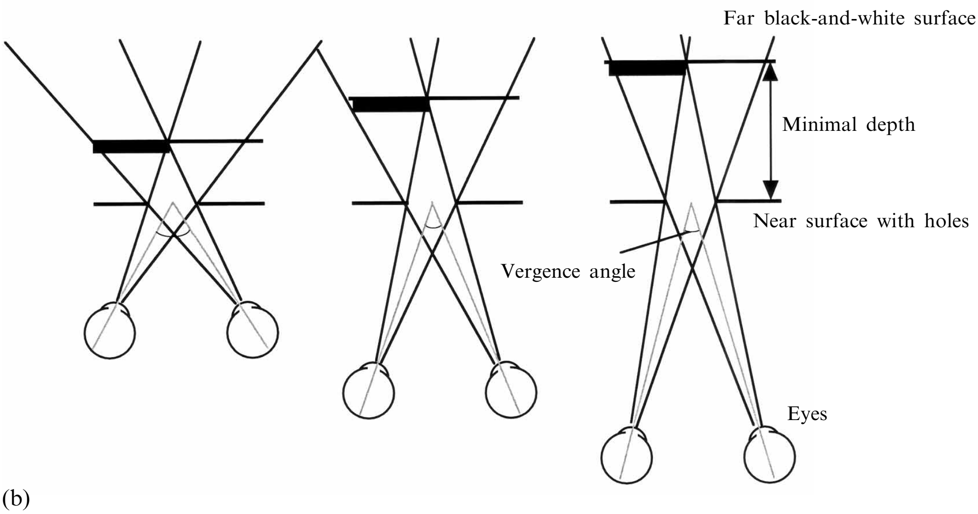
To test if change of the stimulus configuration can account for change of the rate of exclusive rivalry, in experiment 2 we consider the effects of vergence angles on both the sieve-effect depth and the rate of exclusive rivalry. The importance of vergence angle arises from the geometrical considerations shown in figure 6. As illustrated in figure 6a, a stimulus creating the sieve effect geometrically corresponds to the situation that a far black-and-white surface is seen through holes in a near surface (Howard 1995). In this situation, monocular zones are produced by a near surface with holes in front of a far black-and-white surface. These monocular zones can create an impression of depth of the far surface relative to the near surface in their own right without positional disparity (Nakayama and Shimojo 1990; Shimojo and Nakayama 1990; Anderson and Nakayama 1994; Liu et al 1994; Gillam 1995; Gillam and Nakayama 1999; Häkkinen and Nyman 2001; Hayashi et al 2004; Mitsudo et al 2005). Figure 6b shows that the minimal depth created by the monocular zones increases with decreasing vergence angle, although the distance from the eyes to the near surface also increases. On the basis of these considerations, we predict an increase in the magnitude of perceived depth in the sieve effect with a decrease in vergence angle, while the configuration of the stimulus surface is held constant on the retinas. Thus, if the rate of exclusive rivalry is correlated with the magnitude of perceived depth in the sieve effect, the effect of vergence manipulations should affect the rate of exclusive rivalry in the same way as the magnitude of perceived depth in the sieve effect.

3.1 *Methods*

3.1.1 *Apparatus and stimuli.* The apparatus was the same as in experiment 1 except for the viewing distance of 40 cm and that each display subtended 51 deg $\times$ 39 deg. The stimulus was the same as in experiment 1 except that the rivalrous squares were displayed on a uniform gray background (15 cd m^{-2}). The squares were 12 min of arc high $\times$ 12 min of arc wide. The rim around the square was 3 min of arc. The white squares had a luminance of 30 cd m^{-2}. To manipulate vergence of the eyes, the appropriate horizontal shift was applied to the stimulus. We devised the apparatus to prevent the edges of the screens specifying the zero-disparity location. Wide displays were used, and the edges of the displays were surrounded by black sheets. The stimulus was also presented on the black background of the displays. Nonius lines were presented at the centre of the random-dot textures as shown in figure 2a. Even though the random-dot textures were shifted, the nonius lines remained at the centre of the random-dot textures. The subjects were instructed to keep the nonius lines aligned. These procedures prevented the subjects from fusing the edges of the screens. We refer to the simulated viewing distances by their corresponding vergence angles: 17.9°, 9.0°, 4.5°. These vergence angles correspond to simulated viewing distances of 20, 40, 80 cm, respectively.



