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Operant Conditioning of Fusional Convergence Ranges using Random Dot Stereograms

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Abstract
In Experiment 1, four 6- to 10-year-old strabismic patients, who had failed to improve convergence ranges using traditional vision training techniques, were given convergence training using random dot stereograms (RDS). An integral part of the RDS training procedure was the incorporation of an operant conditioning procedure providing for response-contingent positive reinforcement, immediate feedback, and preprogrammed systematic changes in convergence demand during discrimination learning. Findings indicated that operant RDS convergence training produced a significant increase in convergence ranges which transferred readily to vectogram tasks and resulted in a change from exotropia to exophoria for at least one patient. In Experiment 2, it was shown that improved convergence ability was a direct result of exposure to RDS of increasing convergence demand. It was concluded that young, uncooperative, language-deficient, or inattentive patients show improved convergence ranges when such training incorporates proper stimuli and the basic principles of learning and motivation into its training regimen.

Key Words: convergence, strabismus, operant conditioning, behavior modification, random-dot stereograms, vision training, orthoptics, children, exotropia, convergence insufficiency, fusion

Fusional convergence training is often used in the treatment of such binocular anomalies as convergence insufficiency, exotropia, etc.[1-3] A common type of training involves the use of various convergence stimuli presented at progressively greater demands. Sometimes such training fails to result in the remediation of the patient's visual problem, particularly when the patient is young. The most probable reasons for this failure relate to the nature of the stimuli, the ability to generate valid and reliable patient responses, and the specific training procedure used.[4,5]

Typical vision training or orthoptic tasks use line or contour stereograms. These stimuli have few controls to determine if the patient's response is a valid and reliable indicator of what is actually perceived. That is, it is often difficult to evaluate whether a patient's verbal response to questions about blur, diplopia, suppressions,

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SILO,[a] localization,[b] float,[c] motion parallax,[d] etc., represents actual sensory ability. It may be the case that "correct" patient responses reflect prompts from instructional sets or clinician questions, task demands to "please" the therapist, therapist bias in interpreting patient answers, the use of monocular cues, etc. Thus, the use of line or contour stimuli does not allow the clinician to judge accurately the validity of the patient's response.[6, 7]

Recently, a new type of stereogram has been introduced which may solve some of the problems indicated above. These stereograms, called random dot stereograms (RDS), contain a hidden stereoscopic geometric form which can be appreciated only under conditions of bifoveal fixation.[8, 9] Because they contain no monocular cues, they are more likely to generate valid and reliable patient responses than traditional vectograms.

A second characteristic of traditional convergence training procedures has been their lack of concern with instituting formal operations to facilitate patient motivation. The success of therapy, especially for young patients, often hinges upon the degree of motivation they have for engaging in training exercises. Operant conditioning techniques, which emphasize the use of response contingent reinforcers to provide motivation and immediate feedback for responding, have often been demonstrated to facilitate learning and performance.[4, 10, 11] Its use in facilitating convergence training and in improving convergence ranges has not yet been explored.

A third feature of traditional convergence training involves the actual method of training. Although training usually entails the presentation of progressively increasing convergence demands and the use of informal prompts (e.g., the use of a pointer in space to attain the appropriate degree of ocular convergence), a concern for formal programmed learning is usually lacking. Operant discrimination learning, with its emphasis on differential responding and discrimination facilitation techniques, offers a specific methodology which may enhance convergence performance.[4]

The use of RDS in an operant conditioning paradigm incorporating discrimination facilitating techniques would seem to be an effective method for improving convergence ability and binocular vision, especially in children. The initial experiment was conducted to determine whether that procedure is more effective in improving convergence than traditional vision training or orthoptic techniques. A second study was done in order to demonstrate that convergence training, rather than just exposure to stereograms, was the variable most responsible for improvement in convergence ability.

