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SURFACE IN DEPTH AND CAPTURE OF STEREOPSIS BY INTEROCULARLY-UNPAIRED REGIONS

By

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In the present study, an effect of an interocularly-unpaired region was used to interpret interpolation in depth. In Experiment 1, 12 of the 15 subjects perceived the depth surface generated by the interocularly-unpaired segments. Experiment 2 with three subjects showed that disparate correspondence in regularly-repeated dots was induced by the interocularly-unpaired segments with no point-by-point disparity. From the results of Exp.1 and Exp.2, it was proposed that depth interpolation might be based not on point-for-point correspondence, but on surface-for-surface correspondence.

Key words: stereoscopic perception, depth interpolation, interocularly-unpaired region, depth surface, stereoscopic capture.

Introduction

With careful observation of a random-dot stereogram, we would find a region that has no correspondence between the two eyes. For example, when a square depth surface protrudes from background to the viewer, no-correspondence regions arise at the left (right) side of the square surface in the left (right) eye's image. This region is called "the interocularly-unpaired region". In viewing natural scenes, there are many monocularly-viewed areas where the right eye can see but the left eye cannot and vice versa, since near objects occlude far surfaces. Thus, it can be inferred from the monocularly-viewed area that one object is in front of the other. The visual system must take advantage of less ambiguous information in this area. However, it has been considered such a by-product that results from point-for-point correspondence.

Recently, some authors suggested that the resolution of the unpaired region should be a problematic issue for stereopsis. Gillam and Borsting (1988) found that stereoscopic depth perception is facilitated by the unpaired region. Shimojo and Nakayama (1990) reported that it is dependent on ecological validity, whether the unpaired region is suppressed or appears stably as extension of the rear surface. In their subsequent experiment (Nakayama & Shimojo, 1990), subjects perceived the subjective surfaces with clear edges, without point-by-point disparity. More recently, Liu, Stevenson, and Schor (1994) investigated the phenomenon quantitatively.

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The purpose of the present study is to confirm the percept of the subjective surface in depth, generated by the unpaired region. By the following observation, it was investigated whether the unpaired region is available for capture of stereopsis.

EXPERIMENT 1

METHOD

Subjects: Fifteen undergraduates participated in Exp. 1. They had normal or corrected-normal vision. All of them were naive to the purpose of the experiment.

Apparatus: Stereoscopic stimuli were generated by a computer (NEC PC-9801 VX). The left and right half-images of a stereoscopic stimulus were displayed on each half of a monitor. In order to guarantee that only one stimulus was visible to each eye, orthogonally-oriented polarizers were placed in front of the CRT screen and the subject's eyes. Illumination of the room was slightly dim. The subject's head was mounted on a chin-rest at a distance of 80 cm from the screen.

Stimulus: The stimuli were composed of several vertical lines. Each half-stereogram subtended 4.8 × 3.5 deg. Figure 1a depicts the fused pattern. Inner two short lines possessed crossed disparity, thus they appeared in front of background. Two dotted lines indicate "the inducing segments" detailed as follows. One stimulus was a pattern in which the inducing segments were binocularly-presented and seen at background depth as extended from upper and lower segments (Fig.1b). Another stimulus was a pattern in which each of two segments was interocularly-unpaired (Fig.1c).

Procedure: The subject was required to see the stimuli and to describe on a paper, in detail, what he or she saw.

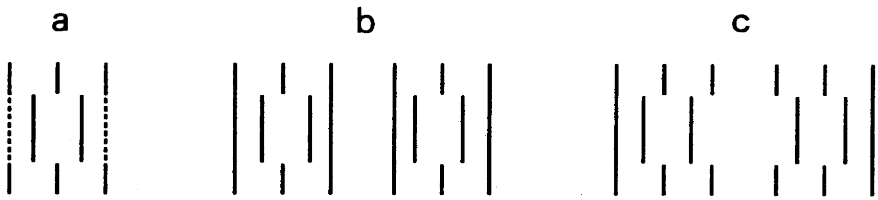

Fig. 1. (a) Inner two short lines possessed crossed disparity. Two dotted lines indicate the inducing segments. The inducing segments were either binocularly presented or interocularly unpaired. (b) The inducing segments are binocularly-presented. (c) Each of two inducing segments is interocularly-unpaired.

RESULTS

For the binocularly-presented pattern (Fig.1b), 14 of the 15 subjects indicated that the central two lines and the surface between the lines were in front of the other lines (Fig.2a).

One of the 14 subjects pointed out ambiguity that the region between the disparate lines was often at background depth. For the interocularly-unpaired pattern (Fig.1c), 12 of the 15 subjects perceived the protruding surface between the inducing segments (Fig.2b). Thus, the perceived surface in this pattern was twice as broad as that in the binocularly-presented pattern.

