0093-7002/78/5509-0599$02.00/0
AMERICAN JOURNAL
OF OPTOMETRY
& PHYSIOLOGICAL OPTICS
Vol. 55, No. 9, pp. 599-609
September 1978

Random-Dot-Stereogram Performance by Strabismic, Amblyopic, and Ocular-Pathology Patients in an Operant-Discrimination Task

JEFFREY COOPER*
JEROME FELDMAN†
State College of Optometry, State University of New York, New York, New York

Abstract
Stereopsis performance was assessed in 88 optometric patients using an operant match-to-sample discrimination task involving random dot stereograms (RDSs). All normals passed the RDS test, and all constant strabismics without amblyopia, microtropes, and amblyopic strabismics failed. Only a portion of anisometropic amblyopes, intermittent strabismics, and ocular-pathology patients passed. The findings were interpreted as indicating that stereopsis with a RDS may be better predicted and explained in terms of binocular fusion and bifoveal alignment than by visual acuity.

Key Words: stereopsis, random-dot stereograms, strabismus, amblyopia, ocular disease

Distinguishing patients with normal binocular vision from those with defective binocular vision or related visual anomalies is of primary concern to the clinician. One of the tests used to screen for binocular anomalies or related dysfunctions involves an assessment of stereopsis. The random dot stereogram (RDS) is particularly appropriate for assessing stereopsis because, unlike other types of stereograms, it provides no monocular contours or lateral-displacement cues. Only when binocularly fused can the centrally hidden stereoscopic form be identified.[1, 2]

Reinecke and Simons[3] used a RDS known as the Random Dot E test (Stereo Optical Co.) to evaluate the stereoscopic ability of a number of patients diagnosed as having amblyopia or amblyopia-related dysfunction. They reported that no patient with more than two lines' difference in visual acuity between the two eyes passed the test. Additionally, no patient with worse than 20/40 corrected visual acuity in the worse eye passed. All constant tropia patients (microtropes not included) also failed. Reinecke and Simons concluded that the RDS could be used as an effective screening device for amblyopia. They also suggested that the absence of stereopsis was related to visual acuity, although two of the five patients classified as anisometropic amblyopes were able to pass the test despite their deficit in visual acuity.

Reinecke and Simons[3] also assessed the stereoscopic ability of 11 patients classified

Presented at the Annual Meeting of the American Academy of Optometry, Birmingham, Alabama, December 12, 1977. Received March 2, 1978; revised June 15, 1978.

*Optometrist, Member of Faculty, F.A.A.O.

† Psychologist, Ph.D., Member of Faculty.

as microtropes. They reported that five of the 11 passed the Random Dot E test; thus, the test did not perfectly differentiate microtropes from normals. Unfortunately, Reinecke and Simons failed to present cover-test or visuoscope data to support their diagnosis of microtropia. For example, three of the microtropes who passed had 20/25 visual acuity. It is possible that they also had central fixation and no manifest deviation. If so, then these patients should not have been classified as microtropes, as defined by Helveston and von Noorden.[4]

Reinecke and Simons[3] also failed to account or control for two other factors that might confound their interpretation. Given the particular performance criterion used, 6% of the patients would be expected to pass the test according to chance probability. More important, the authors failed to carry out a monocular-cue control test, such as unilateral eye patching, to assess the responses obtained during stereopsis testing. Cooper[5] found that some patients were capable of passing the Random Dot E test by using nonstereoscopic cues, such as scratches on the metal borders of the test stimuli. These factors make Reinecke and Simons's "evidence" that microtropes can pass a RDS test inconclusive.

Walraven[6] used a red-green anaglyph RDS known as the TNO test (Alfred Poll, Inc.) to screen for amblyopic dysfunction. He placed his patients into three categories and found that 18 of 18 patients with lowered visual acuity, eight of eight with questionable visual acuity, and three of nine with normal visual acuity failed the test. He concluded that the TNO test could differentiate amblyopic patients from normals. Unfortunately, Walraven did not report the differentiation of his patients on the basis of their binocular status—strabismus, phoria, fixation, and so on. Consequently, one is not able to ascertain the relation between binocular vision and stereoscopic ability. Furthermore, Walraven did not specify the criterion used for passing the tests, the nature of an acceptable response, or the reliability of the test.

More recently, Hill et al.[7] used the TNO test to evaluate the stereoscopic responses of small-angle strabismics. They evaluated 40 patients who had deviations up to 9 prism diopters on a cover test and/or failed the 4-prism-diopter test for suppression; 33 patients passed the test. Unfortunately, the results are inconclusive, since some of the patients may have been improperly classified as microtropes. For example, Hill et al. reported that a number of "microtropes" had central fixation as well as no movement on a cover test. These characteristics, according to Helveston and von Noorden,[4] are excluded from the definition of microtropia.

