



Anisotropy in Werner's Binocular Depth-contrast Effect

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We investigated Werner's binocular depth-contrast effect. Subjects viewed stereograms consisting of a test pattern and an inducing pattern. The half-images of the inducing pattern were either horizontally scaled or sheared relative to each other. Subjects judged the (induced) perceived slant of the test pattern. We were interested in what influence the spatial configuration of the test pattern and the inducing pattern had on the depth-contrast effect. We conclude that the depth-contrast effect is a global effect. In other words, it is not restricted to the location of the inducing pattern. The effect decreases with distance, however, in an anisotropic way. The depth-contrast effect was present most prominently when the test pattern was positioned in the direction along the slant (rotation) axis of the inducing pattern. We suggest that Werner's depth-contrast effect can be explained by the (previously reported) findings that: (1) stereopsis is relatively insensitive to whole-field horizontal scale and shear; and (2) stereopsis is very sensitive to horizontal scale and shear of two stimuli relative to each other. Copyright © 1996 Elsevier Science Ltd.

Binocular disparity Binocular vision Depth-contrast Stereopsis

INTRODUCTION

Horizontal scaling of the two parts of a stereogram relative to each other leads to perception of slant (rotation) about the vertical axis. Horizontal shear leads to perception of slant about the horizontal axis. Suppose there are two patterns in the visual field. Following the traditional ideas about depth perception (Wheatstone, 1838; Julesz, 1971), one would expect the perceived slant of one pattern to be independent of the horizontal scale or shear of the other pattern and vice versa. However, in practice, the processing of disparity for the perception of slant is influenced by the horizontal scale or shear of reference patterns.

Werner (1937, 1938) reported that perception of slant of a test pattern depends on the presence of a reference pattern. He called this effect the binocular depth-contrast effect. To produce the effect, two different line drawings [as in the stereo-pair of Fig. 1(a)] can be placed on the right and on the left in a stereoscope. On the left are three vertical lines, spaced equally, and on the right is the same arrangement, except that the outer lines have been horizontally sheared, with the central line remaining vertical. According to the traditional ideas, one would

expect to see, stereoscopically, a single vertical line between the two lines that are inclined in space (the upper parts are nearer the observer). However, we see the central line inclined in the direction opposite to that of the outer lines and thus the central line looks as if its top part is further away. Another example of a stimulus that gives rise to Werner's depth-contrast effect is given in Fig. 1(b). According to the traditional ideas, horizontal scaling of the outer rectangle results solely in perceived slant of the outer rectangle about the vertical axis. In fact, however, the inner rectangle is also perceived as being slanted but in the opposite direction. Werner (1938) suggested that the depth-contrast effect is caused by a change of correspondence within particular binocular receptive fields.

Ogle (1946) investigated the effect too, and suggested that Werner's binocular depth-contrast phenomena occur as a result of cyclofusional movements of the eyes accompanied by stable retinal correspondence. However, in those days, objective cyclotorsion could not be measured (for a review see Kertesz, 1991; Howard *et al.*, 1993). Nelson (1977) remarked that cyclofusional movements cannot be the sole reason for the depth-contrast effect because some stimuli [such as the stereo-pair of Fig. 1(b)] show the depth-contrast effect but cannot induce cyclotorsion. Howard and Zacher (1991) did objective measurements on the cyclotorsional state of the eyes during observation of one of Werner's stimuli [actually the stereo-pair of Fig. 1(a)] and confirmed

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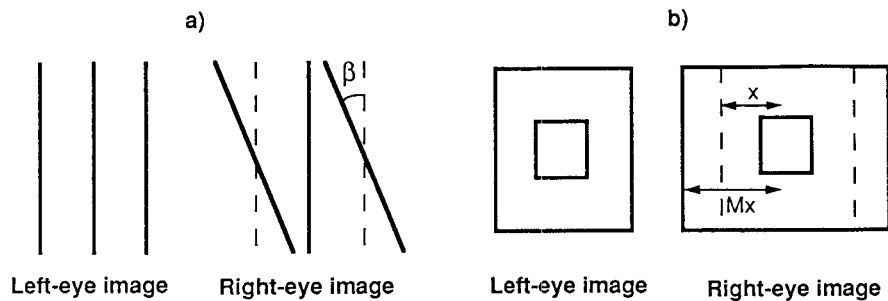


FIGURE 1. Two examples of stimuli which show the depth-contrast effect. The outer lines of the stereo-pair in (a) have been horizontally sheared. The amount of shear is expressed by the angle β . The outer rectangle of the stereo-pair in (b) has been horizontally scaled with a fraction M . For clarity, the horizontal shear of the left stereo-pair and the horizontal scale of the right stereo-pair are exaggerated. The depth-contrast effect is best observed when non-rectangular stimuli are used; the drawings are schematic.

Nelson's idea that cyclofusional movements do not explain the depth-contrast effect.

Kumar and Glaser (1992a) showed that the shapes of the inducing figures contributed significantly to the perceived depth of the test items. They interpreted the extra influence of the shape of the inducing figures as an effect of perspective. However, it is not only the shape of the inducing figure which is important; the shape (and texture) of the test figure also play an important role in the perception of depth of the test figure. McKee (1983), Mitchison and Westheimer (1984, 1990), Fahle and Westheimer (1988), Mitchison and McKee (1990) and Kumar and Glaser (1992a,b) showed what influence figural properties of patterns of dots or lines within the stimuli have on depth perception. Kumar and Glaser (1992a) went a step further and showed by using feedback signals that observers can be trained to use only disparity cues and to ignore shape and texture (perspective) effects.