EXPERIMENT 1

METHODS

Subjects

There were four male children between the ages of 6 and 10. Three of these patients were diagnosed as intermittent exotropes and one as an accommodative esotrope with poor fusion ranges. All had demonstrated stereopsis (660 sec of arc) using the operant RDS test described by Cooper and Feldman.[4] According to the clinicians responsible for vision training, none of the children were making normal progress during training sessions in regard to improving convergence ability with vectograms and other standard clinical training procedures. Each of the children had received at least 6 to 10 sessions of convergence training using vectograms, prior to the experimental intervention, in which fusional ranges were recorded (all children had experienced additional sessions where vectogram convergence performances were unreported).

Apparatus

The RDS used for training convergence during experimental sessions were 100 ×

[a] SILO: a perceptual phenomenon noted during convergence and divergence. SI indicates that the target appears smaller and closer upon convergence, while LO indicates that the target appears larger and further away upon divergence.

[b] Localization: the distance perception changes which are due to vergence changes and are identified by pointing to where the target appears to be.

[c] Float: the subjective response indicating that the target appears to be suspended in space.

[d] Parallax: the apparent movement of the targets when the subject sways. It is due to convergence or divergence.

100 dot matrix slides (2 × 2) photographically reproduced from those pictured in *Foundations of Cyclopean Perception.*[8] The RDS slides were used to create two different pairs of stimuli. One pair contained a right and left slide so that binocular viewing resulted in a dot pattern seen with a central square in crossed disparity (660 sec of arc). The second pair contained two identical right eye slides paired so that no binocular disparity was present.

The RDS slides (average luminance = 816 cd/m^2) were projected by two Kodak model #650H Carousel projectors and were reflected off two 3.8 × 4.4 cm moveable front surface mirrors 8 cm from the projector. The mirrors could be automatically turned in small increments to create a base out fusion stimulus of from 0 to 40 prism diopters.

After the images were reflected by the mirrors, the images were passed through two linear polarizing filters mounted in front of the projector lenses at axis 45 and 135. The RDS was then rear-projected onto a 78 cm × 68 cm piece of clear Plexiglas sandblasted on the rear surface. Each patient was seated 40 cm from the Plexiglas screen so that the RDS subtended an angle of 10.2 deg to the patient.

Programming and sequencing of the stimuli, movement of the mirrors to alter fusional demands, delivery of reinforcers, and recording of the responses and trials were controlled by BRS solid state logic (TECH SERV, INC.) and electromechanical relay circuitry. Reinforcers were delivered by a BRS penny dispenser placed on the side of the viewing screen 70 cm from the child. Responses were made on two BRS illuminated push panels. The panels were 20 cm from the child and tilted 45 deg from horizontal. The right panel contained a centered two-dimensional darkened square. The left panel contained no square.

Procedure

During the first experimental session, the child wore polarizing glasses and was instructed to look at the screen. He was told that he would sometimes see an RDS containing an inner square "popping out" (crossed disparity; base out) and sometimes an RDS with no inner square (lacking stereoscopic disparity). During each experimental training session the two RDS's were presented successively. Each RDS appeared an equal number of times, but in random order, during a session. A correct response to the stimulus (indicated by an appropriate panel push) by the child resulted in the immediate delivery of a penny from the penny dispenser, the onset of a 3-sec positive feedback light cue, and verbal praise by the examiner. If that correct response was made to the RDS containing the inner stereo square, it also resulted in a movement of the mirrors which increased the convergence demand by 0.66 Δ on the next trial. No such mirror movement occurred for a correct response to the RDS without disparity. The first trial of each training session always contained an RDS in which the right and left views were superimposed, i.e., an RDS with a zero convergence demand from Donder's line. An incorrect response to either RDS resulted in the termination of the trial and stimulus presentation without delivery of a penny, the 3-sec cue light, or verbal praise. In addition, any incorrect response also resulted in a decrease in the convergence demand by 1.32 Δ on the following trial (up to the limit of zero demand). The failure of a child to make any response within the maximum 10-sec trial period was also considered as an error. The interval between trials, when the screen was dark, was fixed at 7.5 sec. Each experimental training session lasted approximately 20 min and contained about 100 trials or stimulus presentations. The final level of convergence demand reached was recorded (in prism diopters) at the end of each session. At this time the child was always given either a small toy or a number of pennies. If the pennies were selected, the exact amount was determined by the child's level of performance during RDS convergence training. Following the experimental session, vectogram base out (BO) ranges were measured (blur, break, and recovery points in prism diopters) using the Topper vectogram (Bernell Corp.).