One study that did presumably identify microtropes on the basis of proper cover testing and visuoscopy was reported by Cooper.[5] In that study, stereopsis was assessed in 30 microtropes using projected images of RDS slides. All 30 failed to appreciate stereopsis. This finding is consistent with that of Brenneisen et al., as reported in Hill et al.[7] In that study, 18 of 18 tested microtropes were unable to pass the TNO test.

The aforementioned studies all attempted to show a relation between a patient's visual diagnosis and performance on one or another form of RDS test. Unfortunately, the relation is unclear for a number of reasons. For example, in some studies[3,7] the diagnostic classification of patients may have been improperly assessed. Compounding this problem is the fact that visual measurements used to make diagnoses were not reported in some studies.[3,7] Still another problem is that definitions of, and criteria used for, diagnostic classification were sometimes vague and did not sufficiently differentiate between patients.[6] Finally, in almost all the studies, little attention was given to the method by which the RDS test was administered. Few attempts were made to ensure objective and reliable measurement of responding during testing, to establish a specific criterion for acceptable test performance, or to assess the possibility that patients could pass the test by using cues other than stereoscopic stimuli.

The main purpose of the present study was to measure stereoscopic performance objectively and reliably, using RDS stimuli, in optometric patients displaying a variety of visual problems and diagnoses. In this way, the relation between visual status and stereoscopic ability could be systematically

assessed. In addition to its potential significance for clinical screening, such an analysis might also enable the generation of plausible hypotheses concerning factors affecting stereoscopic appreciation.

This study contains a number of features not found in many previous studies. Relevant optometric findings for most patients, as well as the criteria used for diagnostic classification, are reported. The RDS test was designed to reduce potential experimenter bias through the use of an automated stimulus-presentation and response-recording procedure. A pre-established test-performance criterion was also used. Objective evidence of RDS discrimination performance was achieved by noting the amount of differential responding to RDS stimuli with and without disparity during testing. Binocular responding was assessed, following testing, through the use of a unilateral eye-patching procedure. A reinforcement procedure was used during testing to encourage patient motivation and attention.[8] Finally, to increase the likelihood that patients would respond to stereoscopic cues during testing, monocular contrast cues were initially superimposed and then gradually eliminated—that is, faded.[a] Accurate discriminative behavior during initial stages of testing, when monocular contrast prompts were present, also provided evidence that task instructions were understood.

[a] Previous studies[8] have shown that a stimulus-prompting procedure can enhance an individual's learning a difficult stimulus discrimination. Initially, these prompts make a discrimination task easier because they either exaggerate the relevant cues of the original discriminanda or superimpose additional, easy-to-discriminate stimulus prompts upon the original discriminanda. The function of these prompts is to facilitate attention to the relevant features, or dimensions, of the original discrimination task. When these prompts are gradually faded out (removed) during discrimination training, the individual's behavior and attention are expected to come under the control of the original relevant stimulus dimension. The present study illustrates such a procedure by introducing and then fading out monocular contours to facilitate eventual binocular appreciation of the stereoscopic stimuli.

METHODS

Subjects

All subjects were patients or volunteers from the University Optometric Center who had received a refraction and pathology examination. Additional tests were performed on strabismics and amblyopes: visuoscopy, 4-prism-diopter, sensory-fusion, and unilateral cover tests. The experimental sample comprised 13 constant strabismics with no amblyopia, 11 amblyopic strabismics, 6 microtropes, 10 anisometropic amblyopes, 6 patients with congenital pathology, 8 patients with noncongenital pathology, 13 intermittent exotropes, 7 intermittent esotropes, and 14 normals. The definitions of, and criteria used for, the diagnostic categories can be seen in the Appendix.

Apparatus

The RDSs were 100- x 100-dot matrix slides (2 x 2) photographically reproduced from those pictured in *Foundations of Cyclopean Perception*.[2] Each stereogram consisted of a right- and a left-eye slide. The slides (average luminance = 816 cd/m^2) were projected by two Kodak model 650H Carousel projectors, and the images were reflected off two 3.8- x 4.4-cm front-surface mirrors placed at 45-deg angles. The mirrors were 8 cm from the projector lenses. The images were then passed through two linear polarizing filters mounted at axis 45 and axis 135 deg and rear-projected onto a 78- x 68-cm piece of clear Plexiglas sandblasted on the rear surface. Each subject was seated 40 cm in front of the plexiglas screen, so that the RDS subtended an angle of 10.2 deg to the subject.

