Stereopsis with opposite contrast contours¹

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Helmholtz found that opposite-contrast stereograms may be seen as depthful. Treisman and other investigators could not achieve this result with different opposite-contrast stereograms. These conflicting results may be rationalized in terms of Whittle's Hypothesis. A repetition of Treisman's experiment, however, shows that it is possible to obtain stereopsis with her stereograms. This requires a revision of Whittle's Hypothesis so that seemingly contradictory results may be incorporated in a theory of stereopsis.

Helmholtz (1962) published a now classical stereogram containing a figure of white lines on a black background in one half-field and black lines on a white background in the other half-field. Since it is possible to see the resulting binocular object as depthful, he concluded that the stimulus dimension relevant to stereopsis was disparity of similar spatial contours. Whittle (1963), on the other hand, suggested that the relevant disparity wasn't of similar spatial contours but was, instead, a disparity of similar gradients of brightness. He proposed that the brightness changes across the edges of the contours must be in the same direction in order for stereopsis to occur. The result obtained by Helmholtz is consistent with this view when it is recognized that the opposite sides of corresponding lines in Helmholtz's stereogram do, indeed, exhibit changes in brightness which share a common direction. Just so long as it is held that it is the opposite sides of the lines of small but finite width which interact, it is possible to account for depth in "opposite-contrast" stereograms in terms of brightness disparity.

There have been a number of experiments bearing on this issue and they seem to support what we have dubbed "Whittle's Hypothesis" (Kaufman & Pitblado, 1965). Treisman (1962), for example, published a study which indicated that opposite-contrast rings, analogous to Helmholtz's stereogram, yield depth readily while large opposite-contrast discs produce few if any depth responses. She explains this result in terms of Whittle's Hypothesis. The rings are so thin that the interior edge of a black ring in one half-field can interact with the exterior edge of the white ring in the other half-field. However, the discs are so large that their opposite edges lie outside of the fusional areas. These cannot interact. Hence depth does not occur and all an O can see is the rivalry between the regions of opposite-contrast.

This result is quite consistent with that reported by Julesz (1963) who noted that opposite-contrast random-dot stereograms do not yield stereopsis. He suggested that perhaps the great complexity of this stereogram as compared with the Helmholtz stereogram was somehow responsible for the different results. However, we (Kaufman & Pitblado, 1965) generated an opposite-contrast stereogram comprised of groups of letters of the alphabet which also failed to produce stereopsis. This stereogram was much simpler than that of Julesz and the groupings were monocularly perceptible. It was assumed, therefore, that the structure of the stereogram inhibited opposite-edge interactions and that this was why depth could not be perceived. To buttress this result another stereogram was contrived which contained thin lines of opposite-contrast with respect to their backgrounds but were so arranged that no proximate edges in the two half-fields shared common directions of brightness change. Here, too, depth was not seen.

One of the unfortunate features of experiments which yield negative results is that one can't be sure that a positive result will never occur. This is particularly true of "difficult" stereograms. We have been aware for some time that depth does not always occur immediately upon the presentation of a stereogram. Some patterns require many minutes of observation before the depth-planes make their appearance. Depth is perceived much more rapidly on subsequent presentation of these stereograms. Something has been learned but we are unable to state what it is. Nevertheless, we were suspicious that with continued viewing our stereogram might ultimately be perceived as depthful. After many months of occasional viewing of our line stereogram one of us claimed to see the thin lines in depth. Subsequent testing of this S proved that when the direction of the disparity was changed in a random sequence the direction of depth could be reported correctly on all trials. The opposite-contrast letter pattern still resists arranging itself into depth for us.

This result with one experienced S on one of the opposite-contrast stereograms motivated an examination of Treisman's patterns. Levelt (1965) provided an excellent reproduction of similar patterns in his monograph. When we viewed these patterns we found that we could not only achieve depth when viewing the rings but we perceived equally good depth with the opposite-contrast discs. We decided to see if depth could be perceived in these patterns under good viewing conditions by both naive and trained Ss.