(a)



(b)

Figure 6. A real sieve creates monocular zones. (a) A black-and-white surface seen through holes in a near surface creates monocular zones in the left and right eyes. (b) The minimal depth between far black-and-white and near surfaces varies with vergence angle and distance from the eyes to a near surface.

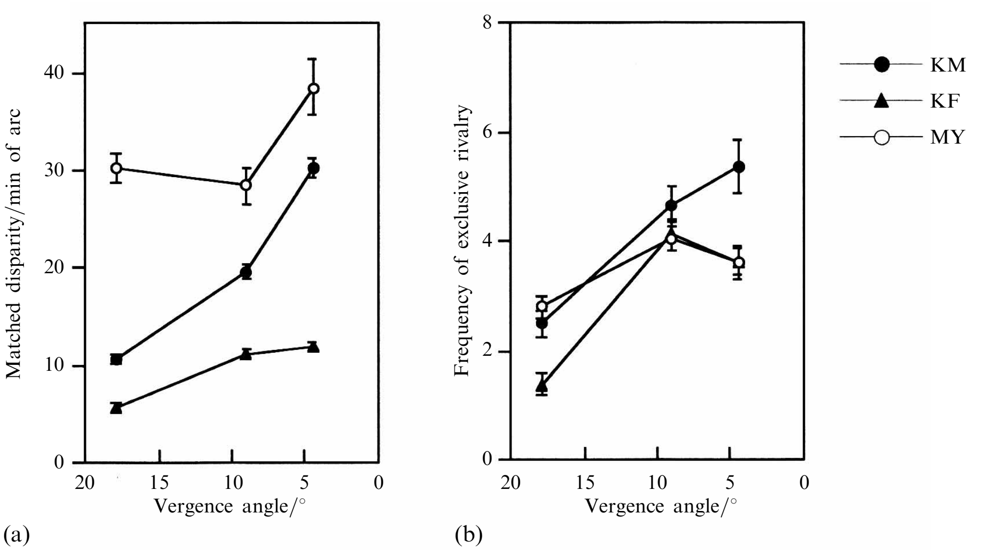
3.1.2 *Procedures.* We measured perceived depth of the sieve effect and the frequency of exclusive rivalry in the same way as in experiment 1. The order of stimulus values was randomised.

3.1.3 *Subjects.* Three male subjects aged between 24 and 31 years, with corrected-to-normal vision, participated in this study. Subjects KF and MY were experienced in other psychophysical experiments but were naive with respect to the purpose of this study. Subject KM was one of the authors and participated in experiment 1.

3.2 *Results and discussion*

Figures 7a and 7b show the mean sieve-effect depth and the frequency of exclusive rivalry as a function of vergence angle (each symbol represents a different subject).

Figure 7c shows the significant correlation between the normalised sieve-effect depth and the normalised frequency of exclusive rivalry from the data of the three subjects ($r = 0.798$, $N = 9$, $p < 0.02$). For subjects KM and KF, there were significant correlations between the normalised sieve-effect depth and the normalised frequency of rivalry ($r = 0.558$, $N = 48$, $p < 0.05$ for KM; $r = 0.498$, $N = 48$, $p < 0.05$ for KF). For subject MY, however, there was no significant correlation ($r = 0.209$, $N = 48$, $p > 0.05$, ns). The normalisation was carried out for each subject. As shown in figures 7a and 7b, decreasing the vergence angle tends to increase both the sieve-effect depth and the frequency of exclusive rivalry. That is, the sieve-effect depth and the frequency of exclusive rivalry were affected in the same way by changes in vergence angle, even though the configuration of the stimulus surface was held constant on the retinas. This confirms that the frequency of exclusive rivalry is correlated with the magnitude of perceived depth in the sieve effect, not the configuration of the stimulus surface.



