Stereo transparency in ambiguous stereograms generated by overlapping two identical dot patterns

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In binocular vision, observers can perceive transparent surfaces by fusing a stereogram composed of two overlapping patterns with different disparities. When dot patterns of two surfaces are identical, the stereogram has potential matches leading to both transparency and non-transparency (or unitary surface) perceptions. However, these two matching candidates are exclusive if the uniqueness assumption holds. This stereogram can be regarded as a random-dot version of the double-nail illusion and a stereo version of the locally paired-dot stimulus that was used to investigate the neural mechanism for motion transparency. Which surface is perceived in this ambiguous stereogram would reflect the property of the transparency detection mechanism in human stereopsis. Here we perform a parametric study to examine the perceptual property in this ambiguous stereogram. The result showed that the ability in transparency detection from this stereogram is determined by the contrast reversal ratio between overlapping patterns within small regions the width of which was about 0.4 deg. The width was similar to the receptive field sizes of neurons in striate cortex. The result suggests that the contrast reversal between two identical patterns would modulate activities of binocular neurons, and this modification gives a crucial effect on the neural representation for overlapping disparities.

Keywords: binocular stereopsis, stereo transparency, double-nail illusion, locally paired-dot stimulus

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Introduction

Transparency perception is recognized as a challenging problem for the theory of the early visual processing in the brain. Transparency perception indicates that the human visual system can naturally deal with overlapping, or multi-valued, visual quantities and suggests that a simple model reconstructing a single-valued field of a visual quantity (such as a disparity map and an optical-flow field) cannot model the early visual processing in the brain. In other words, transparency perception raises a fundamental issue of how binocular disparities and motion directions are represented and detected in the brain.

In recent years, the human ability to transparency perception in stereo and motion has been studied intensively. Many psychophysical studies for stereo transparency employed a stereogram generated by overlapping two random dot patterns with different disparities (e.g., Akerstrom & Todd, 1988; Gepshtein & Cooperman, 1998; Lankheet & Palmen, 1998; Mallot, Roll, & Arndt, 1996; McKee & Verghese, 2002; Stevenson, Cormack, & Schor, 1989, 1991; Weinshall, 1989, 1990). Fusing this type of stereogram, observers can perceive two overlapping disparities simultaneously.

Here we investigate the perceptual property of stereo transparency by using a specific stereogram as illustrated in Figure 1. Suppose that a zero-disparity random-dot stereogram (RDS) is duplicated with a certain offset, i.e., in each eye, every dot is replicated at a horizontal offset of D. The top panel of Figure 1 is an example of such stereogram. Everyone will perceive the resulting stereogram as a single surface, at zero disparity, covered with a duplicate offset dot pattern. However, the same retinal images could also be produced by overlapping two 'identical' dot patterns with opposite disparities (Figure 2a). In other words, this stereogram has potential matches leading to transparent surface perception as well as a unitary (or non-transparent) surface perception. This stereogram can be regarded as a random-dot version of the double-nail illusion (Krol & van de Grind, 1980; Nakamizo & Kondo, 1988) and a stereo version of the locally paired-dot (LPD) stimulus (Braddick, 1997; Curran & Braddick, 2000; Qian, Andersen, & Adelson, 1994; Watanabe & Kikuchi, 2006) that was used to investigate the perceptual property of motion transparency. However, the alternative percept of transparency, though mathematically equally valid, is never perceived from this stereogram. This is not surprising, especially in light of the previous results concerning the double-nail illusion. Similar to the double-nail illusion, depth perception from this stereogram could be interpreted by simple models employing the smoothness constraint (Marr & Poggio, 1976).

When an additional segregation cue for overlapping surfaces is provided, does the visual system overcome the inability to detect transparent surfaces in this stereogram? In the middle panel of Figure 1, a surface segregation cue was provided by reversing the signs of contrast of geometrically paired dots. In this stereogram,