Procedure

Two sets of stimuli were employed. They were photographic reproductions of stereograms in Levelt's monograph (1965, p. 6). One set contained a black disc in a gray background paired with a white disc in the same gray background. Both backgrounds were surrounded by black fields and the discs were disparate relative to these fields. The second set of stimuli was the same as the first except that the central discs were both black. This second set is referred to as a normal stereogram, while the first set is referred to as an opposite-contrast stereogram.

The stimuli were projected onto an aluminized screen by means of a Compco stereo projector. The Ss viewed these superposed cross-polarized stimuli through conventional polaroid spectacles. The spectacles were handed to the S either right-side up or upside down on each trial to permit randomization of the cross of the disparity. The S was seated 79 in. from the screen. The projected size of the inner disc was 1.4 in. The disparity, or difference in distance, between the edges of the inner disc and surrounding black fields was about 0.2 in. This amounts to an angular binocular disparity of approximately 8.5 min of arc.

Six Ss were employed, five males and one female. They were instructed to range on either the disc or its background with a binocularly viewed virtual image of a small red luminous point seen in a combining glass. The screen was also viewed through the combining glass, thereby permitting the S to see the range marker superposed on the gray background of the stimulus field. The method of ranging to obtain perceived depth was described previously (Kaufman, 1965). Trials were paired so that on alternate trials the distance to the disc and the distance from the S to the background would be matched by the marker. The difference between these distances is the

Table 1
Summary of Mean-Depth Data and Standard Deviations with Normal and Opposite-Contrast Stereograms

Subject	Normal Stereogram				Opposite-Contrast Stereogram			
	Crossed Disparity		Uncrossed Disparity		Crossed Disparity		Uncrossed Disparity	
	Mean Depth (cm)	SD	Mean Depth (cm)	SD	Mean Depth (cm)	SD	Mean Depth (cm)	SD
*1	8.73	1.2	10.95	0.6	7.95	1.3	8.90	1.1
*2	10.00	1.6	8.59	1.5	6.68	1.8	7.47	1.3
3	20.1	9.6	28.8	5.1	2.7**	5.3	9.8	5.7
4	10.8	0.8	11.3	0.9	12.8	2.0	7.7	1.1
5	9.7	0.8	11.7	0.7	12.6	1.2	15.4	2.4
6	9.0	4.4	10.7	3.0	10.8	4.5	10.9	10.3

* *Sophisticated Observers*

** *Negative sign indicates incorrect direction of depth*

measure of stereoscopic depth produced by the stimuli. The direction of this difference would vary with the cross of the disparity if the stereoscopic depth were valid. Ascending and descending pairs of trials were employed to derive mean depth differences. The normal and opposite-contrast stereograms were presented in balanced blocks of five each.

Results

The results are summarized in Table 1. It will be seen in the table that all Ss were capable of seeing depth in the normal stereogram. Two of the Ss, however, exhibited wide variability in the magnitudes of their depth effects. These were Ss 3 and 6, who exhibited standard deviations in their depth judgments of 9.6 cm and 4.4 cm, respectively, for crossed disparity, i.e., with the disc seen forward, and 5.1 and 3.0 cm, respectively, with the disc seen behind the background. All other Ss had SDs of less than 2 cm. It will be seen in the same table that these same Ss failed to achieve valid depth when they viewed the opposite-contrast or Treisman pattern. This is indicated in the table by the negative signs which indicate that the mean judged depth is opposite in direction from that which would be predicted from the cross of the disparity. The remaining four Ss demonstrated valid depth in both the normal and the Treisman patterns. The variability in their depth judgments increased slightly with the Treisman patterns although the magnitudes of their depth judgments were comparable to those obtained with the normal stereogram.