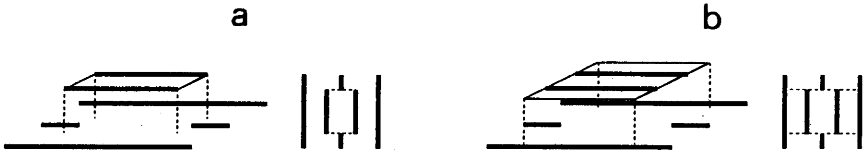

Fig. 2. (a) The binocularly-presented pattern. The inner two lines and the surface between the lines were in front of the other lines. (b) The interocularly-unpaired pattern. The protruding surface between the inducing segments. The perceived surface in this pattern was twice as broad as that in the binocularly-presented pattern.

Discussion

Interpolation in depth has been investigated by many researchers (Collet, 1985; Mitchison & McKee, 1985; Takeichi, Watanabe, & Shimojo, 1992). Most subjects in the present experiment also perceived the depth surface in both patterns. The spread of the surface was dependent on the inducing segments. Surface perception generated by the unpaired regions would help us with interpretation of depth interpolation.

The difference of the two stimuli was only in the inducing segments, which were either presented binocularly or unpaired interocularly. Though a probable alternate percept might be the binocular rivalry at the unpaired regions and the surface percept inside between the disparate lines, it was really not the case. Interpolation of endpoint disparity (Mitchison & McKee, 1985) cannot explain the difference of surface spreading in each stimulus. The edges of the depth surface in the interocularly-unpaired pattern had no point-by-point disparity to decide the accurate depth for interpolation.

Another explanation might be necessary to interpret the phenomena in Exp.1. It is neither attributed to propagation nor to interpolation of disparity information, but to correspondence between clusters of the monocular images. The width of the monocular clusters to correspond might be determined by the cue from the inducing segments. It is, namely, surface-for-surface correspondence. In the interocularly-unpaired pattern, the visual system inferred occlusion from the unpaired segments, and matched the monocular clusters of the inside between the unpaired segments.

EXPERIMENT 2

Stereoscopic capture was reported by Ramachandran and Cavanagh (1985; see also Ramachandran, 1986). If a wallpaper pattern (WPP) which is a pattern of repeated elements (dots or lines) is superimposed on the disparate Kanizsa's square hovering over the four discs, the rows of the elements inside the subjective contour float with the subjective contour, in spite of no disparity information in the WPP by itself.

Experiment 2 showed that the unpaired region was available for stereoscopic capture. In the preliminary observation of similar stimuli to in Exp.2, 10 of the 13 subjects showed an evidence of stereoscopic capture. They labeled the stimulus including unpaired segments, rather than the other stimuli (e.g., including disparate segments), as that in which the rows of dots protruded to the viewer.

METHOD

Subjects: Two university undergraduates and the author participated in Exp.2. They had normal or corrected-normal vision and good stereo vision.

Apparatus: It was identical to Exp.1 except that the room was darkened.

Stimulus: The stimulus consisted of two vertical lines located in a square frame. The inducing segments of the two lines were either interocularly-unpaired or binocularly-presented. A WPP was superimposed on the inducing segments (Fig.3). There was no point-by-point disparity in the stimuli, whereas the stimuli in Exp.1 possessed two disparate lines. A half image of the stereogram was 4 × 4 deg. Interdot spacing of the WPP was 10.5 min. Separation between the inducing segments subtended 1.5 deg.

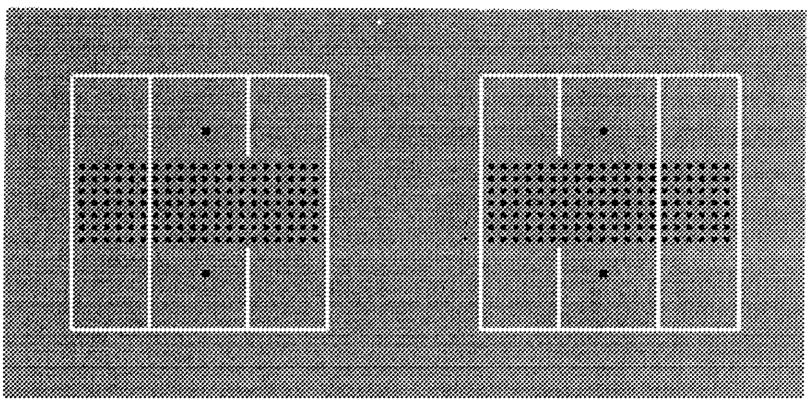

Fig. 3. The inducing segments are interocularly-unpaired. WPP is superimposed on the inducing segments. There is no point-by-point disparity in the stimuli. Single dots above and below the rows of dots are probes to investigate the depth resulted from correspondence of WPP.