RESULTS

Fig. 1 illustrates a typical initial RDS convergence training session of a child.

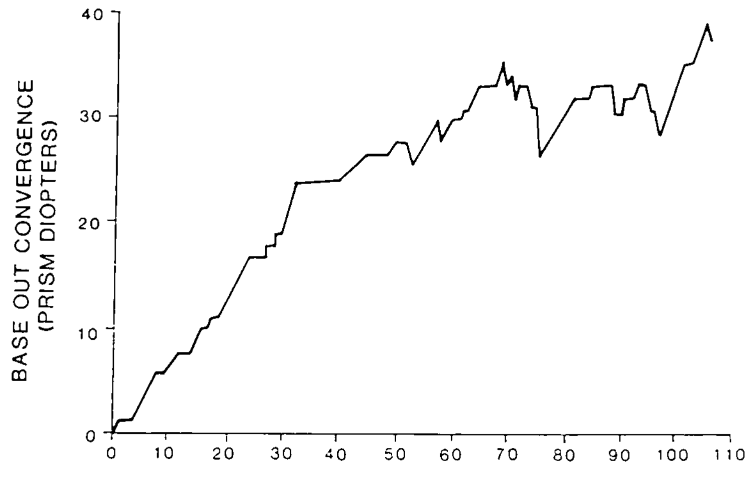

FIG. 1. Represents increases and decreases in convergence demand for patient PL during 105 trials during session 6 of operant RDS convergence training. Increases in the slope of the convergence line are a function of correct responses to disparity RDS of increased convergence demand. Plateaus or decreases in the slope of the convergence line represent correct responses to RDS without disparity or incorrect responses to either training stimulus, respectively.

Trials, or stimulus presentations, are plotted against fusional convergence demand. From this figure, it is apparent that when convergence demand is low, performance is better. When convergence demand approximates the recovery point, response errors occur (decreasing slightly subsequent convergence demand). With continued practice, improved performance reflects an increased ability to fuse the greater convergence demand stimuli. This is represented by an increase in the slope of the convergence line.

Figs. 2–5 depict the final RDS fusional convergence demand obtained by each patient at the end of each training session. The dashed vertical line separates the experimental procedure, operant RDS convergence training, from the vectogram performance levels attained during previous vision training. It is readily seen that all four patients showed dramatic improvements in RDS convergence ability during experimental training. Since vectogram convergence ranges also improved during RDS training, it can be assumed that the effects of RDS training transferred to vectogram testing. This improvement occurred in terms of both vectogram convergence break and recovery points.

Another indication of the effectiveness of RDS convergence training is represented by a general change in each patient's visual performance during subsequent regular vision training sessions. For patient JH, vectogram break and recovery points did not always correspond well with verbal report of size and distance localization.[e] Following RDS training, correspondence occurred regularly. In addition, prior to RDS training, cover testing indicated a 15 Δ intermittent exotropia at distance occurring approximately 50% of the time. After RDS training, an 8 Δ exophoria was measured via cover testing.

Patient PL, an intermittent exotrope who deviated both at distance and at near, showed changes similar to patient JH. Before RDS training, vectogram training yielded inconsistent findings in which reports of suppression on a good number of vectogram training trials predominated. After RDS training, fewer reports of suppression occurred along with obtained convergence ranges greater than 30 Δ.

[e] The vectogram break and recovery point data shown in Fig. 2 represent findings only on those trials in which correspondence occurred with verbal reports of size changes and distance localization.