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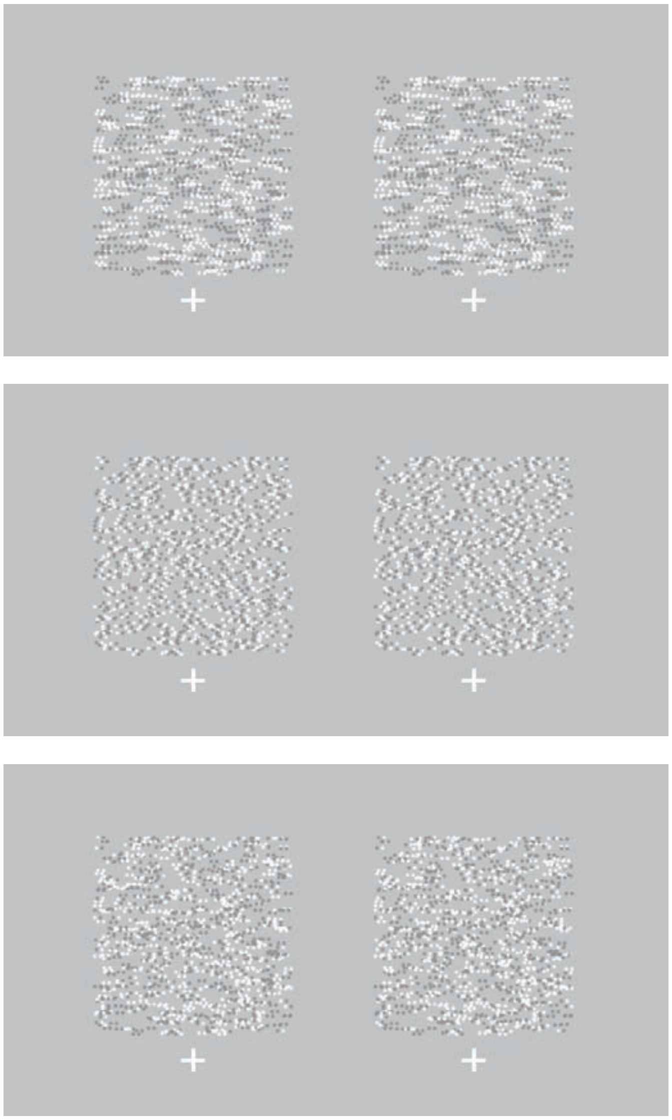

Figure 1. Examples of the stereograms generated by overlapping two identical dot patterns. (Top) All geometrically paired dots on two surfaces have the same contrast polarity. When fusing, a unitary surface is perceived stably. (Middle) All paired dots have the opposite contrast polarity. Although transparent surfaces might be perceived, the perception is unstable. (Bottom) A half of dot pairs has the opposite contrast polarity, while another half the same signs of contrast. Fusing this stereogram, transparent surfaces could be easily perceived rather than the middle panel. In each stereogram, fifty percent of dots were bright, and the others dark. Dot patterns in these stereograms are identical whereas the contrast polarities of each dot were different. In the Experiments 1 and 2, both bright and dark dots had low contrast intensity as shown in this figure. This is because brighter dots were used in the Experiment 3.

two overlapping patterns have opposite signs of contrast, while dot positions in two patterns are identical. In this case, as shown in Figure 2b, there is no potential match leading to a unitary surface perception, and it is expected that the contrast reversal might act as a surface segregation cue. However, it is difficult to obtain stable depth perception from this stereogram. This percept indicates that the contrast reversal does not act as a surface segregation cue as expected.

The third stereogram (the bottom panel of Figure 1) was generated by intermingling above two stereograms, that is, a half of paired dots had the same signs of contrast and another half was reversed. When fusing, two overlapping surfaces could be easily perceived rather than the stereogram illustrated in the middle panel of Figure 1. Why stereo transparency appears stably when only a half of paired dots has the opposite contrast polarity? This phenomenon cannot be explained by simply assuming that the contrast reversal acts as a cue for surface segregation, because, if the assumption is correct, we should easily perceive overlapping surfaces when all paired dots have the opposite contrast polarity rather than when a half of paired dots has the same signs of contrast.