This experiment explored binocular correspondence of the rows of dots induced by the unpaired regions. A probe was used to investigate the depth resulted from correspondence of the WPP. The probe was a single dot, located 20 min above and below the rows of dots between the inducing segments. The disparity of the probe was randomly varied from trial to trial in seven equally-spaced disparity steps (3.5 min of arc).

Procedure: The square frame was always presented. A fixation cross was presented in the center of the frame, which disappeared during the presentation of the test pattern. The test pattern was the inducing segments and WPP. Duration of the test pattern with the probe was 153 msec. The subject was asked to indicate whether the probe was seen in front of or behind the rows of dots between the inducing segments, by pressing one of two buttons of a mouse-key on each trial.

RESULTS

Figure 4 shows the proportion of trials on which the subjects judged the probe to be in front of the rows of dots. Solid squares denote the results of the stimulus in which the inducing segments are binocularly-presented. Open triangles and circles denote the result of the stimulus in which the inducing segments are interocularly-unpaired. Open triangles represent the pattern of which interocularly unpaired segments were localized "between" the columns of dots. Open circles represent the pattern of which interocularly-unpaired segments were localized "on" the column of dots. Each point was based on 30 responses.

For the binocularly-presented pattern, the 50% point of psychometric function was near the zero disparity. For the interocularly-unpaired pattern, the 50% point of psychometric function was near the 10.5 min disparity that corresponds to the interdot spacing of the WPP used in the present experiment.

DISCUSSION

The results of Exp.2 indicated that the unpaired segments affected correspondence of the repeated dots between the two eyes. Difference in the stimulus between Exp.2 and other research (Ishiguchi & Wolfe, 1993; Mather, 1989; Ramachandran, 1986) is that the stimulus in Exp.2 has no binocular disparity resulted from point-for-point correspondence.

It may be that phenomenon in Exp.2 is identical to the interpolation of endpoint disparity. Mitchison and McKee (1985) found that when endpoints of the repeated dots were shifted inwardly, the depth of the intermediate dots was attributed to the endpoint disparity caused as the Panum's limiting case. Therefore, the inducing segments of the present stimulus may be the same feature as the endpoint of their stimulus. In the stimulus of Exp.2, however, there are two points differing from the stimulus of Mitchison and McKee (1985). The first is opposite contrast between the dots and the inducing segments in the present experiment. In the stimulus used by Mitchison and McKee (1985), the inducing endpoint elements and induced intermediate elements were the same local dots. The second is in that even though the inducing segments were localized on the column of dots, the unpaired segments affected the correspondence of the WPP (open circles in Fig.4). The inducing segments and the WPP were located in the in-phase relation. These two points are different from the Panum's limiting case.

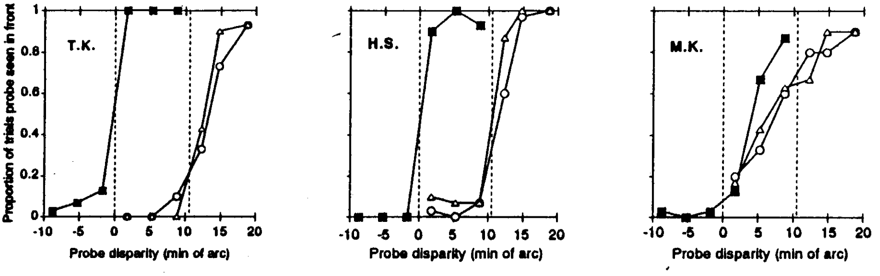

Fig. 4. The proportion of trials on which the subject judged the probe to be in front of the rows of dots in the test patterns. Solid squares denote the stimulus of which the inducing segments are binocularly-presented. Open circles and triangles denote the stimulus of which the inducing segments are interocularly-unpaired.

Of course, it is not considered that stereoscopic capture is dissimilar to the interpolation of the endpoint disparity. One possible explanation for the stereoscopic capture and interpolation is surface-for-surface correspondence suggested in Exp.1. Co-planarity of the WPP would be disrupted by the unpaired region or the subjective contour, and the right and left surfaces with the cluster of dots would be matched cooperatively, depending on those features.
In the present stimulus, the unpaired regions determined correspondence of the repeated dots so as to adjust the occlusion cues (Fig.5).

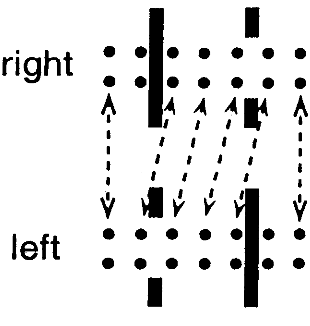

Fig. 5. The repeated dots of the right and left images are matched disparately to adjust the occlusion cues of the unpaired regions.

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