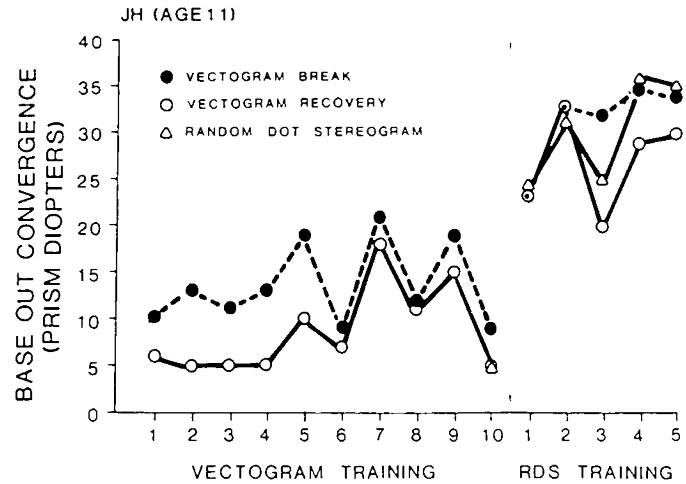

FIG. 2 SESSIONS

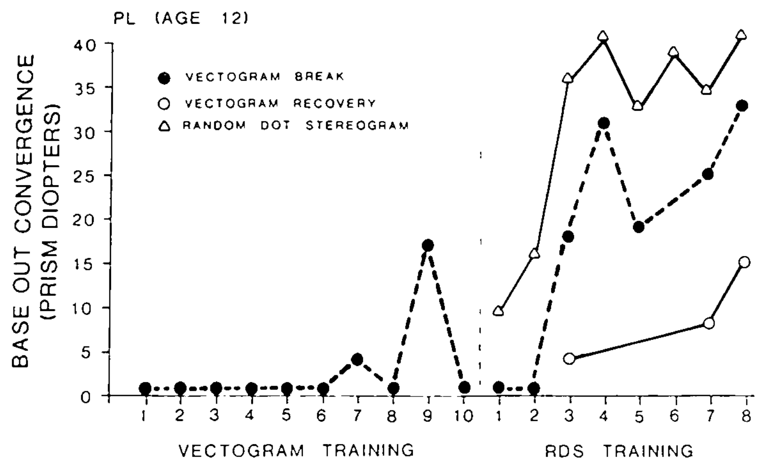

FIG. 3 SESSIONS

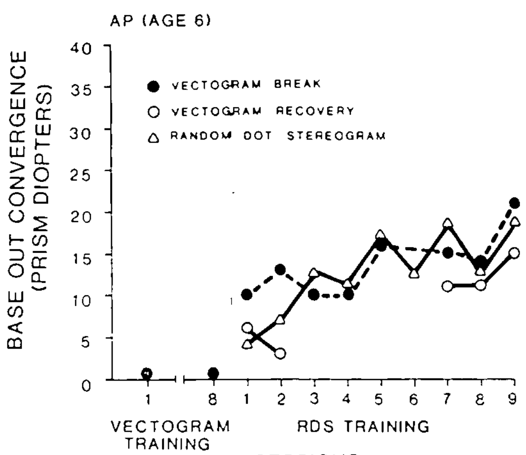

FIG. 4 SESSIONS

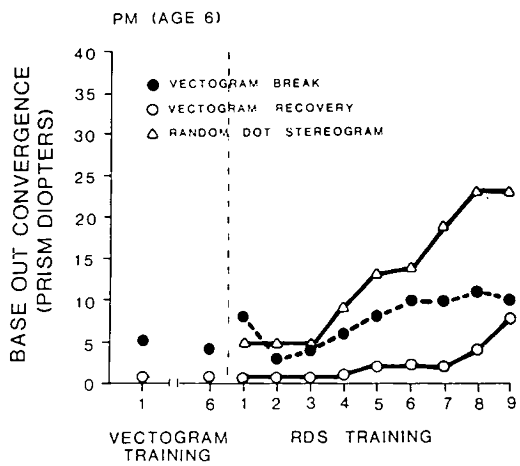

FIG. 5 SESSIONS

FIG. 2–5. Represents the final level of base-out convergence achieved by each of four patients during vectogram training sessions. Corresponding performance measures are presented during RDS training session (following vertical dashed line) for convergence training using RDS and convergence testing using Topper vectogram.

