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Adaptation to the reversal of binocular depth cues: effects of wearing left-right reversing spectacles on stereoscopic depth perception†

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Abstract. The principle of stereopsis, that crossed disparity causes a convex perception and uncrossed disparity a concave one, has for a long time been considered to depend on a very rigid neural mechanism not affected by experience. Experiments are reported here which show that this relationship between disparity and perceived depth can be reversed by experience. An observer wore a pair of left-right reversing spectacles continuously for nine days. The spectacles also reversed the relation between the direction of perceived depth and the direction of binocular depth cues, ie disparity and vergence. For a period starting two days before wearing the spectacles and continuing until seventy-nine days after their removal the observer was examined with a haploscope and an electrooculograph. All the stereoscopic experiments were carried out without spectacles in order to examine some aftereffects of wearing spectacles. For the stereograms with linear contours not only the adaptive reversal of the relation between disparity and perceived depth, but also some abnormal depth perceptions and long-lasting aftereffects were found. For Julesz's random-dot stereograms, however, in which contours can be seen only after binocular combination, no adaptive change or reversal occurred. These results suggest that the process of stereopsis consists of two concurrent subprocesses.

1 Introduction

When a pair of patterns with crossed (convergent) disparity is presented to both eyes by stereoscope the observer always perceives a convex object. When a pair of patterns has uncrossed (divergent) disparity a concave object is always perceived (figure 1). These facts have been accepted for a long time as the principle of stereopsis. However, could this relation between disparity and perceived depth be reversed by experience? Do not our eyes and brain have any flexibility in this regard? If the answer to these questions is 'yes', we may be able to obtain a new insight into stereopsis.

By using a pair of left-right reversing spectacles (an optical device which reverses left and right of both retinal images) we can reverse two kinds of binocular depth cues, namely vergence and disparity. As shown in figures 2a and 2b, in the case of vergence between the direction of movement of the target (advancing or receding) and the vergence change required for the target to be followed is reversed: thus approaching targets are pursued by both eyes rotating outward, and receding targets by both eyes rotating inward. In the case of disparity, as shown in figures 2Ia and 2Ib, the relation between the physical depth and the direction of discrepancy of the two corresponding retinal images (crossed or uncrossed) is reversed by the spectacles.

It might therefore be expected that the observer would experience reversals in depth perception when he wears reversing spectacles. But in fact the observer reports such reversals rarely, although he often reports some ambiguity in depth and the lack of depth impression of the visual world. These facts remind us of Wheatstone's (1852) famous report. He showed that when the disparity of the patterns that were presented to the eyes was reversed by a 'pseudoscope' perceived depth was also

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reversed; but when veridical monocular cues or familiarity cues were also presented normal depth would be experienced in spite of the reversal of disparity. Actually, not only monocular cues but also tactile and kinesthetic cues are present veridically even with the left-right reversing spectacles, and this seems to be the reason why

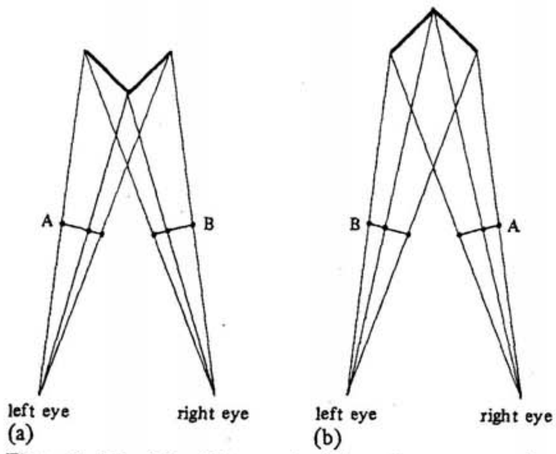

Figure 1. Principle of stereopsis. When the stereogram has crossed disparity (image A is presented to the left eye and image B to the right eye) the observer sees a convex object as shown in (a) by the thick lines. When the stereogram has uncrossed disparity (image B is presented to the left eye and image A to the right eye) the observer sees a concave object as shown in (b).