The RDS slides were paired in order to produce three types of stimuli. A right- and a left-eye slide were paired so that binocular viewing resulted in a dot-pattern stimulus seen with a central square in crossed disparity. This disparity had been created by shifting the inner core two dots horizontally to yield a central square of 660 sec of disparity subtending an angle of 5.1 deg to the subject (6.1 min/element). The second type of stimulus consisted of two identical right-

eye slides paired so that stereopsis could not be appreciated on binocular viewing. The third type of stimulus, containing right- and left-eye slides, was identical with the first, except that each slide also contained a darkened monocular central square superimposed on the crossed-disparity central square. The darkened square was produced by exposing the central portion of the photographic film for a particular time period. The third type of stimulus actually comprised six different stimuli, each containing a different contrast between the central square and the surround (97%, 90%, 68%, 60%, 52%, and 13%).

Fig. 1 shows examples of some of these stimuli.

Programming and sequencing of the stimuli, delivery of reinforcing feedback, and recording of trials and responses were controlled by BRS solid-state logic (Technical Service, Inc.) and electromechanical relay circuitry. Reinforcers were delivered via a BRS penny dispenser placed beside the viewing screen about 70 cm from the subject. Responses were made on two BRS illuminated push panels (7.5 x 7.5 cm) separated by 8 cm. The panels were tilted 45 deg from horizontal and were 33 cm from the subject. The right panel contained a centered two-dimensional plastic decal in the form of a darkened square. The left panel contained no square.

Procedure

All subjects were given instructions pertaining to the operant match-to-sample discrimination task before individual testing. They were told that a stimulus (the sample stimulus) consisting of dots would appear on the screen; sometimes it would contain an inner square "popping out" toward them, and sometimes it would contain no inner square. They were told to press the response panel with the square decal if they saw the inner square, and the response panel without the decal if they saw no inner square (these were the comparison stimuli that were to be "matched" to the sample stimulus). A correct panel-press response resulted in the delivery of a penny from the penny dispenser and the 2-sec display of a cue light. An incorrect response or the absence of any response during a stimulus

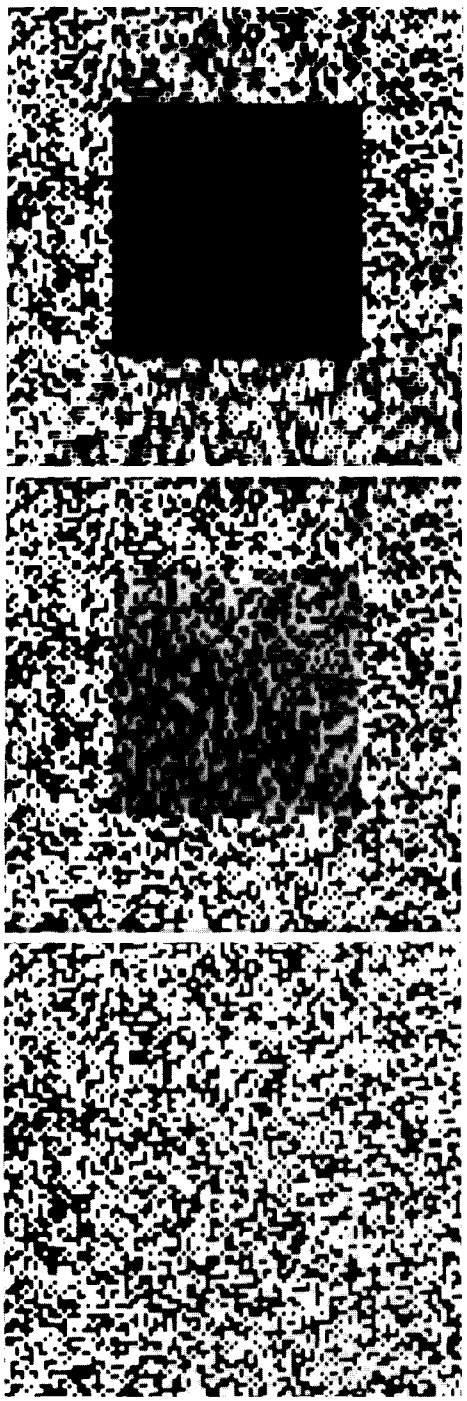

FIG. 1. Examples of crossed-disparity random-dot stereogram (RDS) stimuli used during testing. The top two stimuli contain monocular prompts, of decreasing contrast, superimposed on the central crossed-disparity square of the RDS. The bottom stimulus contains no monocular contrast prompt.

presentation resulted in no such consequences. Each subject was given the operant RDS match-to-sample test while wearing polarizing glasses (axis 45 and axis 135 deg) over his own best refractive correction.

During testing, either a RDS containing a crossed-disparity central square (stimulus type 1 or 3) or one without disparity (stimulus type 2) appeared. The probability of occurrence of each stimulus was 50%. Each subject was allowed a maximum of 10 sec to make a panel-press response, which terminated the trial and stimulus presentation. The interval between the end of one presentation and the beginning of the next was always 6.5 sec.