With regard to stimuli that contain little or no perspective cues, Mitchison and Westheimer (1984) reported that perception of depth can be accounted for quite economically and with considerable numerical accuracy by the concept of salience.* The salience concept quantitatively extends the adjacency principle of Gogel (1963). According to the salience concept, stimuli are perceived to be at equal depth when they have equal salience. Salience, as can be seen from the formula in the footnote below, is in essence an isotropic concept. If the visual system is required to perceive slant of planes relative to each other and to perceive small objects protruding from such planes, then salience could be a useful indicator. As we will see below, salience explains several aspects of the depth-contrast effect, but not all aspects. Mitchison and Westheimer (1984) concluded their paper with the remark that "various caveats concerning the salience concept need to be uttered".

*Salience (L) is the summed disparity inversely weighted with the distance between the test object (with disparity d) and its neighbours (with disparity d_i): $L = \sum w_i (d_i - d)$; w_i is the weighting factor which varies with the individual subject.

These caveats are relevant for realistic stimuli since they merely investigated stimuli in the horizontal plane, slant about the vertical axis and, most importantly, simple figures consisting of a small number of points and lines centrally displayed in the foveal region.

In most studies dealing with the depth-contrast effect, small point or line stimuli have been used (sometimes of the order of degrees but usually smaller). Not many studies have incorporated global aspects. Fahle and Westheimer (1988) suggested that two factors determine depth thresholds: a predominant local one that extracts disparity differences between adjoining points and an additional one that processes more global features of the stimulus configuration which go beyond the next neighbour. Kumar and Glaser (1991) showed that even features which can be as far apart as 51 deg influence the relative depth of two central dots. The effect varied inversely with the spatial separation between the test dots and the remote figures (supporting Gogel's adjacency principle). With regard to global aspects of the depth-contrast effect, it is important to note that many studies (Shipley & Hyson, 1972; Gillam *et al.*, 1984; Mitchison & Westheimer, 1984, 1990; Stevens & Brookes, 1987, 1988; Gillam *et al.*, 1988; van Ee & Erkelens, 1996) have shown that the visual system is relatively insensitive to whole-field horizontal scale and shear. The salience concept does not explain why stereopsis is relatively insensitive to whole-field horizontal scale and shear. Van Ee (1995) investigated the combination of a local depth-contrast effect and whole-field stimuli. He reported that the sign of perceived slant of a small test pattern was judged according to the difference between the transformation magnitude of the small test pattern and that of the large inducing pattern and not according to the transformation magnitude of the test pattern itself. This result supports the salience concept. In conditions in which horizontal scale or shear of a test pattern and an inducing pattern were the same (that is, there was only one single whole-field horizontal scale or shear), both patterns were perceived in the frontal plane. This result supports the findings that whole-field scale and shear are weak stimuli to induce slant (but cannot be described by

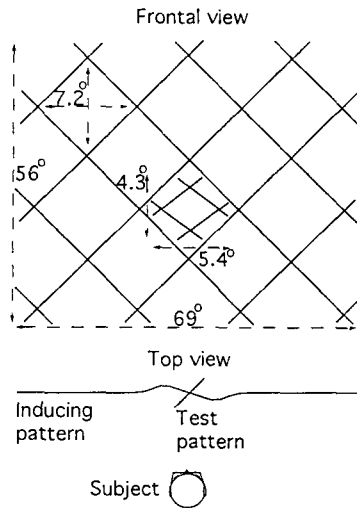


FIGURE 2. A horizontally scaled inducing pattern gives rise to perceived slant of the unscaled test pattern. The subjects had the impression that the large-field pattern remained in the frontal plane, apart from the region near the small pattern. Near the small pattern, subjects perceived the large and the small patterns to have angles with opposite sign.

saliency). Van Ee also found that subjects had the impression that nearly all of the large-field pattern remained in the frontal plane, the exception being the region near the small pattern. With regard to the horizontal scale of the patterns, he found that subjects perceived the large and the small patterns with opposite angles, such as is illustrated in Fig. 2. With regard to horizontal shear, he reported a similar effect, but in the vertical direction. These results support the shielding effect which can be explained by saliency. Mitchison and Westheimer (1984) found for several subjects that only the nearest neighbours contributed to the depth percept.

From the existing literature, it is not clear to what extent Werner's depth-contrast effect results from local and global mechanisms. In the present study, we investigated how the depth-contrast effect depends on the spatial configuration of inducing and test patterns for slant about the horizontal and about the vertical axis. We varied systematically the distance and the relative orientation of the test and reference pattern relative to each other.

METHODS

We used the same experimental set-up as described in detail in van Ee and Erkelens (1995, 1996). The stimuli were presented dichoptically on a large screen (70 × 70 deg) and viewed with anaglyph glasses. The observers were seated about 150 cm in front of the screen and their head or eye movements were not restricted. The stimuli were viewed in a completely dark room. The subjects had normal or corrected-to-normal vision.