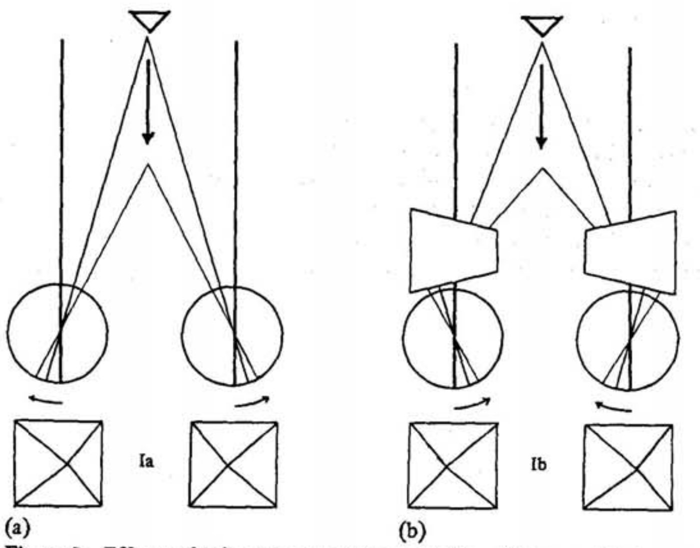

Figure 2. Effects of left-right reversing spectacles. When an object seen without the spectacles moves in the direction of the long arrow, the corresponding retinal images move as shown by the short arrows in (a), and when a convex pyramid is given, the observer gets visual images Ia (with crossed disparity). When an object seen through the reversing spectacles moves in the direction of the long arrow, the corresponding images move as shown by the short arrows in (b), and when the same convex pyramid is given through the spectacles, the observer gets visual images Ib (with uncrossed disparity). Thus two kinds of binocular depth cues are reversed by the left-right reversing spectacles. Actually, the reflective surfaces of the two prisms are not parallel to each other but rotated slightly inside to avoid the rivalry of both the images; this is not considered, however, to be of any significant import for our purpose.

reversals in depth rarely occurred when the spectacles were worn. The question then is as follows: would we be able to find any adaptive changes in stereoscopic depth perception which resolve the conflict between these cues when the observer wears the spectacles continuously?

Investigations with a telestereoscope (Wallach et al 1963), prisms (Mack and Chitayat 1970), and lenses (Epstein and Morgan 1970) suggested that stereoscopic depth perception is very modifiable, but Brown (1928) showed that it is not if the optical distortion is drastic (Welch 1978). This line of evidence could imply that adaptive reversals in stereoscopic depth perception would not occur when reversing spectacles are worn. However, reports of adaptation to inverted and/or reversed visual fields suggest the opposite, since various adaptive changes did take place during the wearing of spectacles [for example regaining of the stability of the visual world, sensory-motor recoordination, rearrangement of the visual direction, etc (Stratton 1896, 1897; Peterson and Peterson 1938; Kohler 1951; Taylor 1962; Shimojo 1978)]. Peterson and Peterson, Kohler, and Taylor, whose spectacles also reversed the disparity, have very little to say about depth perception through the spectacles.

2 General method

The observer, a male student, wore a pair of left-right reversing spectacles continuously for nine days from 24 June to 3 July 1978. The whole schedule consisted of three periods: prewearing, wearing, and postwearing. To detect the effects of reversal of disparity we carried out some experiments on stereoscopic depth perception with a haploscope in a darkroom throughout these three periods (experiment 1); and to detect the effects of the reversal of vergence we recorded eye movements corresponding to changes of fixation distance with an electrooculograph (EOG) (experiment 2).

Our spectacles were constructed from a pair of dove prisms (totally reflecting prisms) fixed on the frame of a hydroscope (see figure 3), and had nearly the same structure and function as Kohler's (1951). During the wearing period the observer unfailingly closed his eyes or masked them with an eye-patch each time he removed the spectacles.

