THE COURSE OF ACQUISITION OF A LINE-TILT DISCRIMINATION BY RHESUS MONKEYS¹

BARBARA A. RAY²

MASSACHUSETTS GENERAL HOSPITAL

Each of four groups of monkeys was trained on a different simultaneous discrimination procedure involving a vertical line as the correct choice. Each group, after acquiring the discrimination, was tested for generalization along the dimension of line tilt. Monkeys that learned to select the vertical line when the alternative choices were distinguished from the correct choice by two aspects (brightness and absence of line) showed almost complete tilt generalization (flat gradient). Monkeys that learned to select the line when the alternatives were distinguished only by the absence of the line showed poor tilt discrimination (generalization gradient slightly peaked at vertical). Monkeys developed a good tilt discrimination when nonvertical lines were gradually introduced by progressively darkening them on the previously blank alternatives. Monkeys developed a tilt discrimination with the lowest error rate when only horizontal alternatives were gradually introduced and then pairs of alternatives progressively closer to vertical were made available.

CONTENTS

Method

Subjects

Apparatus

Preliminary Training

Procedure

Criterion discrimination procedure

Control Group and Groups 1 to 4.

Results

Groups 1 to 4 and Control Group

Correction for the Number of Times a Stimulus Appeared per Trial

Responses per Opportunity as a Function of Training History

White-Black Discrimination Training

Superimposing Line on Correct Key

Eliminating the Brightness Cue for Correct Choice

Progressive Darkening of Nonvertical Tilts on Incorrect Keys

Progressive Introduction of Tilts Closer to Vertical

Summary and Discussion

Discrimination among Stimuli Differentiated by Presence versus Absence of a 1)

Discrimination among Stimuli Differentiated by Presence versus Absence of a Form (Group 2)

Progressive and Simultaneous Introduction of a Range of Nonvertical Alternatives (Group 3)

Sharpening Line-Tilt Discrimination by Progressively Narrowing Tilt Difference between Alternatives (Group 4)

Number of Different Alternatives

Discrimination Training with No Programming of Stimulus Changes (Control Group)

This investigation compared the control by line tilt acquired by animals after different histories of discrimination training. Each training history represents a discrimination procedure currently used for establishing stimulus control. The rationale for their selection may best be explained by a brief discussion of the questions raised by these procedures concerning the acquisition of stimulus control.

A number of experiments have established that the mere presence of a stimulus at the time a response is reinforced is not a sufficient condition for the stimulus to gain control over

¹The work reported here was supported by Public Health Service Research Grant MH 05408 from the Institute of Mental Health. Reprints may be obtained from the author, Neurology Research, Massachusetts General Hospital, Fruit St., Boston, Mass. 02114.

²I wish to thank Drs. W. W. Cumming, M. Sidman, and H. S. Terrace for their advice and encouragement during the course of this research.

the response (Peterson, 1962; Ganz and Riesen, 1962; Jenkins and Harrison, 1960). Whether or not single-stimulus training establishes a discrimination between the training and other stimulus values seems to depend on variables not made explicit in the single-stimulus training procedure.

When single-stimulus training has failed to produce stimulus control, the desired control has sometimes been established by differential reinforcement of responding in the presence of two or more stimuli (Peterson, 1962; Jenkins and Harrison, 1960). Terrace (1966) has suggested that differential reinforcement of responding is necessary to establish stimulus control. However, even when training involves differential reinforcement of responding to two or more stimuli, control may be developed by one differentiating aspect of the stimuli and not by another. Reynolds (1961) reported a case in which two pigeons used different aspects of the training stimuli to accomplish what appeared to be the same discriminative performance. Warren (1953) found that monkeys learned, on the basis of color, a simultaneous discrimination among stimuli that varied in color, form, and size. Newman (1963) found pigeons used color to discriminate among stimuli that were distinguished by both color and the presence of a vertical line. Butter (1963), on the other hand, found pigeons would use both the color and tilt of a line as a basis for responding. These findings raise some questions concerning the procedures necessary to establish control over an organism's responding by a specified dimension of a stimulus. The experiments by Reynolds, Newman, and Butter indicate that where two stimulus dimensions distinguish the stimuli of a discrimination, it is not possible to predict which dimension or dimensions will control responding. For purposes of comparison to these studies, one group of subjects in the present experiment was taught to discriminate a key containing a vertical line from seven alternatives. Both the presence of the line and the background brightness distinguished the positive choice. The animals were later tested to determine how much control line tilt had over their responding.