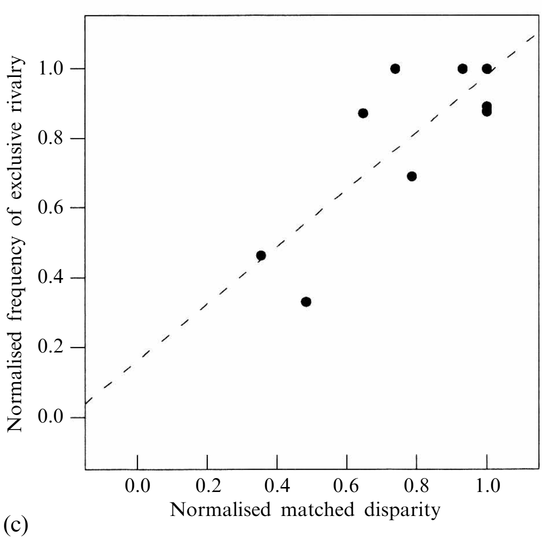


Figure 7. Perceived depth and frequency of exclusive rivalry as a function of vergence angle. (a) Mean results of perceived depth in the sieve effect. (b) Mean results of frequency of exclusive rivalry. Error bars are standard errors. (c) Correlation between matched disparity and frequency of exclusive rivalry ($r = 0.798$, $N = 9$, $p < 0.02$). The details of figure 7 are the same as figure 3.

4 General discussion

In the present study we investigated the relation between the sieve effect and exclusive rivalry. We found that the perceived depth of the sieve effect and the frequency of exclusive rivalry are affected in the same way by changes in the contrast, size, and relative sizes of rivalrous squares, and by changes in vergence angle. These results reveal that the perceived depth in the sieve effect arises under conditions that produce a high rate of exclusive rivalry. This is consistent with the qualitative results of Howard (1995), and confirms the hypothesis that the sieve effect is correlated with the incidence of exclusive rivalry.

In the present study, the rivalrous squares of the sieve were always arranged in a symmetrical 3×3 array. Some studies have shown that global configuration and collinear alignment can increase the strength of rivalry (Alais and Blake 1999; Bonneh and Sagi 1999; Wilson et al 2001). In future investigations, therefore, it would be informative to examine whether the correlations between perceived depth in the sieve effect and exclusive rivalry are affected by having the rivalrous squares located at random.

Stereopsis and rivalry are seen as distinct processes that occur in separate channels. Some studies have indicated that stereopsis can occur at the same time and in the same location of the visual field as binocular rivalry only when the disparity and rivalry information are processed in different channels (Kaufman 1964; Julesz and Miller 1975; Wolfe 1986). However, Blake et al (1991) used stimuli such as those employed by Julesz and Miller but showed that stereopsis and rivalry occur in distinct regions of the stereogram rather than in the same region.

In the sieve effect, an impression of depth occurs simultaneously in the same regions as rivalry. The impression of depth is most evident when the stimulus configuration produces exclusive rivalry (Howard 1995). The present study revealed that the magnitude of perceived depth in the sieve effect is positively correlated with the rate of exclusive rivalry. Moreover, Matsumiya (2006) found that it takes a longer time for the magnitude of depth judgments in the sieve effect to recover from rivalry suppression compared with judgments of depth from disparity. Also, Tsai and Victor (2000) found the lower precision of depth judgments in the sieve effect compared with judgments of depth from disparity. The two recent studies suggest that the mechanism of the sieve effect is different from that of disparity-based stereopsis. These findings allow us to conclude that the sieve effect and rivalry may be processed in the same channel, whereas disparity-based stereopsis and rivalry are processed in parallel channels.

Acknowledgments. We thank the observers who participated in this study: Soyoko Matsumiya, Heather Jenkin, James Zacher, Kazuho Fukuda, and Masashi Yamaguchi.