RDS testing was divided into seven discrete monocular-cue-fading steps. During the first step, the contrast between the central square and the surround of the crossed-disparity RDS was 97% (stimulus type 3). The RDS without disparity (stimulus type 2) contained no central square and, thus, no contrast between the central area and the surround. The response criterion needed to progress to the second step was five consecutive correct responses to five stimulus presentations. A response error made before meeting this criterion always resulted in a minimum of five additional stimulus presentations. When the response criterion was met, the second fading step was initiated. During this step, the contrast between the central square and the surround of the crossed-disparity RDS was 90% (stimulus type 3). The RDS without disparity (stimulus type 2) was identical with the one appearing in the first step. Again, the response criterion had to be met before initiation of the third fading step. In each successive fading step, the contrast between the central square and the surround of the crossed-disparity RDS was progressively reduced. The RDS without disparity always appeared the same. The last, or seventh, fading step required a discrimination between a nondisparity RDS (stimulus type 2) and a crossed-disparity RDS containing no contrast between the central square and the surround (stimulus type 1). On this step, each subject was given a maximum of 20 trials (stimulus presentations). The criterion for passing the RDS test was at least nine correct responses during the last ten trials of the seventh step. Testing was terminated, and a failure recorded, for any subject who made a total of ten response errors in any fading step before the seventh.

After the RDS test, a control test to ensure binocular responding was given to all subjects who had passed step seven. This consisted of a re-presentation of the seventh-step stimuli for 10 trials with the right eye occluded and 10 trials with the left eye occluded. Subjects were told that no feedback would be given after panel presses but that they should respond as they had in the past.

RESULTS

Table 1 depicts the number of subjects within each diagnostic classification who passed or failed the operant RDS test. All the normal (control group) subjects passed the test, and none of the microtropes, constant strabismics, or amblyopic strabismics did. Only a portion of the intermittent strabismics, anisometropic amblyopes, and ocular-pathology patients passed. Interestingly, all subjects who failed did so on the fifth or sixth fading step. These steps contained monocular as well as disparity cues. One may therefore be reasonably assured that test failure was due to inability to appreciate RDSs rather than inability to understand the task requirements.

TABLE 1. Number of subjects passing or failing the operant Random Dot Stereogram (RDS) discrimination test according to visual diagnostic classification.

Visual Diagnosis	RDS Test Performance	
	Pass	Fail
Normal[a]	14	0
Constant strabismus	0	13
Amblyopic-strabismus	0	11
Microtropia	0	6
Anisometropic amblyopia	5	5
Congenital pathology	1	5
Noncongenital pathology	5	3
Intermittent exotropia	10	3
Intermittent esotropia	4	3

[a] *Normal* refers to subjects whose visual diagnosis did not include a strabismus (constant or intermittent), amblyopia, or ocular pathology.

Although Table 1 appears to indicate clear differences in RDS performance between some of the groups, statistical analyses were performed to support these observations. Paired comparisons were initially made between three groups: normals, patients with a constant strabismus, and a combined group consisting of patients with either anisometropic amblyopia, congenital pathology, or noncongenital pathology. These three groups were intended to represent patients with normal visual acuity and no strabismus (normal), normal visual acuity and a strabismus (strabismus only), and reduced visual acuity and no strabismus (reduced visual acuity only), respectively. Because of the small number of patients in each group, the Fisher Exact Probability test was performed.[9] This test determines the exact probability of two groups' differing in the proportion with which they fall into two classifications—in this case, passing or failing the RDS test. Statistical analysis indicated that the normal group was significantly different from both the strabismus-only group ($p < 0.0001$) and the reduced-visual-acuity-only group ($p < 0.0001$). The latter two groups were also significantly different from each other ($p = 0.0029$).

A second set of statistical analyses was carried out to determine whether the RDS performance of the microtropia and the amblyopia-strabismus groups were significantly different from those of the strabismus-only and the reduced-visual-acuity-only groups. The purpose was to assess whether RDS performance of patients having *both* reduced visual acuity and a strabismus was more like that of patients having only one visual anomaly rather than the other. The Fisher Exact Probability test indicated *no* statistically significant difference between the strabismus-only, microtropia, and amblyopia-strabismus groups ($p = 1.00$). However, as was the case with the strabismus-only group, the performances of the microtropia and amblyopia-strabismus groups both differed significantly from that of the reduced-visual-acuity-only group ($p = 0.0457$ and $p = 0.0060$, respectively).