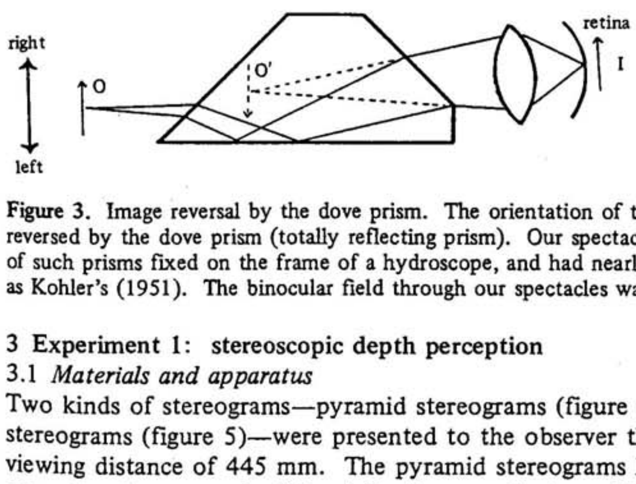

Figure 3. Image reversal by the dove prism. The orientation of the image I of an object O is reversed by the dove prism (totally reflecting prism). Our spectacles were constructed from a pair of such prisms fixed on the frame of a hydroscope, and had nearly the same structure and function as Kohler's (1951). The binocular field through our spectacles was about 33 deg arc.

3 Experiment 1: stereoscopic depth perception

3.1 *Materials and apparatus*

Two kinds of stereograms—pyramid stereograms (figure 4) and Julesz's random-dot stereograms (figure 5)—were presented to the observer through a haploscope, at a viewing distance of 445 mm. The pyramid stereograms had two kinds of disparities, crossed and uncrossed, of the following magnitudes: 12, 23, 35, and 48 min arc. Thus eight pairs of stereograms were used. The Julesz stereograms (Julesz 1971, p 280) are random-dot patterns from which a bar form with a clear outline is perceived only after the fusion of the two visual images, these stereograms having no monocular cues. We used horizontal (cyclopean) bars and vertical (cyclopean) bars. Their disparities were also of two directions, crossed and uncrossed, of 23 min arc.

Thus a total of four pairs of random-dot stereograms was used. Here crossed disparity gives an ordinary observer the perception of a bar in front of its surround, and uncrossed disparity that of a bar behind its surround. This relation between disparity and perceived depth is common to Julesz's stereograms and pyramid stereograms.

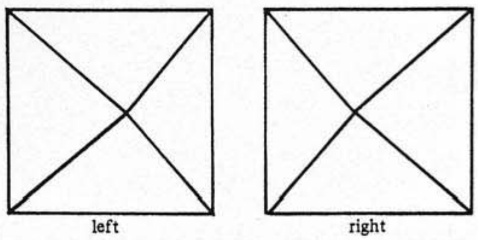

Figure 4. Pyramid stereogram. The pair of patterns shown here as 5·1 deg x 5·1 deg size and 48 min crossed disparity. By exchanging these patterns we get a pair with uncrossed disparity of the same magnitude. In addition, we have used the following disparities: 12, 23, and 35 min arc. The patterns are drawn as transparent lines on perfectly opaque grounds. They are illuminated from behind.

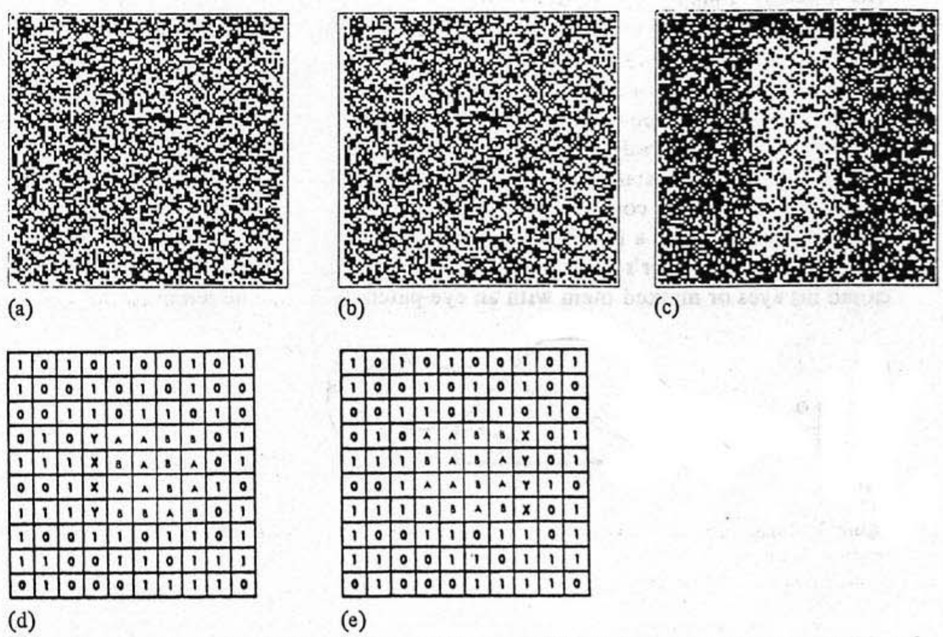

Figure 5. Julesz's random-dot stereogram. When figures (a) and (b) are presented to the left and right eyes respectively, the observer sees a vertical bar raised above the random-dot background as shown in (c). Figures (d) and (e) show how to make a Julesz stereogram with crossed disparity. The square with letters A and B is seen as raised (Julesz 1971).