The subjects viewed two patterns. Figure 3 shows the inducing and the test pattern. Both the inducing and test patterns were circular and contained randomly distributed elements. Both patterns had a radius of 12 deg. The

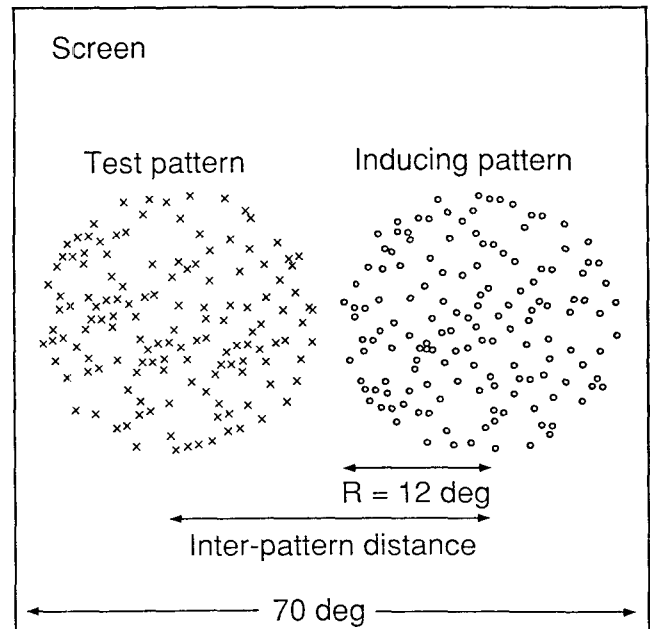


FIGURE 3. The inducing and the test pattern. Both patterns have a radius of 12 deg. The inducing pattern contains small circular elements each with a diameter of 1.2 deg and a density of about 10%. The test pattern contains small crosses with line lengths of 1.2 deg and a density of 10%. The edge of the screen is not visible and the room is totally dark.

inducing pattern contained small circular elements with a diameter of 1.2 deg each and a density of about 10%. The test pattern contained small crosses with line lengths of 1.2 deg and a density of 10%. A different, randomly chosen configuration of elements was presented during each trial. The patterns were presented next to each other (horizontally oriented) or one above the other (vertically oriented). The distance between the centres of the patterns was either 0, 1, 2 or 3 × the radius of the patterns. Figure 4 shows the four possible pattern configurations, which we will denote by A, B, C and D. The test pattern was placed consistently below or on the left-hand side of the inducing pattern. This helped the subject to estimate the slant of the test pattern without confusing it with the slant of the inducing pattern.

Horizontally scaled inducing patterns (scaled with factors -10.0, 0.0 or 10.0%) or horizontally sheared inducing patterns (sheared with -5.5, 0 or 5.5 deg) were presented randomly. The magnitudes of the scale and shear transformations were chosen such that they were identical to each other with respect to the amount of predicted slant (of the inducing pattern)*. For instance, both a horizontal scale of 10% and a horizontal shear of

*As pointed out in the study by van Ee and Erkelens (1996), equal slants require that $\beta = \arctan(2 \cdot (M - 1/M + 1))$, where β indicates the angle of shear in degrees and M the fraction of scale (see also Fig. 1). The relationship between slant about the vertical axis and the amount of horizontal scale is: $\text{slant} = \arctan((M - 1/M + 1) \cdot (2z_0/I))$, where I denotes the interocular distance and z_0 the distance from the stimulus. The relationship between slant about the horizontal axis and horizontal shear is: $\text{slant} = \arctan(\tan \beta \cdot (z_0/I))$.

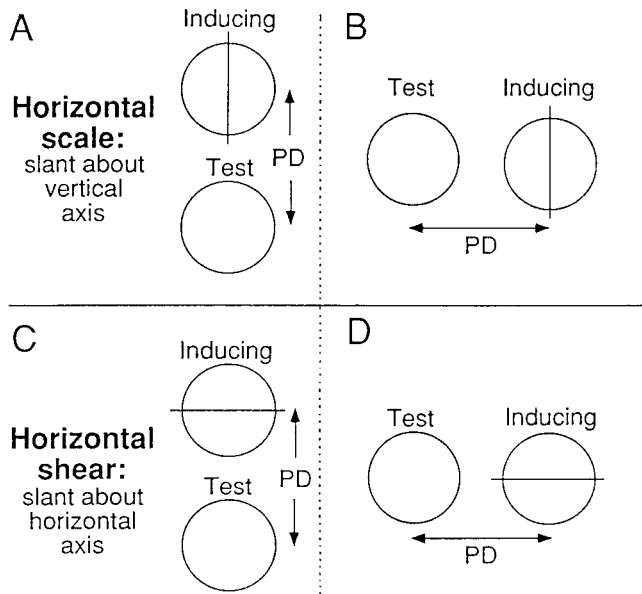


FIGURE 4. The four possible configurations of the inducing and the test pattern. The distance between the patterns (PD) is either 0, 1, 2 or 3 × the radius of the patterns. The test pattern was placed consistently below or on the left-hand side of the inducing pattern.

5.5 deg theoretically induce the same slant (namely 66 deg when the distance from the stereogram is 150 cm and the interocular distance is 6.5 cm). The test pattern was always untransformed.