Table 2 provides relevant visual findings, as well as the RDS performance, of each patient in the first six diagnostic-classification groups. It provides evidence that visual acuity alone seemingly cannot be used to predict RDS test performance. As can be seen, five anisometropic amblyopes passed and five failed the RDS test. Four of five patients who failed had between one and two lines' difference in visual acuity. Patient 89 had six lines' difference in visual acuity, 4.50 D of anisometropia, and passed the test. The findings from the sole congenital-pathology patient who passed RDS testing offer supportive evidence. Patient 47 had a bilateral pendular nystagmus of unknown etiology and substantially reduced visual acuity (20/80 OD; 20/100 OS).

Three noncongenital-pathology patients failed the RDS test. Patient 29 had a corneal scar and only a slight reduction in visual acuity (20/25 OD; 20/25 OS). Patient 48 had a traumatic left hemianopsia due to a previous assault that resulted in severe bleeding and cerebral anoxia. One might have predicted stereoscopic appreciation if this patient gazed to the extreme left (depending on the degree to which the anoxia had affected areas of cortical functioning). Patient 52 was a 79-year-old male who reported having difficulty in following instructions. The failure of these three patients to pass RDS testing was not entirely expected and cannot be readily explained.

After the RDS test, all subjects who passed the seventh step (only lateral-disparity cues present) were given the monocular cue control test. This was done to ensure that patients responded only on the basis of binocular cues during RDS testing. As expected, each subject failed to perform at a level better than chance on this unilateral eye-patching control test.

DISCUSSION

All patients with a constant strabismus, including amblyopic strabismics and microtropes, failed the RDS test. This was expected in light of Fender and Julesz's[10] report that normal sensory fusion and bifoveal fixation are needed to achieve stereopsis on viewing a RDS. However, small-angle strabismics and microtropes (lacking bifoveal fixation) may report stereopsis when shown lined stereoscopic stimuli like those

TABLE 2. Clinical data and Random Dot Stereogram (RDS) test performance of all patients in the present study who were not visually normal. Acuity was measured with the optimum refractive correction using a full Snellen chart. Visuoscopy findings are summarized as central fixation (CF), unsteady central fixation (USCF), eccentric fixation (EF), pendular nystagmous (PN), or unsteady eccentric viewing (USEV). Distance and near cover-test findings are reported as: E = eso(phoria); X = exo(phoria); ϕ = orthophoria; (T) = intermittent tropia; T = constant tropia; H = hyper(phoria/tropia).

Patient/ Age (yr)	Acuity OD/OS (20/)	Ametropia (D) sph/cyl/ax	Visuoscopy	Cover Test (Δ) dist/near	RDS Result	Remarks
Anisometropic amblyopia						
10/8	40+	+5.75/-0.50/15	USCF	4E	Pass	OD: no foveal reflex
	20-	+6.75/-0.50/165	CF	4E		OS: striations disc to fovea
22/12	30-	+5.00/-2.00/90	USCF	ϕ	Pass	
	20	+2.50/-0.75/90	USCF	2E		
71/22	20	pl./-0.50/5	CF	ϕ	Fail	
	400	-3.00/-4.00/30	CF	ϕ		
73/24	20-	+2.50/-0.75/90	CF	8X	Fail	
	15	+0.25/-0.50/120	CF	10X		
78/24	30	+2.00/-1.75/5	USCF	ϕ	Fail	
	20	pl.	CF	ϕ		Wearing 4ΔBO
82/8	20	-1.25	USCF	ϕ	Fail	
	30	-6.75/-2.25/157	USCF	ϕ		
83/29	20	pl.	CF	20 X(T)	Fail	Anis. amblyopia?
	40	-0.50/-0.75/45	USCF	20 X(T)		
85/5	40	+4.00/-1.00/180	CF	2E	Pass	Anis. amblyopia?
	20	+3.25/-1.00/180	CF	4E		
86/23	30	-6.50	USCF	2H 2X	Pass	
	15	-2.25/-0.75/15	CF	2H 2X		
89/9	20	+0.50	CF	6E	Pass	
	80	+5.00	USCF	6E		
Constant strabismus, no amblyopia						
4/6	50	-10.50/-3.00/180		5ET	Fail	
	50	-10.50/-2.50/5		5ET		
5/7	20	-12.25/-1.25/60		6ET	Fail	
	20	-11.50/-1.75/120		6ET		
15/9	30	+1.00/-0.50/130		6XT	Fail	
	30	+0.75/-0.50/60		30XT		
23/9	20	+1.25		13ET	Fail	
	20	+1.25		14ET		
32/4	40	-8.00/-0.75/180		XT	Fail	
	30-	-6.00/-1.50/180		XT		
53/5	30	+4.75/-0.50/90		1HT	Fail	
	30	+4.75/-0.50/90		12HT		
25/8	30	+1.00		8ET	Fail	
	30	+1.00		3ET		
70/5	40	pl.		15ET	Fail	
	40	pl.		15ET		
77/5	40	+5.00/-0.50/180		30ET	Fail	
	30-	+1.75		20ET		
81/16	25	+1.00/-0.25/105		sm XT	Fail	
	20-	+1.00/-0.25/170		5X(T)		
59/6	30	+1.00		20ET	Fail	
	30	+1.00/-0.50/180		35ET		
87/9	30-	pl.		4H 16ET	Fail	
	30-	pl.		4H 16ET		
17/10	20	-0.25		18XT	Fail	
	15-	pl.		10XT		