3.2 *Procedure*

We carried out three experiments using the procedures outlined below (in which the observer removed the spectacles and observed the stereograms in a darkroom) starting with two days before the wearing of the spectacles until some weeks after their removal (for schedules see table 1).

Table 1. Time schedule of the experiments (hours–minutes). During the wearing period the observer was not allowed to look at anything without the spectacles, but it should be noted that he removed the spectacles in the darkened experimental room for the stereoscopic tests.

Period	Day	T[a]	CTW[b]	CTE[c]	Experiment		
					1.1	1.2	1.3
Prewearing	1				*	*	*
	2						
	3[e]				*	*	*
Wearing	1[e]	1-30			*		*
	2	9-06	10-36	5-36	*		*
	3	6-53	17-29	16-59	*	*	*
	4	8-35	26-04	24-19	*		*
	5	7-00	33-04	28-34	*	*	*
	6	12-30	45-34	43-49	*		*
	7	7-40	53-14	51-44	*	*	*
	8	12-50	66-04	61-14	*		*
	9	7-00	73-04	70-34	*	*	*
	10[f]	2-20	75-24				
				(CTR)[d]			
Postwearing	1[f]			5	*	*	*
	2			21	*	*	*
	3			37	*	*	*
	4			53	*	*	*
	5						
	6			85	*	*	*
	7						
	8			120	*	*	*
	9						
	10			150	*	*	*
	11						
	12						
	13			200	*	*	*
	14						
	15						
	16			250	*	*	*
	⋮						
	79			1250	*	*	*

[a]Total time of spectacle wearing during the day; [b]cumulative time of spectacle wearing from the start of the wearing period; [c]cumulative time of spectacle wearing before each experiment; [d]cumulative time of looking without spectacles from the start of the postwearing period; [e,f]within the same day.

3.2.1 *Experiment 1a.* Each pair of pyramid stereograms was presented once in random order. The observer was instructed to report whether the pyramid was convex (with the central part protruding like a mountain), planar, or concave (with the central part indented like a crater). The observer also had to estimate the ratio of the pyramid's height to the length of its base lines.

3.2.2 *Experiment 1b.* Each pair of pyramid stereograms was presented seven times in random order. The observer was instructed to report whether the pyramid was convex, planar, or concave. Thus we were able to obtain the frequency of each percept.

3.2.3 *Experiment 1c.* Each pair of Julesz's random-dot stereograms was presented twice in random order. The observer was instructed to report whether the bar in each pattern was horizontal or vertical, and whether it protruded or receded.

4 Experiment 2: vergence eye movements

The observer wearing spectacles sat on a chair with his head stationary, and was instructed to change his fixation continuously between a target at 3 m distance and the tip of his own nose. This experiment was carried out on day seven of the wearing period.

5 Results

For the pyramid stereograms (experiments 1a and 1b) the observer reported a lot of abnormal depth percepts as shown in table 2. He reported for instance:
"I see a concave pyramid, but its depth (negative height) is infinite as if I were standing in a corridor or tunnel" (C′ type).
"At the moment when I opened my eyes, the pyramid was convex, but it changed quickly into concave and has not changed again" (vC, vC′ type).
"For a few seconds the pyramid was concave, then it became convex after 20 or 40 seconds, and has not changed since" (C–V type).

So far as this observer was concerned each kind of these abnormal percepts occurred frequently for a short period for some of the stimulus pairs. It does not seem appropriate to analyse the results of this experiment mathematically. Instead we have shown in table 3 how the percept types changed. In the prewearing period crossed disparity always caused a clear convex perception and uncrossed disparity a concave perception, but after the third day of the wearing period crossed disparity caused a concave perception and uncrossed disparity a convex perception (without spectacles). In short, the adaptive reversal of the depth perception of the pyramid

Table 2. Perception types for the pyramid stereogram. The wearing of left-right reversing spectacles produced various depth perceptions for the pyramid stereogram shown in figure 4. Except for the first two types, none of them had ever been experienced in the prewearing period (see table 3).