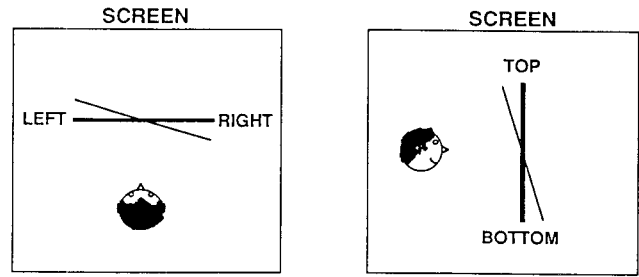


FIGURE 5. The subject estimates the angle of perceived slant by manipulating the computer-mouse. In the case of a pre-set horizontal scale of the inducing pattern (which means slant about the vertical axis), the left panel is presented to the subject. This panel corresponds to a top view of the experimental set-up. Stimuli which contained horizontally sheared inducing patterns (slant about the horizontal axis) are followed by the screen image shown in the right panel (which corresponds to a side view).

The task of the subject was to judge the perceived slant of the test pattern. The stimuli were presented for 1.5 sec. After each trial two lines (one fixed and one rotatable) appeared on the screen such as shown in Fig. 5 (we described this method earlier in van Ee and Erkelens, 1996). By changing the computer-mouse position, the subjects set the angle between the adjustable and the fixed line, the angle representing the perceived slant. The fixed line represented the frontal plane, the adjustable line

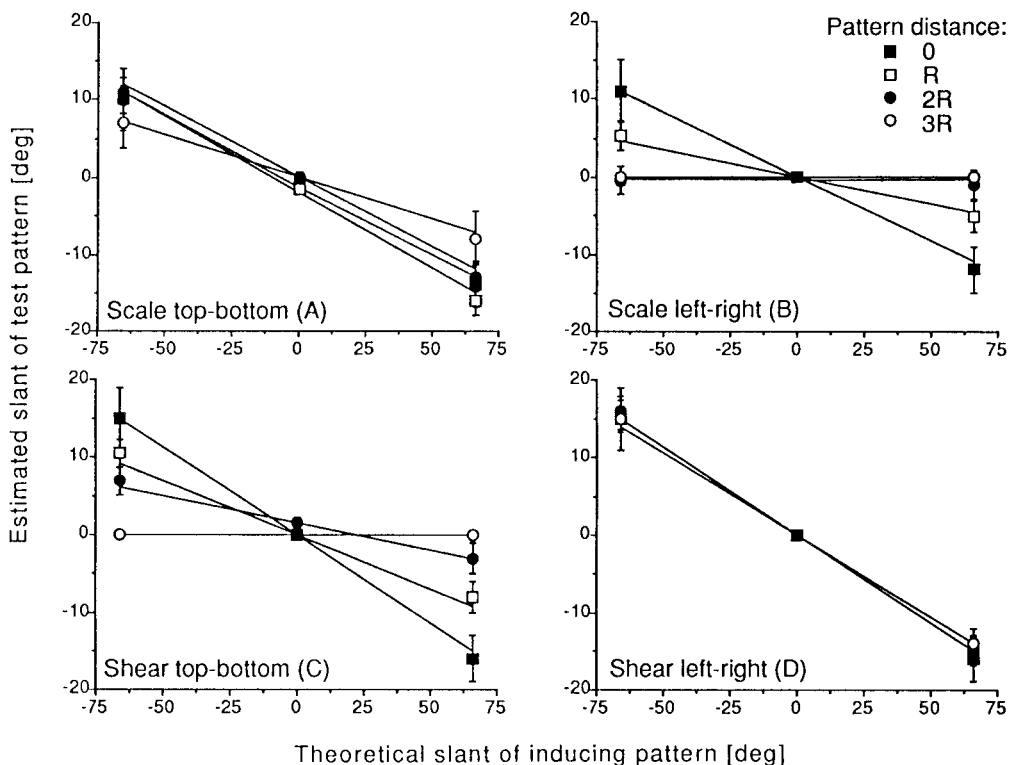


FIGURE 6. Estimated slant of the test pattern vs the theoretical slant of the inducing pattern of a typical subject JL. Each of the panels corresponds to a pattern configuration: A: horizontally scaled inducing pattern above the test pattern; B: horizontally scaled inducing pattern on the right-hand side of the test pattern; C: horizontally sheared inducing pattern above the test pattern; D: horizontally sheared inducing pattern on the right-hand side of the test pattern. Each of the symbols corresponds to a certain distance between the patterns. The lines represent the linear fit to the data points. The larger (more negative) the slope of the fit, the larger is the depth-contrast effect. The error bars represent SDs.