In at least two experiments, control by a particular dimension of a stimulus was established by teaching animals to discriminate the presence of the training stimulus from its ab-

sence (Jenkins and Harrison, 1960; Newman, 1963). In the Jenkins and Harrison experiment, pigeons taught to discriminate the presence of a tone demonstrated control by its frequency. In Newman's experiment, monkeys taught to discriminate the presence of a vertical line demonstrated control by its tilt. These findings suggest that the behavior of an organism which has learned to discriminate the presence of a stimulus may be controlled by any variation in the stimulus. For this reason, a group of subjects in the present experiment was taught to discriminate a key containing a vertical line where only the presence of the vertical line distinguished the positive choice from the alternatives. Later the animals were tested for control by line tilt.

It has long been supposed that differential reinforcement of responding cannot establish stimulus control unless responses occur to the negative stimuli and go unreinforced (Skinner, 1938; Ferster, 1951). In some experiments, however, animals have been trained to discriminate between stimuli without making unreinforced responses or "errors" (Schlosberg and Solomon, 1943; Terrace, 1963a and 1963b). These experiments lead to the conclusion that extinction is not always a necessary feature of discrimination acquisition. In the present experiment, two groups of subjects were taught to discriminate line tilt by progressive procedures derived by analogy with procedures which had previously taught discriminations "errorlessly." It is hoped that the results will extend the analysis of variables affecting the acquisition of stimulus control without the extinction of inappropriate responding.

METHOD

Subjects

Eight young rhesus monkeys, all experimentally naive, served. Their weights ranged from 2.36 to 3.24 kg when shipped to the laboratory, and they were maintained at 80% of average weights under free-feeding conditions during the experiment. The average was obtained from weights measured over approximately four weeks. Their sole diet consisted of a daily quantity of 1-g Ciba banana pellets and a weekly 0.6-cc supplement of multiple vitamin solution. Most of the daily ration was delivered in the experimental chamber. Any

remainder was delivered in the home cages 30 min after a session ended.

Apparatus

Experimental chamber. Schematically diagrammed in Fig. 1, the chamber was 4 ft deep, 2 ft wide, and 4.5 ft tall. A space approximately 2 by 2 by 2 ft was partitioned off to contain the animal. The chamber was located in the middle of a room with three similar chambers being used for other experiments. The solid-state and relay programming equipment for all experiments lined the walls of the laboratory. No sound from the equipment was audible through the walls of the chamber.

Response matrix. A matrix of eight sandblasted Plexiglas keys, arranged in a square, was mounted 10 in. from the floor of the animal's cubicle in an aluminum panel that separated the animal from the stimulus projection apparatus (Fig. 1). Each key was circular with a diameter of 2 in. Adjacent keys were 0.75 in. apart and all eight were contained within an area 8 by 8 in.

Pellet delivery. A dimly illuminated food cup to receive 1-g Ciba banana pellets was mounted in the aluminum panel below and to the left of the response matrix. Pellets were dispensed from behind the aluminum panel by a Foringer pellet dispenser. During a session, the only light in the chamber came from the keys and the dimly illuminated food cup. The food cup was illuminated to help the animals locate the banana pellets.

Stimulus projection. In the rear of the chamber, a Kodak Carousel 35 mm slide projector stood on the floor and projected stimuli by means of two surface-silvered mirrors onto

the back of the keys (Fig. 1). Because of some play in the slide housing the position of the projected image varied from trial to trial. The variation was always horizontal and never exceeded 0.25 in. The vertical position of the slides was constant so that the tilt of a projected stimulus was not affected by the horizontal variation. A motor-operated shutter, mounted in front of the projector, kept light from the keys during an 8-sec intertrial interval. During the intertrial interval, the keys were dark and responses had no effect. At the end of the 8-sec period, the keys were illuminated with the stimuli for the next trial. Each slide in the projector contained the stimuli for all eight keys for a given trial. The projector was positioned so that each of the eight stimuli projected onto the back of the corresponding key. A hole punched in each slide allowed light to fall on one of 12 photocells mounted beside the rear of the response matrix. The particular photocell which received light on a given trial determined the correct key for that trial. These light signals were never visible to the animals.