Type	Depth perception
V	*Finite convex:* the top of the pyramid appears to be in the foreground, and its height is finite
C	*Finite concave:* the top appears to be in the background, and the pyramid height is finite
C′	*Infinite concave:* the top appears to be in the background, and the pyramid height is infinite
vC	*Finite concave with momentary convex:* for a moment the top appears to be in the foreground, then C-type perception appears
vC′	*Infinite concave with momentary convex:* for a moment the top appears to be in the foreground, then C′-type perception appears
C–V	*Concave to finite convex:* for at least a few seconds the top appears to be in the background, then V-type perception appears
V–C	*Convex to finite concave:* for at least a few seconds the top appears to be in the foreground, and then C-type perception appears
vC–V	*Concave with momentary convex to convex:* for a moment the top appears to be in the foreground, then it is seen in the background; finally, V-type perception appears
cV	*Finite convex with momentary concave:* for a moment the top appears to be in the background, then V-type perception appears (perception of this type has occurred only once)

stereograms in terms of direction occurred rapidly and completely. Thus we could reverse the principle of stereopsis (figure 1).

The aftereffect, however, lingered for a long time. Until fourth day of the postwearing period this tendency to reversed perception did not change. Furthermore, even on seventy-ninth day of the postwearing period the aftereffect did not seem to have disappeared completely as the observer reported some C–V type percepts, and the viewing times required to stabilize the depth percepts were apt to be longer than in the prewearing period.

We also carried out a supplementary experiment to experiment 1a, in which the observer was presented with the stereogram *through* the spectacles. Under this condition the same stereogram caused a depth perception the direction of which was roughly opposite to the direction shown in table 3. For example in the second half of the wearing period the stereoscopic depth perception through the spectacles had the same direction as that of an ordinary observer without spectacles, in spite of the reversal of disparity by the spectacles.

Figure 6 shows the results of experiment 1b—the frequency of convex perceptions for pyramid stereograms with crossed disparity and with uncrossed disparity. The upper limits of shadowed portions in the graphs were obtained by treating the percepts C–V, V–C, vC–V (in table 2) as type V percepts; the lower limits show the profiles by regarding these percepts as type C. Thus, the upper and lower curves describe different ways of treating the same set of data so that we can get the frequency of type V percepts as the lower curves and the frequency of type C–V, V–C, vC–V percepts as the shadowed portions. With the 48 min arc crossed-disparity stereogram, for example, convex percepts were reported seven times from a possible seven in the prewearing period, only once on the third day of the wearing period, and were wholly abnormal percepts (type C–V, V–C, vC–V) even on sixteenth day of the postwearing period. Here we can confirm the results of experiment 1a (tables 2 and 3) quantitatively, showing that the adaptive reversal of stereoscopic depth perception occurred quickly in the wearing period and that its aftereffect was slow to decay during the postwearing period.

To summarize, in our experiments with the pyramid stereograms we found remarkable effects of the wearing of left–right reversing spectacles, namely an adaptive reversal of stereoscopic depth perception, a long-lasting aftereffect, and the occurrence of various types of abnormal perceptions.

In contrast with these results obtained with stereograms with monocular contours, we could not find such effects with Julesz's stereograms. Through the three periods the observer perceived without spectacles the stereograms with crossed disparity as

Table 3. Result of the observation of the pyramid stereogram (35 min arc disparity) with monocular contours (experiment 1.1, see figure 4). All tests were conducted without spectacles. The key to the symbols is given in table 2. Early on the third day of the wearing period crossed disparity caused the observer a concave perception and uncrossed disparity a convex perception, although he did not wear spectacles, as in the prewearing period. That is, the adaptive change occurred rapidly. In the post-wearing period, however, a considerable aftereffect remained even 79 days after the removal of the of the spectacles. Some abnormal depth perceptions (type vC, vC′, C–V, vC–V) and, especially, the order of the successive reversals in these perceptions should be noted. Nearly identical types of depth perception were reported for the pyramid stereograms with 12, 23, and 48 min arc disparity.