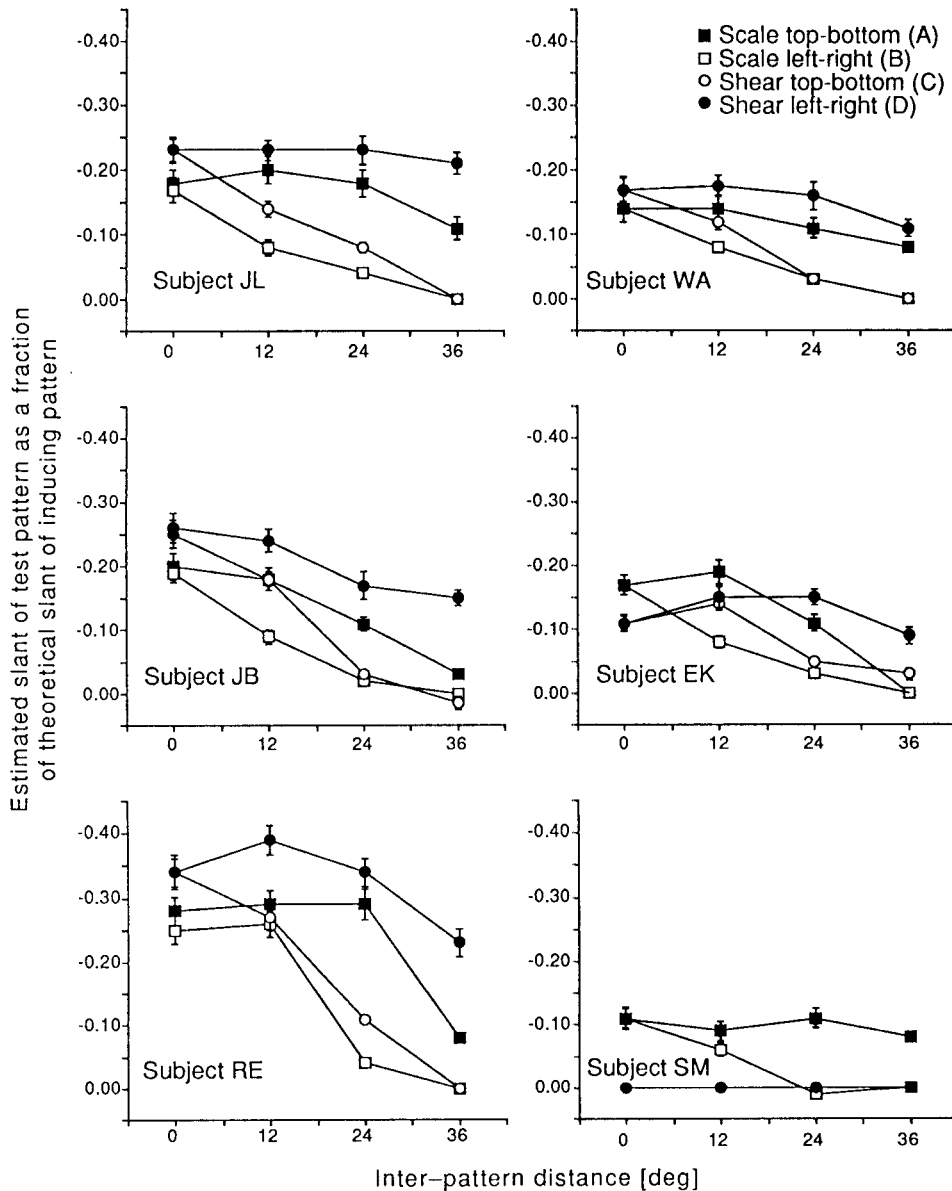


FIGURE 7. Estimated slant of the test pattern vs the distance between the inducing and the test pattern for each of the six subjects. Estimated slant of the test pattern is expressed as a fraction of the theoretical slant of the inducing pattern. Each data point is based on 27 slant judgments. The depth-contrast effects in the case of pattern configurations A (scale top-bottom) and D (shear left-right) are consistently more evident than in the case of the configurations B (scale left-right) and C (shear top-bottom). (For a number of points the error bar is smaller than the size of the symbol.)

represented the slanted plane. The setting of the perceived slant angle could be performed in a stepless way. The two lines were displayed in the plane of the screen and thus also served as a mask between successive stimuli.

In all, each subject had to judge 432 slants (all within one session), namely four pattern configurations (A, B, C and D), four inter-pattern distances (0, 1, 2 and 3 \times the pattern radius), three magnitudes of transformations (-10.0 , 0.0 , 10.0% or -5.5 , 0 , 5.5 deg) and nine repetitions. The interesting parameter in this experiment was the inter-pattern distance in combination with the four pattern configurations.

Six subjects (four males and two females, aged 22–61

years) took part in the experiment. The subjects were inexperienced in binocular depth experiments (except for subject RE, the first author) and had not been informed about the purposes of the experiment. Although each subject was familiar with the concept of mathematical angles, we checked before doing the experiment whether the subject was able to estimate slant in a consistent manner using our method. Therefore, during a short training session, we conducted a series of trials with real and dichoptically projected slanted planes with each of our subjects. During the training session, we gave feedback about the estimated angles of slant. During the actual experiment no feedback was given about the results.

RESULTS

The raw data (the means of perceived slants of nine repetitions) of a typical subject (JL) are presented in Fig. 6. The slant estimations for each configuration and distance between the patterns were characterized by a linear fit.* The steeper (more negative) the slope of the linear fit, the larger the depth-contrast effect. From this figure, it can be seen that the distance between the patterns played an important role. Particularly in configurations B (scale left–right) and C (shear top–bottom) this distance strongly influenced the estimated slant of the test pattern. In the case of stimulus configuration D (shear left–right) subject JL was least sensitive to the influence of the distance between the two patterns.