References

Alais D, Blake R, 1999 "Grouping visual features during binocular rivalry" *Vision Research* **39** 4341 – 4353

Alais D, Blake R, 2005 *Binocular Rivalry* (Cambridge, MA: MIT Press)

Anderson B L, Nakayama K, 1994 "Toward a general theory of stereopsis: binocular matching, occluding contours, and fusion" *Psychological Review* **101** 414 – 445

Blake R, O'Shea R P, Mueller T J, 1992 "Spatial zones of binocular rivalry in central and peripheral vision" *Vision Neuroscience* **8** 469 – 478

Blake R, Yang Y, Wilson H R, 1991 "On the coexistence of stereopsis and binocular rivalry" *Vision Research* **31** 1191 – 1203

Bonneh Y, Sagi D, 1999 "Configuration saliency revealed in short duration binocular rivalry" *Vision Research* **39** 271 – 281

Breese B B, 1899 "On inhibition" *Psychological Monographs* **3** 1 – 65

Gillam B, 1995 "Matching needed for stereopsis" *Nature* **37** 202 – 204

Gillam B, Nakayama K, 1999 "Quantitative depth for a phantom surface can be based on cyclopean occlusion cues alone" *Vision Research* **39** 109 – 112

Häkkinen J, Nyman G, 2001 "Phantom surface captures stereopsis" *Vision Research* **41** 187 – 199

Hayashi R, Maeda T, Shimojo S, Tachi S, 2004 "An integrative model of binocular vision: a stereo model utilizing interocularly unpaired points produces both depth and binocular rivalry" *Vision Research* **44** 2367 – 2380

Helmholtz H von, 1867/1962 *Treatise on Physiological Optics* volume 3 (New York: Dover, 1962); English translation by J P C Southall for the Optical Society of America (1925) from the 3rd German edition of *Handbuch der physiologischen Optik* (first published in 1867, Leipzig: Voss)

Howard I P, 1995 "Depth from binocular rivalry without spatial disparity" *Perception* **24** 67 – 74

Julesz B, Miller J E, 1975 "Independent spatial frequency tuned channels in binocular fusion and rivalry" *Perception* **4** 125 – 143

Kaufman L, 1964 "Suppression and fusion in viewing complex stereograms" *American Journal of Psychology* **77** 193 – 205

Levelt W J M, 1965 *On Binocular Rivalry* (Soesterberg, The Netherlands: Institute for Perception RVO-TNO)

Liu L, Stevenson S B, Schor C M, 1994 "Quantitative stereoscopic depth without binocular correspondence" *Nature* **367** 66 – 69

Liu L, Tyler C W, Schor C M, 1992 "Failure of rivalry at low contrast: evidence of a suprathreshold binocular summation process" *Vision Research* **32** 1471 – 1479

Matsumiya K, 2006 "Influence of exclusive binocular rivalry on perceived depth in the 'sieve effect'" *Optical Review* **13** 39 – 45

Mitsudo H, Nakamizo S, Ono H, 2005 "Greater depth seen with phantom stereopsis is coded at the early stages of visual processing" *Vision Research* **45** 1365 – 1374

Nakayama K, Shimojo S, 1990 "Da Vinci stereopsis: Depth and subjective occluding contours from unpaired image points" *Vision Research* **30** 1811 – 1825

O'Shea R P, Blake R, 1987 "Depth without disparity in random-dot stereograms" *Perception & Psychophysics* **42** 205 – 214

Shimojo S, Nakayama K, 1990 "Real world occlusion constraints and binocular rivalry" *Vision Research* **30** 69 – 80

Tsai J J, Victor J D, 2000 "Neither occlusion constraint nor binocular disparity accounts for the perceived depth in the 'sieve effect'" *Vision Research* **40** 2265 – 2276

Wheatstone C, 1838 "Contributions to the physiology vision—Part the first: On some remarkable, and hitherto unobserved, phenomena of binocular vision" *Philosophical Transactions of the Royal Society of London* **128** 371 – 394

Wilson H R, Blake R, Lee S H, 2001 "Dynamics of traveling waves in visual perception" *Nature* **412** 907 – 910

Wolfe J M, 1986 "Stereopsis and binocular rivalry" *Psychological Review* **93** 269 – 282

ISSN 0301-0066 (print) ISSN 1468-4233 (electronic)

PERCEPTION

VOLUME 36 2007

www.perceptionweb.com