Sequence of correct choices. A basic sequence was developed for the positioning of the correct choice on successive trials. The sequence repeated every 64 trials so that the session length of 60 trials ensured that the animals started at a different point in the sequence on successive sessions. The repeating sequence of 64 was arranged so that each key was correct eight times in the total sequence and no key position was correct more than twice in succession. When there were more than two kinds of stimuli per trial, each incorrect alternative varied in position so as to meet the same counterbalancing requirements. Extensive pilot data indicated that monkeys did not learn the sequence of 64 correct key positions as a basis for responding.

Whenever the end of a tray of slides was reached during a session, the last slide in the tray activated a photocell which automatically turned off the session. When this occurred, the tray was manually recycled and the session turned on until the total of 60 trials had been completed.

Recording equipment. A 20-pen Esterline Angus operations recorder provided a running account of responses during and between trials. The scheduling of trials, operation of the projector, delivery of reinforcement, and

Fig. 1. Experimental apparatus: (a) house light; (b) response matrix; (c) pellet tray; (d) feeder; (e) and (f) surface-silvered mirrors; (g) Kodak Carousel 35 mm slide projector.

recording of responses were all controlled by solid-state programming equipment.

Preliminary Training

When the animals first entered the box, the response matrix was covered by a sheet of Plexiglas painted black. Each monkey was magazine trained until the sound of a pellet being delivered would bring the animal to the food cup from anywhere in the cubicle.

All animals were trained to look toward the covered response matrix before any keys were exposed. The Control Group (see below) learned to press the keys when the cover was removed and all eight keys were white. One pellet was delivered for looking at the keys, one for approaching the keys, and the third pellet was usually delivered automatically when the monkey pressed one of the eight keys. This was continued until each Control-Group animal received 60 pellets for responding to the keys. All other animals were trained to press each key separately by covering all but one of the keys with a black mask. The exposed key was white. They received five pellets for responding to each of the eight keys, or 40 pellets in all. A more detailed description of the apparatus and preliminary training is available in Ray, 1966.

Procedure

Since the purpose of this investigation was to discover training procedures that might facilitate the learning of a criterion discrimination, and to chart the progress of acquisition of the discrimination, the criterion-discrimination procedure is described first.

Criterion-discrimination procedure. During each trial, a monkey was confronted with eight tilted lines simultaneously and rewarded for selecting the vertical line. A different tilted line appeared on each key of the response matrix. The tilts were designated by their deviation from vertical as follows: 0° , $+22.5^\circ$, -22.5° , $+45^\circ$, -45° , $+67.5^\circ$, -67.5° , and 90° . Each line was 0.25-in. wide when projected onto the keys. A trial began when the stimuli illuminated the keys and terminated as soon as the subject had pressed one or more keys and then released all keys. A pellet dropped into the feeder tray whenever a monkey responded to the vertical choice alone. If the animal pressed any other key, the trial terminated without reward even when a correct and incorrect re-

sponse were made simultaneously. Any response advanced the stimulus projector to the next trial.

The criterion-discrimination procedure was used as a training procedure (Control Group) to teach subjects to select a vertical line, and as a generalization test (Experimental Groups) to assess the effects of previous training procedures on the subjects' ability to select a vertical line.

Control Group (R7, R8). These two subjects were given extended training on the criterion procedure in order to assess its efficacy as a method for training the tilt discrimination. An arbitrary time limit, 43 to 45 daily sessions of 60 trials each, was placed on the length of training if the animal showed no evidence of tilt discrimination. One animal, R7, failed to develop a tilt discrimination during this time and was retrained as a Group 3 subject.

Group 1 (R10, R12). Before being tested on criterion discrimination, these subjects were taught to select one white key from among seven dark keys on each trial. The location of the white key in the matrix varied from trial to trial. Responses to the white key were reinforced until the subjects satisfied a predetermined level of accuracy, defined as fewer than four errors per 60-trial session for three consecutive sessions. When the subjects achieved the white-black discrimination at this level of accuracy, a black vertical line was superimposed on the white key at the beginning of the next session (Fig. 2, top row). When the subjects selected the white key containing the vertical line often enough to again satisfy the accuracy level, they were shifted to the criterion-discrimination procedure. One animal, R12, showed no tilt discrimination after six sessions on the criterion procedure. This lack of discrimination seemed to justify using R12 to investigate another training procedure. The animal was returned to the previous training conditions in which the correct key contained a vertical line. After satisfying the accuracy requirement again, R12 received additional training. (See Group 4).