Stereograms with ambiguous matches have been used to investigate the tendencies, or constraints, of the stereo matching process in human visual system (e.g., Anderson & Nakayama, 1994; Goutcher & Mamassian, 2005, 2006; Petrov, 2002; Ramachandran & Cavanagh, 1985). In this paper, we carried out a parametric study to examine the property of transparency perception with the ambiguous stereograms as illustrated in Figure 1. These stereograms have potential matches leading to both transparent and non-transparent surface perceptions. These two matching candidates are exclusive if the uniqueness constraint holds (Marr & Poggio, 1976). Therefore, which surface is perceived from the ambiguous stereogram would reflect the property of transparency detection in human stereopsis. The results showed that depth perception in this stereogram is affected by the contrast reversal ratio within small regions the widths of which were about 0.4 deg. This width was similar to the receptive field sizes of neurons in early visual cortex. This result suggests that the contrast reversal between two identical patterns would

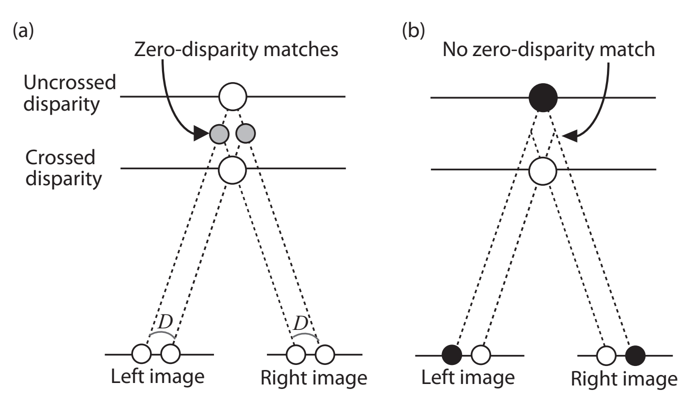

Figure 2. Candidate matches generated by geometrically paired dots with (a) the same and (b) the opposite contrast polarities.

modulate the activities of binocular neurons, and this modification would affect transparency detection in binocular stereopsis.

General methods

Here, we describe the basic methods for all experiments. More specific details will be provided for each experiment.

Apparatus

Stimuli were generated by an ELSA Quadro FX3000 graphic board and presented on a NANAO T766 CRT monitor at a viewing distance of 100 cm, leading a spatial resolution of 49.9 pixels per degree of visual angle. To provide independent stimulations of the eyes, the graphic board was synchronized with stereoscopic liquid crystal glasses (MacNaughton NuVision 60GX) at 120 Hz (60 Hz for each eye). Observers seated in front of the monitor with their heads supported by a chin-rest. The experimental room was darkened, but the light from the monitor provided dim illumination.

Observers

Three observers participated in the experiments; one was the author, and the others were naive to the conceptual basis of the experiments. All had normal or corrected-to-normal visual acuity.

Stimuli

The stimuli were composed of a red fixation cross and two stereograms plotted within square areas subtending 5 deg. The fixation cross was composed of vertical and horizontal nonius lines surrounding a small dot the width of which was 0.1 deg. The horizontal and vertical lengths of the fixation cross were 0.5 deg. The fixation cross was located at the center of the display and was presented throughout a session. In each trial, two stereograms were presented simultaneously and centered 4 deg either side of the fixation cross; one was the ambiguous stereogram generated by overlapping two identical dot patterns, and the other a simple RDS with a single disparity. Which side the ambiguous stereogram was presented at was chosen at random from trial to trial.

Each stereogram consisted of 700 dots (0.06 deg diameter; density 10%, or 27 dots per square degree). A half of dots was bright (L = 6.82 cd/m^2) and the others dark (L = 1.72 cd/m^2); the luminances were measured through the stereo glasses. The luminance of a gray background was L_{mean} = 4.29 cd/m^2. Therefore, Weber contrasts, $|L - L_{\text{mean}}|/L_{\text{mean}}$, of both bright and dark dots against the background were 0.6. The ambiguous stereogram was generated by overlapping two dot patterns each of which consisted of 350 dots. These two patterns had disparities of ±7.2 arcmin, and the dot distributions of them were identical. Therefore, in each eye's images, dots were plotted in closely spaced pairs, while the dot 'pairs' were located randomly. Note that, because the horizontal offset of paired dots in one eye's image was 7.2 arcmin, the disparity gradient (disparity/distance) between them exceeded the disparity gradient limit (Burt & Julesz, 1980; Tyler, 1975). However, McKee and Verghese (2002) reported that, in the case of stereo transparency, observers could fuse binocular images with steep disparity gradients. The disparity gradient of present stimuli was 2 and was well within the range of stereo transparency could be perceived. The RDS with a single disparity consisted of randomly distributed dots. In each trial, the disparity of the RDS was selected randomly from 9 different levels between −6.0 arcmin and +13.2 arcmin in a step of 2.4 arcmin; a positive and a negative value represents a crossed and an uncrossed disparity, respectively.