Figure 7 shows the data of all subjects as a function of the distance between the patterns. Each data point in this figure represents a regression coefficient obtained by the best-line fit as showed in Fig. 6. The depth-contrast effect was significantly more evident when both patterns were adjacent in the direction of the slant-axis of the inducing pattern.

In the case of a horizontally scaled inducing pattern, the depth-contrast effect on the test pattern was most evident when the stimuli were located one above the other. In the case of horizontally sheared inducing patterns, the depth-contrast effect on the test pattern was most evident when the patterns were located next to each other. In contrast, with regard to horizontally scaled inducing patterns, the depth-contrast effect on the test pattern was weak when the stimuli were located next to each other. With regard to horizontally sheared inducing patterns, the depth-contrast effect was weak when the stimuli were located one above the other. We show also the results of a subject experienced in binocular depth perception experiments (RE). He showed a more evident depth-contrast effect compared to the results of the other subjects but his results were basically the same. Another interesting subject is the one shown in the bottom-right panel (SM). Although she was able clearly to perceive slant caused by horizontally sheared patterns, she was not sensitive to the depth-contrast effect caused by horizontal shear of the inducing pattern. With regard to horizontal scale of the inducing pattern, she was moderately sensitive to the depth-contrast effect. Most subjects showed a more evident depth-contrast effect for the shear conditions than for the scale conditions.

A number of subjects showed a weaker depth-contrast effect when the distance between the two patterns was 0 deg than when the distance was 12 deg. This is probably an artefact of the set-up. Subjects found it more difficult

to distinguish the inducing pattern from the test pattern when these patterns were presented at the same location. Therefore they sometimes estimated the slant of the test pattern to be zero when it was not.

DISCUSSION

The results of the experiment show that:

(1) The distance between the inducing pattern and the test pattern is an important parameter. If this distance increases, the depth-contrast effect decreases. This supports earlier findings (e.g. Gogel & Mershon, 1977). However, we do not find that the effect varied inversely with the spatial separation as predicted by the adjacency principle.

(2) The depth-contrast effect is best observed when the test pattern is placed in the direction along the slant-axis of the inducing pattern.

We conclude that the depth-contrast effect is a global effect. In other words, it is not entirely restricted to the location of the inducing pattern. The effect decreases with distance, however, in an anisotropic way. Figure 8 demonstrates this anisotropy.

A possible explanation for the depth-contrast effect

It has been found (Shipley & Hyson, 1972; Mitchison & Westheimer, 1984, 1990; Stevens & Brookes, 1987, 1988; Gillam *et al.*, 1988; van Ee & Erkelens, 1996) that the visual system is relatively insensitive to whole-field horizontal scale and shear between the two half-images of a stereogram. In addition, horizontal scale caused by an aniseikonic lens leads to perception of slant only after considerable latencies in the order of tens of seconds (Ames, 1946; Seagram, 1967; Gillam *et al.*, 1984). The observer's low sensitivity to whole-field transformations means that the visual system is relatively insensitive to whole-field orientation. In contrast, the stereopsis system is very sensitive to slant relative to a visual reference (Gillam *et al.*, 1984, van Ee & Erkelens, 1996). Thus, the visual system is better at judging orientation of one stimulus relative to another than at judging absolute orientation [supporting Gogel's (1963) ideas]. In our experiment (and other experiments concerning Werner's depth-contrast effect) the perceived orientation of the two patterns contains an uncertainty (namely the whole-field orientation). The observer's high sensitivity to disparities relative to a visual reference explains the preservation of the relative angle between the two patterns. The uncertainty in the whole-field orientation can explain why the test pattern is perceived to be slanted.

Thus, the low sensitivity to whole-field disparities and the high sensitivity to disparities relative to a visual reference can explain the anisotropy in the depth-contrast effect. In configurations A (scale top–bottom) and D (shear left–right), the two patterns are aligned with each other according to the axis of slant of the inducing pattern, which means that they are susceptible to the uncertainty caused by misperception of the whole-field orientation. Therefore, in these configurations subject perceive the depth-contrast effect. In configurations B

*In a control measurement for each of the subjects we also presented slants of the inducing pattern which were theoretically predicted to be ± 22 and ± 44 deg. However, we found that slant perception of the test pattern does not vary linearly with the slant of the inducing pattern. This means that there are other valid methods for characterizing the raw data of the subjects. However, since there is no underlying model for the relationship between slant of the inducing and of the test pattern, so far there is no suitable characterization.