TABLE 2—*Continued*

Patient/ Age (yr)	Acuity OD/OS (20/)	Ametropia (D) sph/cyl/ax	Visuoscopy	Cover Test (Δ) dist/near	RDS Result	Remarks
Amblyopic strabismus						
1/9	25	+1.00	CF	8ET	Fail	
	40	+2.00/-0.50/180	USCF	8ET		
21/7	30	+2.00/-1.75/5	USCF	10XT	Fail	Postsurg. ET
	40	+3.00/-2.50/175	USCF	15XT		
39/6	200	+0.25	EF	45ET	Fail	
	40	+1.25	CF	45ET		
46/25	200	+6.00/-1.25/180	USCF	13XT	Fail	
	20	pl./-0.50/90	CF	18XT		
55/8	200	+4.50/-0.25/175	EF	20ET	Fail	
	80	+3.50/-1.00/15	CF	20ET		
54/8	20	+3.25/-1.25/15	CF	microtr	Fail	
	400	-5.75/-1.50/180	EF	15ET		
69/5	200	+2.75	EF	30ET	Fail	
	20	+2.75	CF	35ET		
84/12	100	-8.25/-2.00/180	USCF	15XT	Fail	
	30	-10.00/-1.50/90	CF			
88/4	30-	+1.00	USCF	8ET	Fail	
	15-	+0.50	CF	4ET		
7/16	400	+4.25/-2.00/170	EF	45ET	Fail	
	20	+1.25	USCF	45ET		
79/6	40	+8.00/-0.75/180	USCF	6ET	Fail	
	25	+7.50/-1.25/175	CF	12ET		
Microtropia						
3/8	50	+6.50/-1.00/180	EF	ϕ	Fail	
	20	+5.50/-1.00/180	CF	ϕ		
49/7	30	-3.50/-1.25/40	CF	ϕ	Fail	
	50	-3.75/-1.25/135	EF	3E		
56/7	20	+0.25/-0.75/15	EF?	ϕ	Fail	Poor fixation
	60	+1.25/-0.75/75		ϕ		
75/25	20	+4.00/-4.00/175	CF	ϕ	Fail	
	60	+4.00/-4.00/12	EF	ϕ		
12/10	40	+1.25/-1.00/5	EF	4E	Fail	
	20	+0.25/-0.75/175	CF	4E		
90/6	20	-0.25	CF	ϕ	Fail	
	200	-4.00/-1.00/30	EF	ϕ		
Pathology						
6/24	200	-11.00	PN	6ET	Fail	Ocular albino, foveal hypoplasia
	200	-11.00		6ET		
8/8	10/77	-4.00	PN	ET?	Fail	Ocular albino, macular hypoplasia
	10/87	-4.00				
2/27	20	-0.50	CF	ϕ	Fail	Macular hypoplasia OS
	40	-1.75/-1.50/90	USCF	X		
47/6	100	+2.25	PM	ϕ	Pass	Nystagmus, etiology unknown
	80	+1.50		X		
51/5	30	+1.00/-0.75/15	CF	6ET	Fail	Ocular albino, post-surgical squint
	30	+1.00/-0.75/15	CF	E		
68/8	100	-0.75/-1.25/180	PN	ϕ	Fail	Macular hypoplasia
	100	-0.75/-1.00/180		ϕ		
26/9	20	+0.75	CF	ϕ	Pass	Ant. polar cataract OS
	30	+1.75/-1.00/150	USCF	X		
29/12	25-	pl./-0.50/30	–	ϕ	Fail	Corneal scar OS
	25	pl.	–	X		

TABLE 2—*Continued*

Patient/ Age (yr)	Acuity OD/OS (20/)	Ametropia (D) sph/cyl/ax	Visuoscopy	Cover Test (Δ) dist/near	RDS Result	Remarks
33/27	20	pl.	CF	ϕ	Pass	Traumatic cataract OS
	60	−1.75/−1.75/180	CF	ϕ		
60/74	40	+1.75/−2.00/75	−	ϕ	Fail	Macular hole OS
	80	+1.75/−1.50/90	−	E		
64/72	70	+3.50/−1.00/90	CF	ϕ	Pass	Preret. fibrosis, poss. macular hole OD
	25	+3.25/−1.00/90	CF	ϕ		
65/19	40−	+0.75/−0.50/80	USEV	ϕ	Pass	Red. VER, VA const. on filter test.
	50	+0.50		ϕ		
67/18	20	pl./−0.25/180	CF		Pass	Best's macular degeneration
	50	−0.25	CF?			
48/29	40	+0.50	−	ϕ	Fail	Left hemianopsia (traumatic/anoxia)
	40	+0.50	−	ϕ		

included in the Titmus Stereo Test (Stereo Optical Co.). Therefore, contoured or lined stereograms cannot be used to test for a constant strabismus.