Procedure

A two-alternative forced choice (2AFC) procedure with the method of constant stimuli was used to examine depth perception in the ambiguous stereograms. Observers indicated which stereogram, presented in the left side or the right side, had a nearer disparity via a key press. Therefore, if observers perceive two overlapping surfaces separately, the nearest disparity obtained by the experiments should be +7.2 arcmin, whereas 0 arcmin of disparity should be obtained if observers detected alternative matches leading to unitary surface perception. All observers performed training sessions before they participated in the experiments. In the training session, the ambiguous stereogram was replaced by a normal RDS with a single (0 arcmin) or transparent (±7.2 arcmin) disparities, and all observers could compare the depths of two simultaneously presented stereograms based on the nearest disparity in each stereogram. Note that the present experiments were not strictly testing transparency perception, because subjects were only required to judge the nearest disparities in two stereograms. Stereograms were presented for 2 s in one trial, and no feedback was given. Each observer performed 20 trials for each disparity level of the RDS. Therefore, 180 trials were carried out to obtain the nearest depth perceived in an ambiguous stereogram.

To estimate the perceived disparity, a psychometric function was fitted to the data with psignifit 2.5.41, a software package that implements the maximum-likelihood method (Wichmann & Hill, 2001). A logistic function

$$F(x;\alpha,\beta) = \frac{1}{1+\exp\left(\frac{\alpha-x}{\beta}\right)}, \quad (1)$$

was employed as a psychometric function. It has been known that the logistic function is a fairly good approximation to the cumulative Gaussian with the mean α and the standard deviation 1.7β (Treutwein, 1995). α and β are the position (corresponding to the point of subjective equality; PSE) and spread (or slope) parameters of the function.

Experiment 1: Effect of the contrast reversal ratio

As described in the Introduction, depth perception in the ambiguous stereogram is affected by the contrast reversal ratio between two overlapping patterns. However, in the Introduction, we only showed the ambiguous stereograms with the typical contrast reversal ratios at 0%, 50%, and 100%. In the present experiment, we examine the effect of the contrast reversal ratio more precisely.

Method

In Experiment 1, we used 11 levels of contrast reversal ratios selected between 0% and 100% in a step of 10%. Therefore, the number of combinations of the ambiguous stereogram and the RDS was 99 (11 levels of the contrast reversal ratios × 9 levels of the RDS disparities). In each session of the experiment, these 99 conditions were presented in random order, and all observers carried out 20 sessions to obtain the results.

Result and discussion

Figure 3a shows the average PSEs for all 11 conditions. The result clearly shows that depth perception in the ambiguous stereogram was affected by the contrast reversal ratio. An ANOVA showed that this effect was significant ($F_{10,20}$ = 8.18, p = 3.9 × 10^{-5}), and post hoc multiple comparisons with Tukey's test showed that the PSEs with the contrast reversal ratios of 0% and 100% were significantly different from others (p level < 0.05 in all comparisons).

When the contrast reversal ratio was 0%, the average PSE was 0.05 arcmin. This perceived depth corresponded to the disparity of the unitary surface (0 arcmin), and this result confirms the description in the Introduction section. On the other hand, the average PSE at the contrast reversal ratio of 100% was 1.8 arcmin. The long error bar in Figure 3a indicates that the individual difference in this condition was greater than others. This result suggests that depth perception in this condition was unreliable. As described in the Introduction, when the contrast reversal ratio was 100%, it was hard to perceive transparency. Because depth judgments were unstable in this condition, the great individual difference arose in the PSE.

Figure 3b directly shows that observers could not perform the task stably when the contrast reversal ratio was 100%. This graph shows the average spread parameters of the fitted psychometric functions. The spread parameter determines the slope of the psychometric