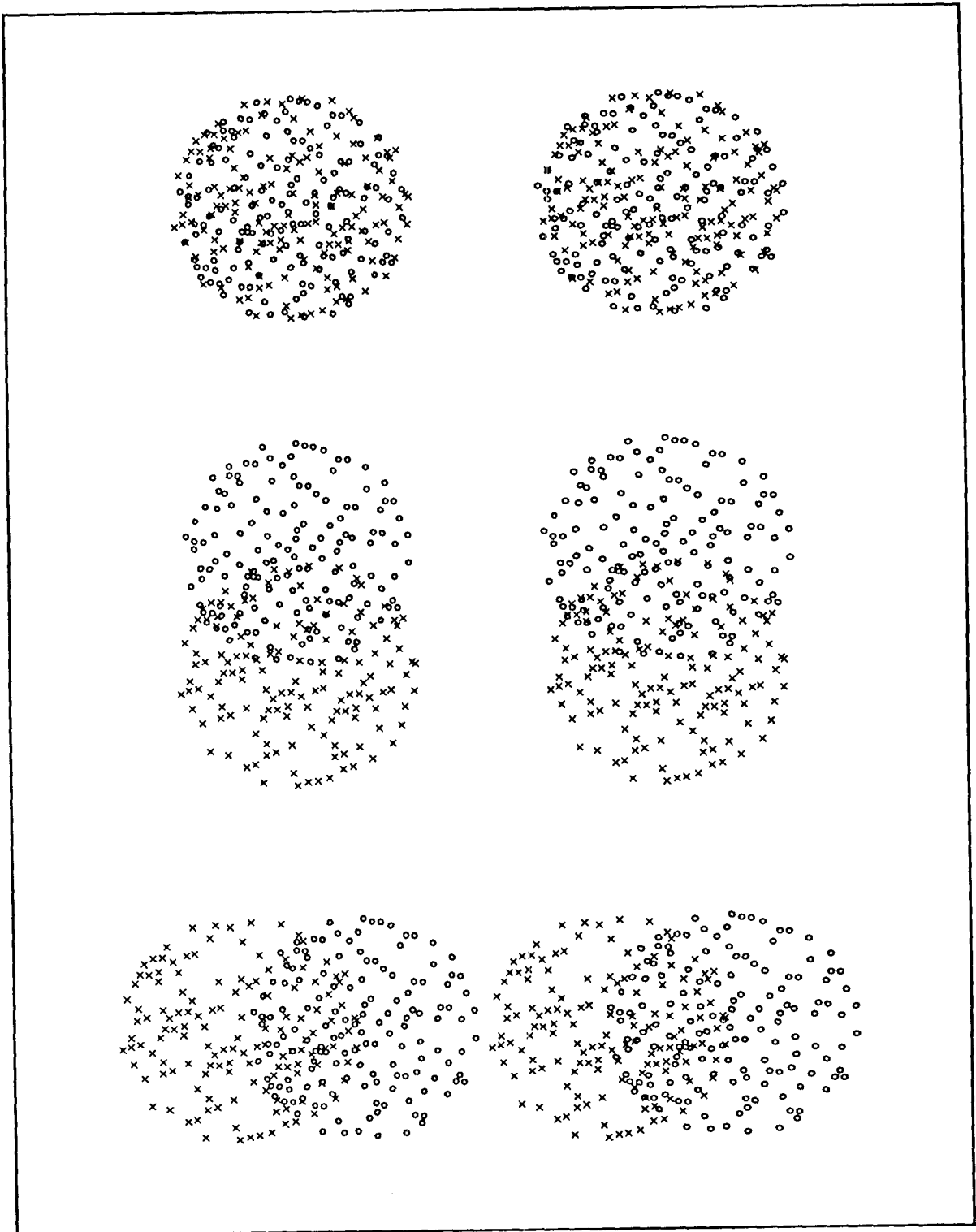


FIGURE 8. Demonstration of the anisotropy in the binocular depth-contrast effect in the case of slant about the vertical axis. The inducing pattern consists of circles, the test pattern of crosses. In each of the three stereograms the inducing pattern is 10% horizontally scaled. The test pattern is always untransformed. In the top stereogram the inducing pattern and the test pattern are presented at the same location (in fact the 0R condition in Figs 6 and 7). In the middle and bottom stereogram, the distance between the test pattern and the inducing pattern is one radius. In the middle stereogram, the inducing pattern and the test pattern are shifted along the slant axis of the inducing pattern. It can be seen that the induced slant is about as large as in the upper stereogram. The middle stereogram corresponds to the situation scale top-bottom (configuration A in Figs 6 and 7 for an inter-pattern distance of 1R). In the middle stereogram, the inducing and the test patterns are shifted perpendicular to the slant axis of the inducing pattern. The bottom stereogram corresponds to scale left-right (configuration B, 1R). It can be seen that the induced slant is not as large as in the middle stereogram. In order to obtain conditions as far as possible similar to those in the actual experiment, it is important to view the stereograms from a very short distance. The larger the viewing distance, the larger the effect of extra (uncontrolled) stimuli in the visual field. The latter can serve as a visual reference so that the effect of the inducing stimulus is overruled.

(scale left–right) and C (shear top–bottom), the test and the inducing pattern do not have a common axis of slant. In these configurations, the result of a misperceived whole-field orientation would cause the slant-axis of one of the patterns to be perceived either in front of or behind the screen, not on it. In practice, however, several cues will contradict such a percept in these configurations (B and C). Therefore, we can explain that in configurations B and C subjects do not easily perceive the depth-contrast effect.

In a number of studies (Westheimer, 1986; Kumar & Glaser 1991, 1992a) it has been suggested that depth-contrast effects are due to the fact that the visual system redefines the fronto-parallel plane. Other authors have suggested that depth-contrast effects are caused by the fact that the visual system uses an internal frame of reference (Mitchison & McKee, 1990; Kumar & Glaser, 1991, 1993). These ideas are in accordance (at least not in contrast) with the reported low sensitivity to the whole-field horizontal scale and shear and with the above-mentioned possible explanation of the depth-contrast effect.