Group 2 (R9, R14). Like the animals of Group 1, these subjects were taught to select the white key and then the black vertical line was superimposed on the white key. After the animals met the required level of accuracy, the brightness difference between correct and incorrect choices was removed. Gradually, the

Fig. 2. Schematic representation of stimulus changes during training.

brightness of the previously dark keys increased every 10 trials for 12 steps, taking two entire sessions, until all eight keys were equally bright (Fig. 2, second row). The series of brightness increases was prearranged and did not depend on behavior. The series was empirically derived in pilot work with monkeys not included in the present experiments. The materials used for photographing the slides comprising the series of progressive brightness increases can be found in Ray, 1966. After the series, the only cue which remained for correct choice was the presence of the vertical line on one of the eight keys. After reaching the required level of accuracy, the subjects were tested on the criterion discrimination.

Group 3 (R7, R11). This group was trained initially in the same way as Group 2. Subjects first learned to select a blank white key. Then a vertical line was added to the white key. Next, the brightness of the negative keys was increased until the subjects selected the one white key which contained the line. When these stages of training were complete, all seven nonvertical lines of the criterion discrimination were gradually introduced on the incorrect keys. This was accomplished by gradually darkening the nonvertical tilts from grey to black on the previously all-white keys (Fig.

2, third row). The incorrect tilts were darkened in 23 steps with eight and sometimes four trials at a step until they matched the vertical line in brightness. Again, the progression proceeded in a prearranged manner and did not depend on behavior. The series can be duplicated by reference to Ray, 1966. The progression took the better part of three sessions to complete. By the end of the third session, the criterion-discrimination procedure was in effect and was continued for all subsequent sessions.

Group 4 (R12, R15). This group served to test still another progressive method for introducing the criterion-discrimination procedure. Initial training was the same as that described for Group 2. The subjects learned to pick the white key; then to pick the white key with a line; and, finally, to select the key which contained a line when all keys were white. After meeting the accuracy requirement on all these prior discriminations, Group 4 was taught to select the vertical line from among seven horizontal lines. This was accomplished by progressively darkening horizontal lines from grey to black on the previously all-white keys (Fig. 2, fourth row). The technique was identical to that used in Group 3 except that all the nonvertical lines were horizontal. There were

two differences between this discrimination and the criterion discrimination. First, the tilt discrimination between vertical and horizontal was not as fine as that required by the criterion procedure, which presented alternatives tilted as little as $\pm 22.5^\circ$. Second, all of the negative keys contained lines at the same tilt, whereas on the criterion procedure each key contained a different tilt.

After the subjects had mastered the vertical-horizontal discrimination, alternatives which were somewhat closer to vertical, namely, $+67.5^\circ$ and -67.5° , were abruptly introduced on two keys each, so that each trial presented a choice among: one vertical line, three horizontal lines, two lines of $+67.5^\circ$, and two lines of -67.5° (Fig. 2, fourth row).

Once this discrimination was learned, alternatives still closer to vertical ($+45^\circ$ and -45°) were abruptly added. During this stage, subjects were offered a choice among: one vertical line, one horizontal line, one line of $+67.5^\circ$, one of -67.5° , two of $+45^\circ$, and two of -45° (Fig. 2, fourth row). This procedure was also maintained until the subjects reached the accuracy level of fewer than four errors per session for three consecutive sessions.

The abrupt introduction of lines tilted at $+22.5^\circ$ and -22.5° , completed the transition to the criterion-discrimination procedure, and presented the subjects for the first time with a different tilted line on each of the eight keys.

Experimental Questions

The procedures outlined above were designed to provide information concerning two aspects of discrimination learning.

Of primary interest was the effect which previous training would have on initial performance on the criterion procedure. The first 60-trial session on the criterion procedure provided generalization gradients for line tilt for each group. These initial gradients indicated the degree of control exerted by the dimension of line tilt over responses. Any peaking of the gradient around vertical was presumably the result of the training procedure used.

Of secondary interest was the performance during transitions from one training procedure to another, in particular, the errors made when subjects were confronted with a novel set of discriminative stimuli on the response matrix. When errors increased, the increase indicated that what the subjects had already

learned did not fully apply to the new combination of correct and incorrect choices.