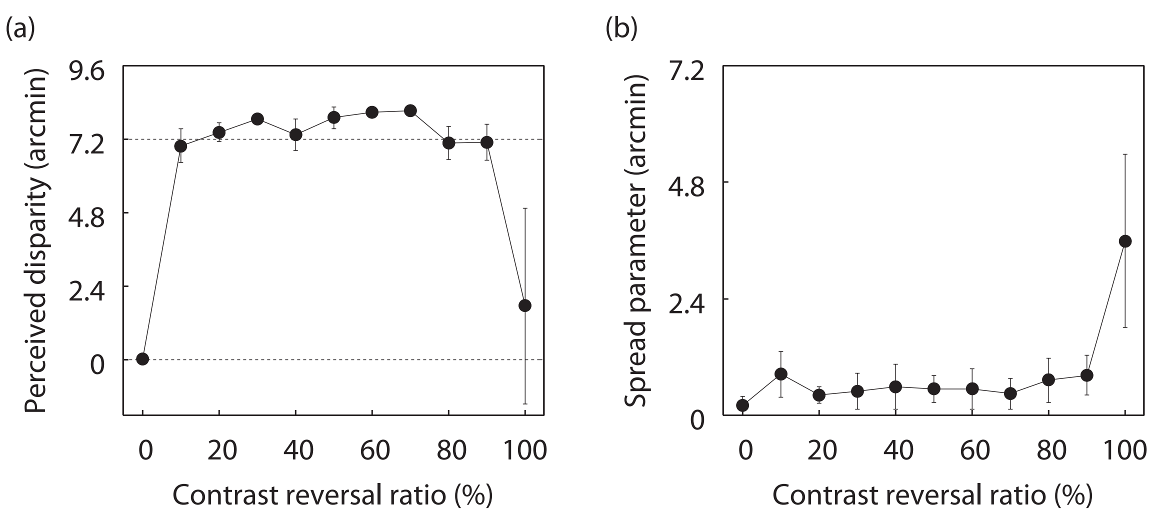

Figure 3. Results of Experiment 1. (a) Average PSEs for the nearest depths perceived in the ambiguous stereograms are plotted as a function of the contrast reversal ratio. (b) Spread parameters (β) of the psychometric functions. In both graphs, error bars represents ±1 *SE*.

function and provides a measure of the precision of judgments. As shown in Figure 3b, the spread parameter in the case of the 100% reversal was greater than others. An ANOVA showed that the effect of the contrast reversal ratio on the spread parameters was significant ($F_{10,20}$ = 3.16, p = 0.013), and multiple comparisons with Tukey's test indicated that there were significant differences between the 100% reversal and others (p level < 0.05 in all comparisons). This result indicates the precision of the depth judgment in the case of the 100% reversal was poorer than others.

When the contrast reversal ratios were between 10% and 90%, the obtained PSEs were similar to the nearer disparity of the transparent surfaces (+7.2 arcmin). This result indicated that, regardless of the proportion of the opposite contrast pairs, observers could detect overlapping disparities stably. The present result showed that the contrast reversal by itself was insufficient to segregate two overlapping disparities in the ambiguous stereograms, and it is necessary for transparency perception that both two types of pairs, the same and the opposite contrast pairs, coexisted in the stimuli. The contrast reversal ratios of 0% and 100% are the specific cases that the ambiguous stereograms only contain the same and the opposite contrast pairs, respectively. In these cases, the human stereopsis tended to avoid matching candidates leading to transparency perception. Especially in the case of 100%, there was no alternative match with zero disparity, and depth perception became unstable.

In the present experiment, both two types of pairs were located randomly. Therefore, it is still unclear whether the coexistence of two types of pairs is a sufficient condition for transparency perception in the ambiguous stereogram. Do the spatial positions of these pairs affect the disparity detection? In the following experiment, we examine the effect of spatial positions on depth perception in the ambiguous stereograms.

Experiment 2: Effect of spatial position

In Experiment 2, we examine whether the spatial positions of the same and the opposite contrast pairs affect depth perception in the ambiguous stereogram. The size of the stereogram used in the experiment (5 × 5 deg) was larger than the receptive field sizes of neurons in primary visual cortex. If transparency perception in this ambiguous stereogram requires that individual neurons receive both the same and the opposite contrast pairs simultaneously, the two types of dot pairs have to be plotted in spatially neighbors. In the present experiment, we located the two types of dot pairs in spatially segregated regions and examined the effect on depth perception.