A third intermittent exotropic patient, PM, could only demonstrate 5Δ fusional convergence ranges prior to RDS training. Though his progress during RDS training was relatively slow, improvement in both RDS and vectogram convergence ability was achieved. Patient PM, like the other two intermittent exotropes, also demonstrated an improvement in controlling his deviation during subsequent cover testing (as reported by the referring clinician).

The fourth subject, patient AP, was an accommodative esotrope who demonstrated zero vectogram fusional ranges (wearing his correction) prior to RDS training. He also exhibited an inability to maintain attention after working for only a few minutes on vectogram tasks. Following RDS convergence training, improved motivation and task attention were noted, as well as increased fusional abilities during subsequent vectogram sessions. As a matter of fact, all four patients reported enjoying vision training and looking forward to subsequent sessions.

EXPERIMENT 2

The second experimental investigation was done to test whether the improved convergence ranges attained with the four patients in the first study were a result of stimulating convergence rather than just exposure to RDS using an operant conditioning procedure. The second study used normal adult subjects matched on initial convergence ability. One group was given the same type of RDS convergence training as patients in experiment 1. The other group received no increase in convergence demand during operant RDS training. Thus, the RDS stimuli remained at a zero convergence demand.

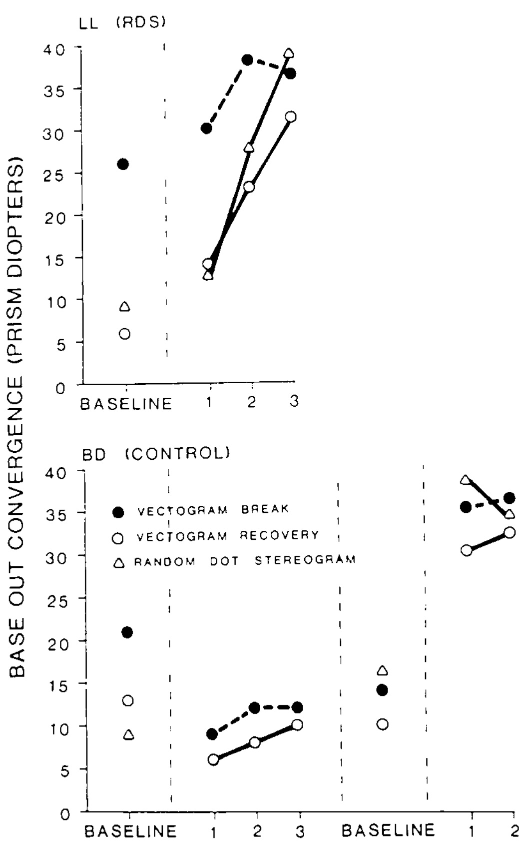

FIG. 6 SESSIONS

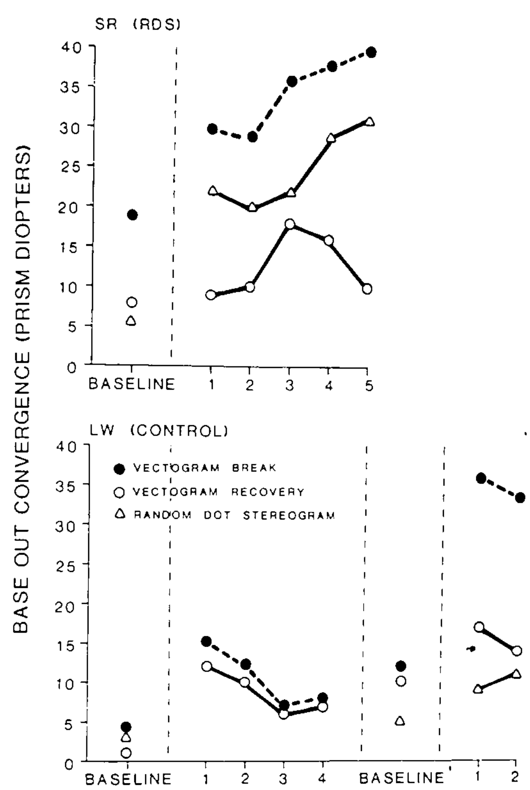

FIG. 7 SESSIONS

METHODS

Subjects

There were 6 males and 2 females between the ages of 21–25. All were students at the State College of Optometry. All had less than 25 Δ of convergence ability as demonstrated on the Topper vectogram, on RDS convergence pretests, and on phorometric testing using Risley prisms at 40 cm. The eight subjects were then matched according to average convergence ability and randomly assigned to one of two groups, experimental or control.

The apparatus and stimuli were the same as described previously. Both groups received the same instructions and experiences as had the patients in experiment 1 except that the convergence demand was always set at zero (superimposition of RDS) for the control group. After experimental subjects had received approximately four sessions of RDS convergence training, the control subjects received a second baseline convergence test. The control subjects then received RDS convergence training for two sessions.

RESULTS

Figs. 6–9 represent the performance of each matched pair of subjects during baseline and experimental sessions. The top panel depicts the RDS convergence training performance, as well as vectogram test performance, of the experimental subjects. The bottom panel shows the performance of control subjects. It is readily apparent that during RDS convergence training ses-