Disparity	Prewearing period, day		Wearing period, day								Postwearing period, day								
	1	3	2	3	4	5	6	7	8	9	1	2	3	6	8	10	13	16	... 79
Crossed	V	V	V	C′	C′	vC′	vC′	C′	vC	vC	vC	vC′	C	V	C–V	C–V	C–V	C–V	C–V
Uncrossed	C	C	C	V	V	V	V	V	V	V	V	V	V	V	C	V–C	V–C	C	C

convex and the stereograms with uncrossed disparity as concave, as would an ordinary observer. Moreover, the observer reported that the depth perceptions were so clear that they could not be misperceived. The latencies of response also showed little variation; they were always between 2 and 3 s through all periods. These results reveal yet another characteristic of Julesz's stereograms, which has not been described by Julesz himself or, to the authors' knowledge, by any other writer.

Finally, figure 7 shows the result of experiment 2, the eye movements accompanying the changes of fixation from the observer's nose to the target at a distance of 3 m on the seventh day of the wearing period (cumulative wearing time 47·5 h). Clearly, both eyes rotated outwards to watch the closer object and rotated inwards to watch the more distant object. This was a reversal of the trend in the prewearing period.

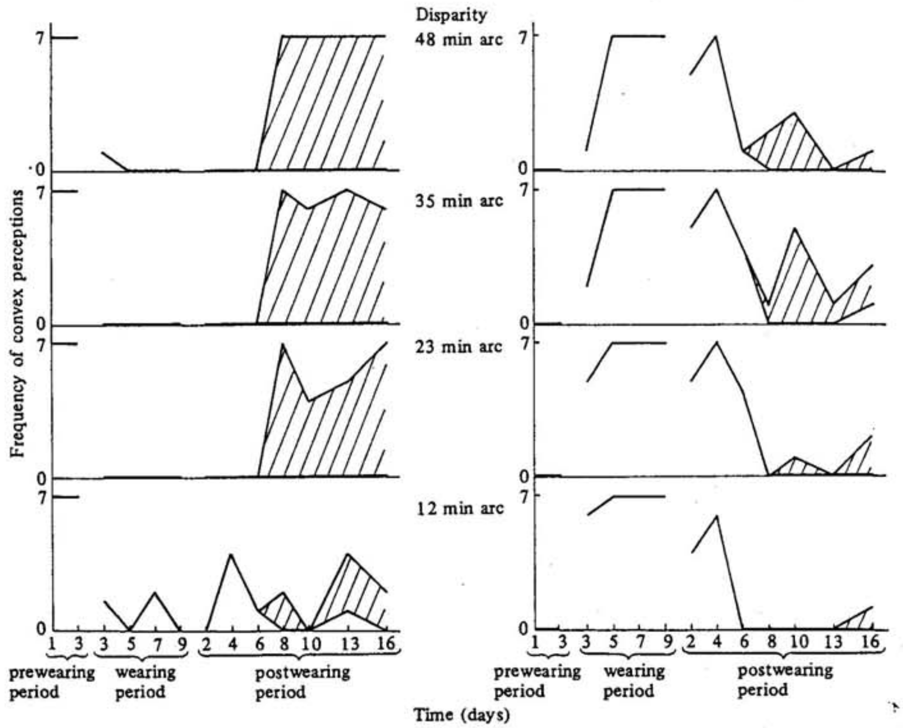

Figure 6. Result of the observation of the stereogram with monocular contours (experiment 1.2, see figure 4) at different crossed disparities (left) and uncrossed disparities (right).

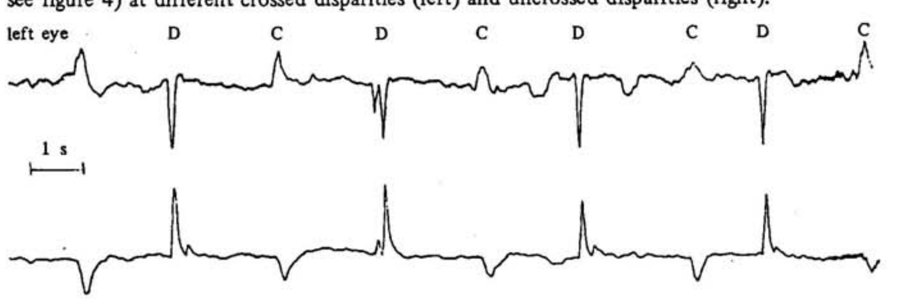

Figure 7. Adaptive vergence change in relation to watching distance measured with an electro-oculograph. Instruction to the observer to look at the target at 3 m distance is signified by D, and to try to look at his own nose by C. The recordings were made on the seventh day of the wearing period, with the subject viewing the target through the spectacles.