Method

Figure 4 shows the schematic illustrations of dot arrangements in Experiment 2. Each ambiguous stereogram was divided into an even number of horizontal bars of equal width. In the experiment, we used 8 levels of bar widths between 0.28 deg (18 bars) and 1.25 deg (4 bars). The same and the opposite contrast pairs were attributed to the odd and the even bars, respectively. As the bar width decreases, the stimulus becomes similar to the ambiguous stereograms the same and the opposite contrast pairs in which are located at random. Therefore, when the bar widths are sufficiently small, it is expected that the PSE became 7.2 arcmin. On the other hand, when the bar widths are broad, many dot pairs are surrounded by the same types of dot pairs. If it is necessary for transparency detection that both two types of pairs are located in nearby positions, we would see zero disparity regions and vague regions alternately arranged in adjacent bars. In this case, the PSE would be 0 arcmin. The dot arrangement of the present experiment was similar to the stimuli used by Mestre, Masson, and Stone (2001) for investigating the perceptual property of motion transparency. In their experiment, dots with different motions were alternately positioned in different bars. However, in the present experiment, each bar had potential matches with both crossed and uncrossed disparities, and the only difference between adjacent bars was the contrast reversal ratio of paired dots.

In the present experiment, to maximize dot homogeneity, each bar had the equal dot density, and therefore, the contrast reversal ratio was fixed at 50%. The number of combinations of the ambiguous stereogram and the RDS was 72 (8 levels of bar widths × 9 levels of the RDS disparities). In each session, these 72 conditions were presented in random order, and all observers carried out 20 sessions.

Result and discussion

Figure 5 represents the average PSEs in our corrugated stimuli. When the bar widths were small, the PSEs were

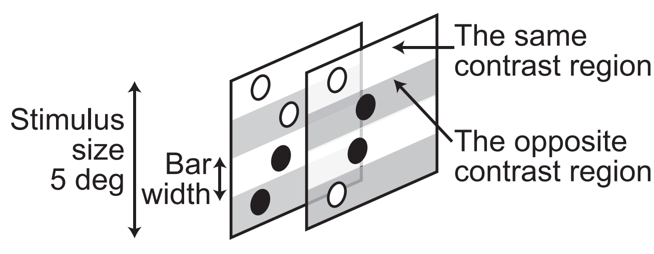

Figure 4. Schematic illustrations of dot arrangements of the ambiguous stereograms used in Experiment 2. The same contrast pairs were located in white regions, and the opposite contrast pairs in dark regions. In this figure, the number of bars is 4.

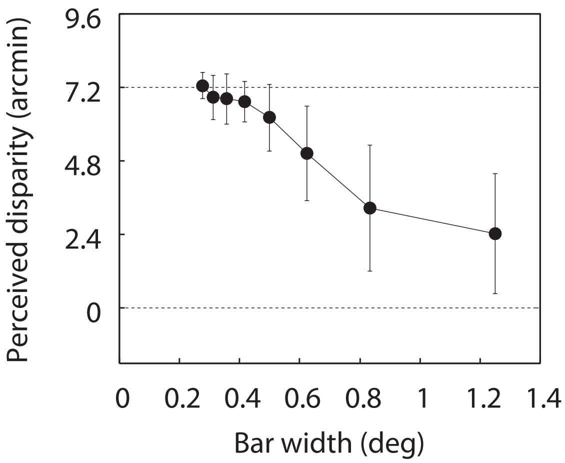

Figure 5. Result of Experiment 2. The average PSEs for three observers are plotted as a function of the bar width.

nearly equal to the nearest disparity in the ambiguous stereogram (7.2 arcmin). However, as the bar width increased, the PSE decreased toward zero disparity. An ANOVA showed that the effect of the bar width was significant ($F_{7,14}$ = 6.92, p = 0.0011), and multiple comparisons with Tukey's test indicated that there were significant differences between the PSEs the bar widths of which were 0.42 deg or smaller and the PSEs the bar widths of which were 0.83 deg or higher (p level < 0.05 in all comparisons).

In Experiment 2, the proportion of contrast reversed pairs was fixed at 50%. Therefore, the present result indicated that only the coexistence of both the same and the opposite contrast pairs was insufficient to perceive two overlapping disparities from the ambiguous stereogram, and it is necessary to locate these pairs in nearby positions. This result suggests that the existence of the same contrast pairs in neighboring locations would help to detect transparent matches from the opposite contrast pairs. The maximum bar width that could lead to stereo transparency were 0.42 deg, and there is a possibility that this width would be related to the receptive field sizes of neurons in striate cortex (Dow, Snyder, Vautin, & Bauer, 1981).