Local autonomy in binocular visual space

In several visual domains the effectiveness of cues between objects is inversely related to the relative separation of the objects. This is termed the adjacency principle (Gogel, 1963), which has been found to apply also to depth from binocular disparity (Gogel, 1971). It follows from the adjacency principle that there is a degree of local autonomy in visual space, i.e. the cues that determine perceived characteristics tend to occur between objects that are in the same portion of the visual field (Gogel & Mershon, 1977).

Several studies show an interaction of signals in the disparity domain. Anstis *et al.* (1978) showed the existence of a Craik–O'Brien–Cornsweet illusion in the disparity domain and speculated about a lateral inhibition mechanism. Westheimer (1986) and Westheimer & Levi (1987) showed that interaction in the domain of disparity can be either of the kind where the depth difference between adjacent targets is enhanced, as if the two targets repelled each other in depth, or it can be in the opposite direction, i.e. the targets are attracted to each other [see also Parker & Yang (1989) and Stevenson *et al.* (1991)]. Very recently, Fahle and Westheimer (1995) found indications for an active inhibitory process in the disparity domain. Fahle and Westheimer (1988) questioned the pooling of disparities over a local area as a possible cause of the depth-contrast effect. Their doubts are in accordance with our finding that the depth-contrast effect is essentially global.

The stimulus

Different cues can support or oppose each other with regard to perception of depth (Gillam, 1968; Youngs, 1976; Stevens & Brookes, 1988; Buckley *et al.* 1989; Kumar & Glaser, 1992a; Johnston *et al.* 1993; Buckley & Frisby, 1993; Uomori & Nishida, 1994; Ryan & Gillam,

1994). In our stimuli, we do not use horizontal and vertical line elements because the presence of rectangular shapes might interact with perspective or outline cues; these might then counteract the slant and could be used as a cue for flatness. Furthermore, we use stimuli with irregular boundaries and low density of pattern elements so that the observers will not use conflicting configural outline–shape cues in their slant estimations. Exclusion of the flatness cues means that as far as possible slant perception is based on disparity alone.

As a control we tested the influence of: (1) interchanging the textures of test and the inducing pattern; (2) interchanging the locations of the test and inducing pattern (which means that the test pattern was consistently placed above or on the right-hand side of the inducing pattern); (3) other (but equal) sizes of inducing and test patterns. The results of these control experiments showed quantitative differences. However, the qualitative effects remained unchanged. The differences were certainly not consistent over the subjects. For example, a number of subjects experienced a larger depth-contrast effect after the inducing and test pattern had been interchanged. Other subjects, however, experienced a smaller depth-contrast effect. More important for our study is that the trends or the main findings of the experiment remained the same.

Observation period

Werner (1937) reported that the depth-contrast effect appeared to be more pronounced at the beginning of an observation than in the course of the observation. Kumar and Glaser (1993) investigated systematically temporal aspects of the depth-contrast effect. They found that the depth-contrast remained significant for viewing times of 1.5 sec, but that the effect was about half as large for viewing times larger than 500 msec than it was for 10 msec. These authors used an acuity task in which the subjects were required to judge whether the left-hand side of two vertical line elements was closer than the right-hand side. Their stimulus always appeared at the same location, this location being known to the subject. However, in our experiment, it was necessary to present our stimuli for much longer periods, namely 1.5 sec. First of all, estimating slant takes more time than determining the sign of slant. Secondly, our patterns appeared at an unknown location, which means that eye movements were necessary before slant could be estimated. Thirdly, when the inducing and the test pattern partly overlapped, the subject had to distinguish the inducing pattern (consisting of circular elements) from the test pattern (consisting of crosses). Fourthly, in our set-up, slant was either about the vertical or about the horizontal, making the task more complicated. Finally, we used naive and inexperienced subjects. For all these reasons, the subject's task was difficult. Even a number of informally tested experienced subjects could not do the task when the presentation time was shortened to 1 sec.

Very recently, Pierce and Howard (1995) examined induced perception of slant about the horizontal axis.

They found that a horizontally sheared inducing pattern produced little or no depth-contrast effect on a test pattern. Pierce and Howard did not concentrate on short observation periods. In their experiment, the subjects were not limited in their viewing time (which was in practice about 15 sec). The long observation period may be the reason why these authors did not find the depth-contrast effect.

CONCLUSION

The binocular depth-contrast effect is more prominent when the test pattern is placed along the slant (rotation) axis of the inducing pattern. In other words, there is an anisotropy in the depth-contrast effect.

Fahle and Westheimer (1988) suggested that two factors determine depth thresholds: a predominant local one that extracts disparity differences between adjoining points and an additional one that processes more global features of the stimulus configuration that go beyond the next neighbour.

Our explanation of Werner's binocular depth-contrast effect corroborates the suggestion of Fahle and Westheimer. It may well be that the depth-contrast effect is caused by the low sensitivity of the visual system to global horizontal scale and shear between both half-images within a stereogram. Pooling of disparities (Westheimer, 1986), shielding [as described by the salience concept of Mitchison and Westheimer (1984)], or figural (texture or perspective) influences (McKee, 1983) may be responsible for additional local effects during the observation of Werner stimuli.

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