These results were confirmed by one of the authors (SS) who wore the same left-right reversing spectacles for four days (cumulative wearing time 42 h), and observed the stereograms following the procedures of experiments 1a and 1c every 6 h. Though the directions of perceived depth of pyramid stereograms were apt to be reversed, those of random-dot stereograms were the same as before.

It became clear that such a reversal of stereoscopic depth perception does not occur suddenly but gradually. This reversal appeared as fragility of depth perception at first, then as alternation between concave and convex, and finally as relatively stable depth perception of the new direction.

There were some differences between the first observer and the second. For random-dot stereograms the stereoscopic depth perception of the second observer became sometimes fragile in the wearing and postwearing period, though the direction of depth was never reversed. And for pyramid stereograms the successive reversals of depth perception during his viewing were not in a fixed order, as in the case of the first observer (see table 2), but closely related to the changes of fixation point. This was not considered in the first case. The effect of fixation must be examined in future.

6 Discussion

Julesz has already named the stereopsis of his random-dot stereograms 'global stereopsis', to be distinguished from the stereopsis of the classical stereograms with monocular cues, termed 'local stereopsis' (Julesz 1971). He showed various distinct characteristics of random-dot stereograms (RDS). For example, it takes relatively longer to perceive the depth in RDS (Julesz 1964; Uttal et al 1975; Julesz and Chang 1976; Julesz et al 1976). The perception of RDS shows remarkable plasticity (Julesz 1971) and stronger hysteresis (Fender and Julesz 1967). Disparity dependent up-down anisotropy and left-right isotropy of the duration thresholds can be demonstrated with RDS (Breitmeyer et al 1975; Julesz et al 1976), as well as its utilization of monocular cues that are undetectable monocularly (Julesz and Oswald 1978). Different spatial frequencies in RDS may be handled by different spatial frequency channels (Julesz 1961; Julesz and Miller 1975). The whole range of possible disparities may be detected simultaneously and processed in parallel (Julesz 1964, 1971; Julesz and Chang 1976; Julesz and Tyler 1976; Tyler and Julesz 1976). There is also evidence for the existence of global stereopsis detectors (Blakemore and Julesz 1971).

In addition to these facts our findings point to another characteristic that clearly distinguishes RDS from the classical stereograms, namely, the same disparity causes opposite depth perceptions in RDS and in classical stereograms after wearing left-right reversing spectacles. From the results described above it is assumed that the process of stereopsis consists of two concurrent subprocesses. One, an experience-independent process, plays the main part in the case of Julesz's stereograms. The other, a process which can change adaptively, plays the main part in the case of stereograms with linear contours. This interpretation leads to a modification of the widely accepted assumption that the depth cue given by stereopsis is rather primary and is not affected by experience as easily as other depth cues. At present, one of the most hopeful hypotheses concerning this point is that these two processes correspond to so-called 'sensory fusion' and 'motor fusion'.[1] While motor fusion as a depth cue is assumed to be a process which can undergo adaptive changes, sensory fusion is assumed to be unchangeable and determined regularly and geometrically by disparity. At least some of the results reported here can be

[1] This hypothesis was suggested to us by Professor T Makino and Mr K Bingushi of Waseda University.

explained by this hypothesis. For example, the cause of the adaptive reversal in the pyramid stereogram may lie in the fact that the radiating lines in the pyramid stereogram easily lead to motor fusion (Julesz's stereograms do not have lines like these before fusion). In addition, the finding that the pyramid stereogram with crossed disparity often causes vC type perception (finite concave with momentary convex, see table 2) can be explained by the fact that sensory fusion can occur more rapidly than motor fusion. This hypothesis, however, can hardly explain the occurrence of C–V type perception (concave to finite convex) and vC–V type perception (concave with momentary convex to convex) from the stereogram with crossed disparity in the postwearing period (table 3).