Experiment 3: Effect of contrast intensity

In Experiments 1 and 2, both bright and dark dots had the same contrast intensities. In the present experiment, we examine the effect of the contrast intensity difference between bright and dark dots on the perceptual properties in the ambiguous stereograms. The contrast intensity difference does not affect the potential matches in the same contrast pairs, because, in this case, all matching candidates are made up of the dots with the same contrast intensities (see Figure 2a). The contrast intensity difference would influence the potential matches in the opposite contrast pairs (Figure 2b). In this case, matching candidates in front and rear surface have different contrast intensity. Therefore, when the contrast reversal ratio is greater than 0%, there is a possibility that depth perception is changed qualitatively.

Method

In this experiment, except for the luminance of the bright dots, stimulus parameters were identical to Experiment 1. We used four luminance levels of the bright dots: 6.82, 7.67, 8.54, and 9.44 cd/m^2. These luminances correspond to Weber contrasts of 0.6, 0.8, 1.0, and 1.2. Because Weber contrast of dark dots was fixed at 0.6, the result should be identical to Experiment 1 when Weber contrast of bright dots was 0.6.

In Experiment 3, we employed two conditions for the contrast reversal ratio: 50% and 100%. Therefore, the number of combinations of the ambiguous stereogram and the RDS was 72 (4 levels of contrast intensities × 2 levels of the contrast reversal ratios × 9 levels of the RDS disparities). In each session of the experiment, these 72 conditions were presented in random order, and all observers carried out 20 sessions to obtain the results.

Result and discussion

Figure 6 shows the result of Experiment 3. Open circles in Figures 6a and 6b represent the PSEs and the spread parameters when the contrast reversal ratio was 50%. In this case, observers could always perceive stereo transparency stably. Therefore, even if there were contrast intensity differences in the opposite contrast pairs, the perceptual property in this case was unchanged quantitatively.

Filled circles in Figure 6 represent the results when the contrast reversal ratio was 100%. When Weber contrast of bright dots was 0.6, the results were quantitatively identical to that of Experiment 1. However, as Weber contrast of bright dots increased, the PSE approached a disparity of 7.2 arcmin, and the spread parameter became smaller. Although no significant effect was observed in the spread parameter ($F_{3,6}$ = 3.15, p = 0.11), the effect of Weber contrast on the PSE was significant ($F_{3,6}$ = 5.11, p = 0.04), and multiple comparisons with Tukey's test indicated that there was significant difference between Weber contrasts of 0.6 and 1.2 (p = 0.04). This result indicates that, when the contrast intensities of bright and dark dots were different, observers could detect transparency matches even if the same contrast pairs did not exist.

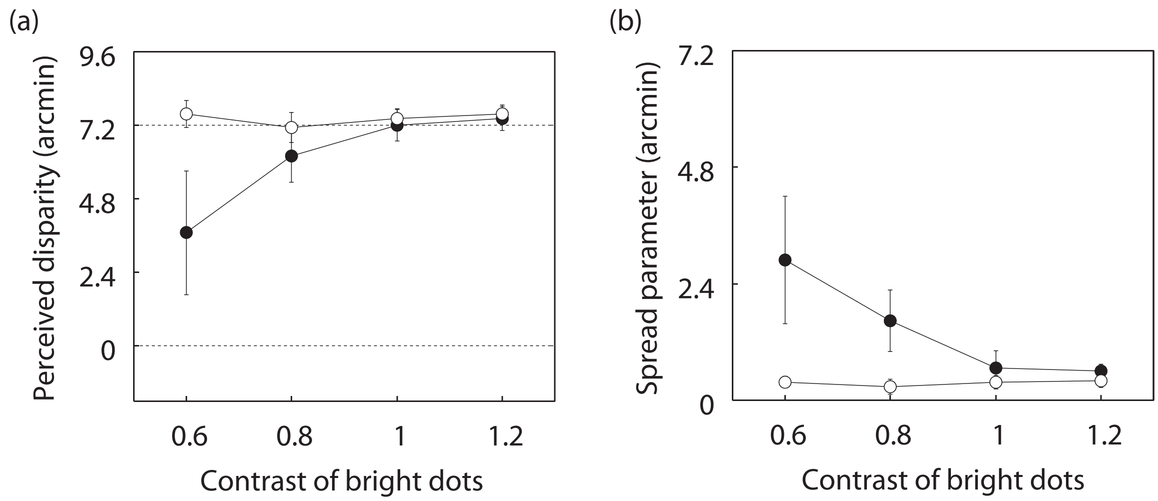

Figure 6. Results of Experiment 3. (a) Average PSEs for three observers are plotted as a function of Weber contrast of bright dots. The open and filled circles represent the results when the contrast reversal ratios were 50% and 100%, respectively. (b) Spread parameters of the psychometric functions. In both graphs, error bars represent ±1 *SE.*