RESULTS

Figure 3 shows the gradients obtained in each of the four experimental groups on the first day of the criterion procedure. The particular training history which preceded the generalization test is schematically represented for the four pairs of animals. The figure summarizes the accumulated effect of the various training programs in establishing the criterion vertical-tilt discrimination. For Groups 1 and 2, the gradients represent the first session in which nonvertical lines were offered as choices. Groups 3 and 4 had had previous experience with nonvertical choices in a different context. The effect on acquisition of the various training programs is most appropriately analyzed starting with the first time nonvertical lines were offered as choices. This is done in Fig. 4 through 7, which are discussed below.

Group 1 (R10, R12)

These animals were tested on the criterion procedure after having mastered the discrimination in which both the line and the brightness of the correct key could have provided bases for correct choice. This training produced poor tilt discrimination. Monkey R10 responded to the vertical choice more often than to the other tilts, indicating some degree of tilt discrimination. The gradients from the next five sessions on the criterion procedure (Fig. 4), indicated the same slight preference for the vertical line. With continued training (not shown), the generalization gradients sharpened until Monkey R10 finally made fewer than four errors per session for three consecutive sessions.

Monkey R12, on the other hand, failed to show any preference for vertical on the first day of testing. The succeeding five days on the criterion procedure (Fig. 4) confirmed that the animal's responses were not systematically related to line tilt. At that point, testing of Monkey R12 was discontinued and the animal was trained further as a Group 4 subject.

Group 2 (R9, R14)

Figure 3 shows that both animals in Group 2, for which the presence of the vertical line had been the only cue for a correct choice,

FIRST DAY ON CRI-
TERION PROCEDURE

TRAINING HISTORY

Fig. 3. Generalization gradients from the first session on the criterion-discrimination procedure as a function of training history. Note that the data point for the 90° alternative is plotted at both ends of each gradient.

Fig. 4. First six sessions on the criterion-discrimination procedure. Group 1.

demonstrated a slight preference for the lines closest to vertical. Monkey R9 continued to show this preference for the next five days on the criterion procedure (Fig. 5). With continued training, however, both animals eventually developed a vertical tilt discrimination which satisfied the three-day accuracy requirement.

Group 3 (R7, R11)

In Group 3, the first session on the criterion procedure came after all the possible nonvertical tilts had progressed from grey to black on the incorrect choices. The progression had taken three sessions to complete. Figure 3 shows the gradient on the first day in which all the lines were black. The animals' pref-

Fig. 5. First six sessions on the criterion-discrimination procedure. Group 2.

erence for vertical or near-vertical lines is quite clear and much more pronounced than it was for any of the animals in Groups 1 and 2. The gradients obtained during the progression from grey to black, and for the succeeding three days on the criterion procedure, are shown in Fig. 6. Both animals responded almost exclusively to the vertical line during the first session involving grey lines on the incorrect keys. By the second session, the animals were making a few more responses to the non-vertical tilts, but the maximum number was only five responses to $+45^\circ$ (Monkey R11). In the third session, the change from grey to

Fig. 6. Three sessions during which nonvertical tilts darkened from grey to black on incorrect keys and followed by three sessions on criterion-discrimination procedure. Group 3.

black was completed near the end, and the gradients were the flattest observed during the entire training of these animals, with the majority of errors occurring at $\pm 22.5^\circ$. The gradient progressively sharpened during succeeding days on the criterion procedure until the animals satisfied the accuracy requirement.

Group 4 (R12, R15)

The responses of Monkeys R12 and R15 on the first day of the criterion procedure are shown as the bottom pair of gradients in Fig. 3. This was the first day that lines of $\pm 22.5^\circ$ had appeared as choices. The monkeys responded most frequently to vertical and made all their errors either to $+22.5^\circ$ or -22.5° .