As indicated above, we found no microtropes who were able to pass our RDS test. However, Reinecke and Simons,[3] as well as Hill et al.,[7] reported that some of their microtropes were able to pass the Random Dot E and TNO tests of stereopsis. This difference in findings may be accounted for in a number of ways. The studies by Reinecke and Simons and by Hill *et al.* may have included some patients who were improperly diagnosed as microtropes (neither study provided relevant visual findings or criteria to support the diagnosis of microtropia). Moreover, neither study instituted procedures to control for correct guessing due to chance responding or examiner bias during testing. Lastly, neither study employed a control test to assess whether patients actually used binocular cues during testing.

Some anisometropic amblyopes passed our RDS test, and others failed. There were no apparent binocular or acuity characteristics that differentiated between those patients passing and those failing. This finding is different from that reported by Reinecke and Simons,[3] who stated that no patient with more than two lines' difference in visual acuity between the two eyes, or 20/40 visual acuity in the worse eye, passed their Random Dot E test. No such relation was observed in our study. We found patients with moderately large refractive errors or visual acuity differences (for example, 20/20 OD; 20/80 OS) who passed and some with minimal differences (for example, 20/20 OD; 20/15 OS) who failed. It should also be noted that some pathology patients with a significant reduction in visual acuity showed stereopsis on our RDS test.

One factor that could account for the discrepancy between our findings and those of Reinecke and Simons[3] is the difference in the size of the matrix elements of the stereograms. The Random Dot E test, used by Reinecke and Simons, contains very small elements; the elements in our RDS test are larger. Hence, one might expect patients with reduced visual acuity to be more likely to fail the Random Dot E test than our RDS test. To assess this hypothesis, we recalled three patients with the greatest amounts of visual acuity reduction and presented them with the Random Dot E test (at 40 cm). Each had originally passed our RDS test. Two were anisometropic amblyopes (cases 86 and 89), and one had a nystagmus (case 47). All three were able to pass the Random Dot E test by reporting that they saw "an E popping off the card." It may be concluded that the difference between our findings and Reinecke and Simons's cannot be explained solely on the basis of difference in element size.

The RDS test performance of our constant strabismic patients corresponds well to that of normal subjects presented with

diplopic RDS stimuli. Fender and Julesz[10] used stabilized retinal images to neutralize vergence movements as well as to manipulate the retinal location of the RDS. They noted that when sensory fusion was broken, all their normal subjects reported a loss in stereopsis of the RDS. Similar findings were reported by Julesz[2] when stimulus manipulations creating greater than 15% of aniseikonia or 9 deg of cyclodeviation resulted in diplopia and loss of RDS appreciation. Therefore, the limit of RDS appreciation seems to be related to Panum's area. Since all patients with a measurable constant strabismus have a deviation greater than Panum's area, they would not be expected to experience stereopsis using RDS stimuli.

Julesz[2] was also able to produce in normal subjects a state analogous to amblyopia by extensive blurring of one or both images of an RDS. Because his subjects showed RDS appreciation, it can be inferred that normal visual acuity is not necessary for RDS appreciation. In some respects, our findings support that notion, because many patients with lowered visual acuity passed our RDS test. However, some of our anisometropic amblyopic patients also failed the RDS test. One hypothesis that might account for this result is that some of our amblyopes had greater changes in the physiological characteristics of cells in the lateral geniculate body and/or visual cortex than others. Moreover, our patients had long-term experiences with their amblyopic condition, whereas Julesz's subjects did not. These experiences may have resulted in permanent physiological and/or sensory changes.

All but three of our intermittent exotropes (divergence-excess type) passed the RDS test, as expected.[11] One patient who failed, when questioned, reported awareness of his ocular deviation during testing. However, he said that he was "too tired" to align his eyes. But only about half the intermittent esotropes passed the RDS test. The difference in RDS performance between intermittent exotropes and esotropes may be related to differences in binocular alignment or sensory/motor capabilities. Unfortunately, binocular alignment was not specifically measured during the present study.