In addition to the foregoing some rather strange phenomenological data were reported. One S reported spontaneously that when viewing the Treisman pattern he could see one disc in front of the other behind the background. At times it appeared as though the black disc was in the most forward plane and the white disc, seen "through" the black disc, in the more distant plane. This seemed not to vary with the cross of disparity. When the remaining five Ss were questioned after their trials they, too, reported that they could see the two discs on corresponding places as being simultaneously in two different depth planes. The phenomenon was not noticed by these Ss until it was called to their attention. Moreover, once this feature of the display was noted it did not seem to interfere with the depth judgment as measured with the range marker. Four Ss still behaved as though the "disc" was localized in depth in accordance with the cross of the disparity when depth judgments were made after they claimed to see the double representation of the disc. All Ss also reported strong rivalry between the white and black discs during stereopsis with occasional total suppression of one disc or the other. This, too, did not affect the major depth judgment. It became evident to the authors in viewing this stereogram that the perception was far more complicated than could be explained solely in terms of the geometry of the disparity of the contours. This situation needs clear introspective analysis. Nevertheless, the major effect of the disparity was depth as predicted by the rules of stereopsis.

Conclusions

It is evident that Ss can see depth in Treisman's patterns under our experimental conditions. This may be due to the fact that the stereograms were projected onto a screen instead of being displayed in a stereoscope. This would be consistent with our earlier observation that some stereograms which do not yield depth perceptions readily may do so when accommodation and convergence are brought into agreement (Kaufman & Pitblado, 1965). Variation in interpupillary distance from S to S may require a different degree of convergence for each S for a constant lateral separation of the two half-fields in the stereoscope. Since the stereogram is at optical infinity, thereby requiring relaxed accommodation of emmetropic Ss, there is bound to be some disagreement between these normally coordinated functions. This problem is not so great when a projection scheme is used since the S can converge and accommodate for the distance of the screen when viewing the physically superposed backgrounds.

It must be concluded, then, that in spite of the large amount of evidence in support of Whittle's Hypothesis it must be rejected as it stands. It is true that opposite-contrast Julesz patterns cannot be seen in depth. This is also still the case for letter analogues to the Julesz patterns. This is in clear disagreement with the inferences about contour disparity drawn from Helmholtz's diagram. Moreover, substantial evidence is accumulating that contour disparity per se is not necessary to the occurrence of stereopsis (Kaufman, 1964, 1965; Kaufman & Pitblado, 1965). It has been suggested that differences in average brightness of regions in the two eyes generates the appropriate disparity (Kaufman & Pitblado, 1965). The present result leaves all of this in a rather difficult situation. Assuming that disparity of some stimulus parameter is the basis of stereopsis, we must either accept the view that both contour disparity and brightness disparity may yield depth perception under still undefined sets of boundary conditions, or we may revise Whittle's Hypothesis so that disparity of brightness is somehow still the pertinent stimulus dimension. Since there are a finite number of brain cells, though they are large in number, there is something attractive about developing a theory which attributes depth to but one class of disparity. It is difficult to believe that a very large population of cells would be involved in so marginal an adaptive function as stereopsis. In the interest of parsimony, then, we propose the following revision of Whittle's Hypothesis so that the present results may be incorporated in a theory based upon disparity of brightness.

We may assume that the lateral inhibition associated with the brightness changes at the edge of the inner disc serves to produce Mach bands. These bands are associated with sensation curves such as those described by von Békésy (1960). These curves suggest that apparent brightness changes across the region of the contour, so that there is a bright band surrounding the black disc and a still darker band near the edge, though inside the disc. Conversely, the white disc is

surrounded by a dark band and contains a still lighter ring. These bands provide annuli which have common directions of brightness change in the two eyes, thereby fulfilling the conditions set forth in Whittle's Hypothesis. In this view, the stimulus to depth is not represented directly in the distal stimulus objects, nor is it represented in the proximal stimulus, but is represented in the retinal activity initiated by the proximal stimulus. The fine grain of opposite-contrast Julesz patterns would effectively "blur" the inhibitory regions associated with the Mach bands, as in brightness assimilation phenomena, thereby preventing the occurrence of stereopsis. While we have serious doubts about the validity of this theory, it does permit a more parsimonious view of stereoscopic phenomena than would a theory which requires both a contour and a brightness mechanism.

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NOTES

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