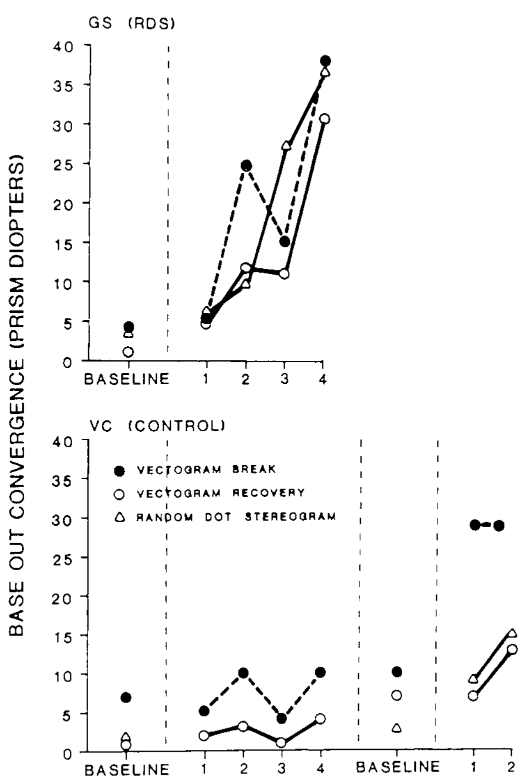

FIG. 8 SESSIONS

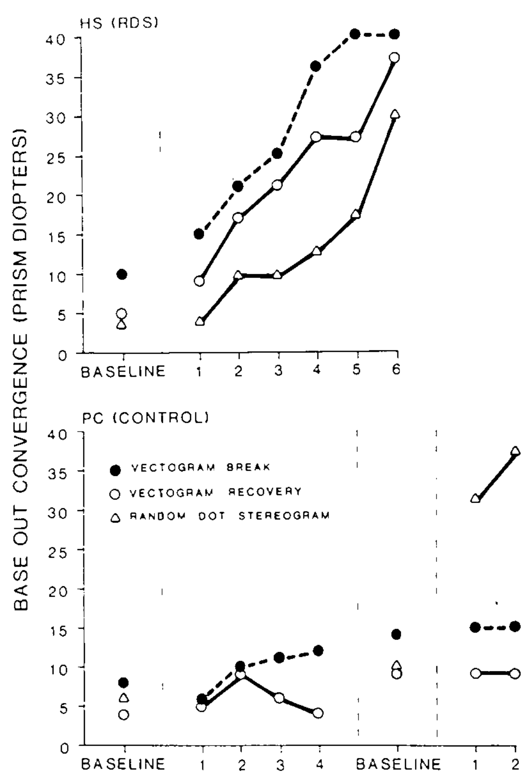

FIG. 9 SESSIONS

FIG. 6–9. Depicts the final level of base-out convergence performance during each session for four experimental subjects initially given RDS convergence training (top panel) and four matched controls initially exposed to RDS with zero convergence demand (lower panel). Vectogram testing and RDS convergence training task performances are presented. After exposure to zero RDS convergence demand stimuli, control subjects were given a second baseline which was followed by the same type of RDS convergence training as experienced by experimental subjects.

sions, both RDS and vectogram convergence ranges improved dramatically. However, during sessions in which RDS were presented without any convergence demand, the control subjects demonstrated little or no improvement in convergence ability as measured during vectogram testing. The second baseline assessment also supports the finding that the RDS and vectogram convergence ranges of the control subjects were about the same as during the initial baseline and significantly lower than that of the experimental subjects. However, when the control subjects received subsequent RDS convergence training, changes in RDS and/or vectogram convergence performances occurred.

DISCUSSION

All four young patients in the first experiment demonstrated similar results. Prior to RDS convergence training, little or no improvement in convergence ranges occurred with vectogram training during regular vision training sessions. Subsequent RDS convergence training resulted in a gradual increase in convergence ranges during each training session. Moreover, there was a concomitant transfer of convergence ability evidenced during vectogram testing. These findings occurred for all children within 5 to 10 RDS convergence training sessions.

The success of operant RDS convergence training was most likely related to the combined effects of a number of factors provided during training. For example, the use of RDS as training stimuli did not allow the use of monocular contour cues to aid responding as in vectogram training. Discrimination training presumably facilitated patients' attention to relevant cues differentiating stereograms with disparity from those not containing disparity, a feature not present in traditional vectogram training. Patient motivation and attention were directly manipulated and encouraged by the use of response-contingent positive reinforcement and immediate response