As indicated previously, pathology patients were initially included in the study in order to assess the effects of visual acuity reduction on large-disparity-RDS appreciation. Results indicated that reduced visual acuity alone is not sufficient to interfere with RDS appreciation. However, a number of pathology patients did fail the RDS test. That this percentage was greater for congenital- than for noncongenital-pathology patients provides indirect support for the importance of binocular critical periods in binocular cell development (a factor more likely to affect congenital-pathology patients).[12, 13] A plausible hypothesis for the RDS test performance of the few noncongenital-pathology patients who failed might be that reduced visual acuity (or other anomalies) can interfere with the transmission of cortical information necessary for binocular functioning. Further research in this area is needed to evaluate factors affecting binocular functioning as well as the usefulness of RDS testing to aid in the diagnosis of ocular pathologies.

In summary, presentation of RDS stimuli with operant conditioning provides an objective and reliable method of measuring responses to stereoscopic stimuli. The reinforcement and monocular cue-fading procedures are intended to encourage patient motivation as well as attention to relevant stereoscopic cues. Whereas all normal control subjects passed the RDS test, all constant-strabismic patients (including microtropes and amblyopic strabismics) failed. Only a portion of the anisometropic-amblyopia, ocular-pathology, and intermittent-strabismus patients passed the test. This latter finding was assumed not to be directly or simply related to lowered visual acuity but, rather, to be related to a more direct disturbance in binocular vision or the pathways serving it.

APPENDIX

Definitions and criteria for diagnostic categories used in the present study are:

Amblyopia: a reduction in visual acuity by at least one line in the worse eye which is not due to an observable pathology and not fully correctable by lenses alone.

Constant strabismus: deviation of the visual axis from the object of regard at all times and at all distances.

Amblyopic strabismus: a constant strabismus with amblyopia.

Anisometropic amblyopia: amblyopia without strabismus and with at least 0.75 D difference in refractive errors.

Microtropia: amblyopia in which the amount of eccentric fixation equals the objective angle of squint. Hence, there is no observed movement on a cover test.

Congenital pathology: observable or definable pathology thought to occur within the 1st year of life.

Noncongenital pathology: an acquired pathology thought to be environmentally produced with onset after the 1st year of life.

Intermittent strabismus: deviation of the visual axis from the object of regard at some time at 40 cm or 6 m without an associated amblyopia.

ACKNOWLEDGMENT

This research was supported in part by a grant from the Optometric Center of New York Foundation.

REFERENCES

1. Julesz, B., Binocular depth perception of computer generated patterns. Bell System Tech. J., 39(6): 1125–1162, 1960.
2. Julesz, B., Foundations of Cyclopean Perception. Chicago, Univ. of Chicago Press, 1971.
3. Reinecke, R. D., and K. Simons, A new stereoscopic test for amblyopia screening. Am. J. Ophthalmol., 78(4): 714–721, 1974.
4. Helveston, E. M., and G. K. von Noorden, Microtropia—a newly defined entity. Arch. Ophthalmol., 78(8): 272–281, 1967.
5. Cooper, J., Random dot stereograms, *in* Advanced Diagnostic Procedures, Optometric Extension Program. 2(1/2): 1–13, 1976.
6. Walraven, J., Amblyopic screening with random dot stereograms. Am. J. Ophthalmol., 80(5): 893–900, 1975.
7. Hill, M., J. Perry, and I. C. J. Wood, Stereoacuity in microtropia, *in* Orthoptics: Past, Present, Future, edited by S. Moore, J. Mein, and L. Stockbridge, New York, Stratton Intercontinental Medical Book Corp., 1976, pp. 25–29.
8. Cooper, J., and J. Feldman, Operant conditioning and the assessment of stereopsis in young children. Am. J. Optom. & Physiol. Optics, 55(8): 532–542, 1978.
9. Siegel, S., Nonparametric Statistics for the Behavioral Sciences. New York, McGraw-Hill Co., 1956, pp. 104–166.
10. Fender, D. H., and B. Julesz, Extension of Panum's fusional area in binocularly stabilized vision. J. Opt. Soc. Am., 57(6): 819–830, 1967.
11. Cooper, J., Intermittent exotropia of the divergence excess type. J. Am. Optom. Assoc., 48(10): 1261–1273, 1977.
12. Hubel, D. H., and T. N. Wiesel, Binocular interaction in striate cortex of kittens reared with artificial squint. J. Neurophysiol., 28(10): 1041–1059, 1965.
13. Hubel, D. H., and T. N. Wiesel, Stereoscopic vision in the Macaque monkey. Nature (London), 225(1): 41–42, 1970.

AUTHOR'S ADDRESS:

Jeffrey Cooper
State College of Optometry
State University of New York
100 East 24th Street
New York, New York 10010