What kinds of mechanisms actually correspond to these two hypothetical processes? How do these processes interact? What are the differences between the pyramid stereogram and Julesz's stereogram that directly determine whether adaptive perceptual changes will occur or not? These are likely to become subjects for future research. But the difference between the results for RDS and those for classical stereograms (pyramid stereograms) in our study seems to have some relation to the remarkable demonstration of Yellot and Kaiwi (1979). They projected RDS onto an inside-out relief mask of a face, which can be seen in reverse perspective, and showed that a depth inversion of relief and a normal direction of stereopsis for RDS can occur simultaneously. They explained this result by postulating that the low-frequency and high-frequency mechanisms of disparity detection are relatively independent of each other. This postulate, with the additional one that only the low-frequency mechanism is affected by other depth cues, may provide an explanation not only of their results but also of those reported here. Thus, the low-frequency mechanism and the high-frequency mechanism may possibly underlie the experience-dependent process and the experience-independent process of stereopsis respectively.

The finding that these dramatic adaptive reversals or changes occur with stereograms with monocular contours is new.[2] This cannot be explained by the conventional notion that objects which are seen stereoscopically lie at the intersections of lines projected out from their left and right retinal images (see figure 1). We have to explain what kind of mechanism causes these changes. Although we can say little about this point, the various abnormal perceptions reported here may perhaps contribute to our explanation about this mechanism through the following three findings. First, continuous watching was accompanied by reversal of the depth perception, though the disparity in a physical sense did not change. Second, the order of the reversals had some regularity as far as the first observer was concerned. Third, there are a few facts which suggest dissimilarity or assymmetry between the concave perception process and the convex perception process. For example, there occurred many percepts of the vC and vC′ type (finite concave with momentary convex and infinite concave with momentary convex) but few symmetrical percepts (convex with momentary concave). This may be related to the so-called 'stereo-anomalous' subject who can detect the depth of an object correctly when the disparity is crossed but not when it is uncrossed, or vice versa (Richards 1971).

Another remarkable finding in the present experiments is that in the pyramid stereogram, though the depth perception was rapidly reversed by wearing the spectacles for only two or three days, the aftereffect from the wearing period continued for four days into the postwearing period. And, even after almost eighty

[2] This effect must not be confused with so-called 'stereoscopic aftereffects' (Mitchell and Baker 1973). The latter term refers to the effect of looking for some minutes at a stereogram with a certain disparity on test stereograms with slightly different disparities. It is noteworthy, in comparison with our results, that Blakemore and Julesz (1971) have found some aftereffects in this sense with Julesz's RDS.

days had elapsed, some aftereffects were found. This is interesting in view of the fact that in the case of prism adaptation aftereffects are generally weaker and shorter than adaptations. For example the time required for the adaptive reorientation of the perceptual world was about one week in Stratton's (1897) experiment with up-down and left-right inverting spectacles, and was two to three weeks or more in Kohler's (1951) experiment with left-right reversing spectacles. But in these cases few aftereffects of spatial orientation were found on removal of the spectacles. As to 'the swinging of the scene' (Stratton 1897) which was found to accompany head movements, this vanished within three to five days, but the aftereffect did not linger for more than several hours [these perceptual changes may depend on the compensative changes of the vestibuloocular reflex (Gonshor and Melvilljones 1976; Shimojo 1978)]. In addition, sensory-motor coordination was not obstructed even when the spectacles were removed. This variety of adaptations and aftereffects suggests that the human perceptual system adapts to the reversing spectacles on various levels which are relatively independent of each other, although the effects of spectacles in the physical sense are described as a single effect, namely the reversal of the retinal images.

From the result of experiment 2 we can assert that vergence eye movements accompanying the change of watching distance are reversed by wearing left-right reversing spectacles. But it is unlikely that this reversal of vergence could result in the adaptive changes of stereoscopic depth perception. In fact we conducted an experiment through the three periods, in which the observer was instructed to estimate the subjective distance from himself to a small light in the darkroom. The physical distance to the target was varied from 30 cm to 90 cm. In this kind of situation, in which vergence became the main depth cue, remarkable confusions were found in the estimates in the wearing and postwearing period. The observer reported, for instance: "it looks as far as a star", "50 or 60 metres", "very close or very distant", or I cannot estimate".

This result suggests that the observer could not detect when the pyramid was convex or concave by vergence alone, and that it must be *minute* eye movements that result in motor fusion in the stereoscopic depth perception of linear patterns like our pyramid stereogram, even when motor fusion may be operating this process to some degree.

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