feedback. The automated procedure used to present stimuli and record responses did not allow clinician bias in interpreting patient responses or unintentional prompting of patient answers. Furthermore, the whole procedure placed less emphasis on verbal communication skills of our young uncooperative patients. Finally, the precise and automatic manner in which preprogrammed changes in convergence demand took place was most likely a primary factor in generating large increases in convergence ranges. It is unlikely that such gradual and small incremental and decremental changes in convergence demand could have been accomplished during the course of standard vectogram training. Further controlled studies are planned in order to evaluate the relative contribution of each of the factors contained in the present procedure.

The second experiment demonstrated that improvement in convergence ranges was due to programmed increases in convergence demand rather than exposure to stereograms containing no convergence demand. Experimental subjects receiving RDS convergence training demonstrated increased convergence ranges, whereas control subjects did not. This finding, although not unexpected, supports the notion that strict attention should be paid to the manner in which changes in convergence demand are programmed in convergence training.

The findings from experiment 1 not only demonstrated a relatively direct transfer of convergence skills acquired during RDS training to standard vectograms, but also indicated that such training can affect more general binocular dysfunctions. For example, one of our young patients, originally exhibiting an intermittent exotropia prior to training, was found to have an exophoria following training. Thus, the operant RDS convergence training procedure might be helpful in reducing the amount of deviation in intermittent strabismics.

In summary, although the present operant RDS convergence training technique was performed with fairly sophisticated equipment, we feel that the general characteristics of the procedure might easily be translated into an effective and efficient clinical tool. The training of convergence skills, especially with young, poorly motivated, inattentive, and communicatively inexperienced patients, should always involve a procedure demanded by these patient characteristics. Thus, it is the clinician's responsibility to design training experiences incorporating such features as reinforcement, feedback, and programmed training.

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