This result can be explained with the saliency of each dot. As the contrast intensity of bright dots increased, the saliency of them becomes greater, and the black dots have less influence on depth perception. In this case, each opposite contrast pair would be effectively regarded as a single bright dot with a crossed or an uncrossed disparity and would only contribute a unique match on one of the two depth planes. Therefore, the result indicated that the effect of the contrast reversal ratio shown in the previous experiments could be obtained only when the contrast intensities of all dots were identical.

Conclusions

In the present study, we have examined depth perception in the stereograms generated by overlapping two identical dot patterns. These stereograms have potential matches leading to transparency and non-transparency perceptions, and which depth perception occurs from the stimuli would reflect the transparency detection mechanism in human stereo vision. The present result showed that the contrast reversals between geometrically paired dots by itself did not act as a surface segregation cue as expected. Observers could easily detect overlapping disparities when the same contrast pairs remained in the stimuli rather than when all dot pairs had the opposite signs of contrast. In addition, to perceive overlapping disparities in the ambiguous stereograms, the same and the opposite contrast pairs had to be located within small regions (≤0.42 deg). This size is sufficiently small for each neuron in striate cortex to receive both contrast pairs simultaneously. Moreover, Experiment 3 indicated that the perceptual properties described above occurred only when the contrast intensities of bright and dark dots were identical. When the contrast intensity of the bright dots was greater than that of the dark dots, depth perception was mainly due to the matching candidates composed of bright dots, and the dark dots had less influence on the percept.

In the initial stage of visual processing, bright and dark information against background is processed separately (Schiller, 1992; Schiller, Sandell, & Maunsell, 1986). Therefore, it is considered that, at least at the early stereo process that first combines monocular information, matching primitives with bright and dark contrasts are treated independently and are never integrated as matching candidates (e.g., the compatibility constraint proposed by Marr & Poggio, 1976). Harris and Parker (1995) showed that bright and dark information is processed separately in human stereo vision, at least at the dot-matching stage. They examined the efficiency of a depth judgment task in RDSs. When an RDS consists of bright or dark dots only, there should be many matching candidates in the RDS. If opposite contrast dots are never matched binocularly, the total number of matching candidates would be reduced by half by making half the dots dark and half bright. Therefore, it is expected that reversing the contrast polarity helps stereo matching process. They showed that the efficiency of depth judgment was improved when the RDS contained both bright and dark dots. Their result suggests that the contrast reversal could disambiguate binocular correspondences in RDSs. However, the perceptual property in the ambiguous stereogram was different from this finding. In the present study, all ambiguous stereograms had both bright and dark dots, and the total number of possible matches depended on the proportion of the opposite contrast pairs. Because the number of matching candidates in the opposite contrast pairs was smaller than that of the same contrast pairs (see Figure 2), the efficiency of depth perception should be improved when the contrast reversal ratio became greater. However, in the ambiguous stereogram, the existence of the same contrast pairs helped transparency perception. When no dot pair with the same contrast polarity existed in nearby positions, it was hard to detect transparent disparities from the opposite contrast pairs. Therefore, it is considered that this specific dot pattern would lead to a unique neuronal activity.

The details of the neural representation of overlapping disparities remain an open question, but the present result could be a clue to investigate the encoding strategy for multiple disparities. The result suggests that the coexistence of the same and the opposite contrast pairs would modulate neuronal responses, and this modulation would be related to the neural representation of transparent disparities. Therefore, examining how the contrast polarities of paired dots modulate the responses of binocular neurons with physiological and/or computational ways, we could investigate how the binocular neurons represent transparency situations. These researches should include mathematical analysis of the response of the disparity energy model (Ohzawa, DeAngelis, & Freeman, 1990; Tsai & Victor, 2003; Watanabe & Idesawa, 2003) to the ambiguous stereograms.

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