Figure 7 shows gradients from these same monkeys obtained while horizontal lines were being darkened on seven keys, and whenever new alternatives appeared abruptly on the key matrix. The first three gradients for each animal show their responses to 0° and 90° while the 90° line was being darkened on the incorrect keys. The fourth gradient represents their responses during the next session when the horizontal lines were black. The remain-

Fig. 7. Generalization gradients for: (a) three sessions during which 90° (horizontal) gradually darkened on incorrect keys, (b) the next session, in which the 90° alternatives were black, (c) first session in which $\pm 67.5^\circ$ abruptly introduced, (d) first session in which $\pm 45^\circ$ abruptly introduced, and (e) first session on criterion-discrimination procedure. Gradients for $\pm 67.5^\circ$, $\pm 45^\circ$, and $\pm 22.5^\circ$ follow sessions (not shown) in which the animals reached the required accuracy for the preceding tilt discrimination.

ing gradients represent the introduction of lines tilted at $\pm 67.5^\circ$, $\pm 45^\circ$, and $\pm 22.5^\circ$, respectively. Monkey R12 made almost all its errors to the $\pm 22.5^\circ$ alternatives. This animal had previously been tested for six days on the criterion procedure in Group 1 and had failed to exhibit any evidence of tilt discrimination (see above). Monkey R15 made most of its errors to 90° and $\pm 22.5^\circ$. This animal had no previous experience with the criterion procedure. With continued training on the criterion procedure, both animals satisfied the accuracy requirement.

Control Group (R7, R8)

Of the animals trained from the outset on the criterion procedure, one monkey learned to discriminate tilt, but the other did not. The error rate for Monkey R8 gradually declined to zero, whereas Monkey R7 failed to show any change in error rate over the course of 43 days. The distribution of responses to the various tilted lines are presented for each animal separately in Fig. 8 and 9. The distributions represent the first day of training on the criterion procedure and performances after successive tenths of their total training. The first peaked gradient for Monkey R8 includes a high rate of responding to lines tilted at $\pm 22.5^\circ$ from vertical. In general, responding to these tilts was the last to disappear before the monkey achieved the accuracy level of fewer than four errors per session for three consecutive sessions.

Monkey R7 might eventually have developed the discrimination if it had remained long enough on the procedure. However, the fact that 43 days produced near-perfect tilt discrimination in one animal, and none in the other, indicated the large influence of uncontrolled factors in the training method. Monkey R7 later learned to discriminate tilt as a Group 3 subject.

Correction for the Number of Times a Stimulus Appeared per Trial

To compare the results from Groups 3 and 4, it was necessary to correct for the fact that a particular tilt sometimes appeared more than once per trial in Group 4. For example, in Group 4, horizontal lines appeared on seven keys simultaneously before any other nonvertical tilts were made available. During this period, any pattern of responding which was

random with respect to the stimuli appearing on the keys would automatically have produced a 7:1 preference for horizontal over vertical. Consequently, in Fig. 10, the total number of responses to horizontal lines was divided by seven when these lines appeared

Fig. 8. Generalization gradients selected at successive tenths of training on the criterion-discrimination procedure. Monkey R7.

Fig. 9. Generalization gradients selected at successive tenths of training on the criterion-discrimination procedure. Monkey R8.

on seven keys. Likewise, total responses to $+67.5^\circ$ were divided by two when that particular stimulus appeared twice in every trial, and so forth, for each individual tilt. In this way, the apparent imbalance created by the unequal number of opportunities to press a particular tilt was eliminated from the comparisons.

Responses per Opportunity as a Function of Training History

The conditions under which the nonvertical tilts were first introduced varied according to the particular experiment. In Groups 1 and 2 all the nonvertical tilts were introduced simultaneously and abruptly after different

Fig. 10. Errors to each nonvertical tilt during the first six sessions it appeared as a choice. Errors are corrected for the number of times a particular tilt appeared per trial.

training histories. In Group 3, they were also introduced simultaneously, but were changed gradually from grey to black. In Group 4, the nonvertical tilts were introduced at different points in training; the horizontal lines appeared first and were gradually changed from grey to black, and later, other nonvertical lines were abruptly introduced.

Figure 10 shows the effect of training history upon subjects' initial tendency to respond to a particular deviation from vertical. The animals in Group 1, which had had both the vertical line and brightness available as a cue for correct choice, made many more responses to all of the nonvertical tilts than the animals in Groups 3 and 4. The animals in

Group 2 also responded heavily to nonvertical tilts when they were first introduced, even though their previous cue for correct choice had been presence of the vertical line.

The gradual darkening of nonvertical tilts that took place in Group 3 greatly reduced the maximum level of responding to all nonvertical tilts except $\pm 22.5^\circ$. When all lines became black (indicated by arrows about the curves in Fig. 10), the Group 3 animals were responding most frequently to $\pm 22.5^\circ$ and then, in decreasing order, to $\pm 45^\circ$, $\pm 67.5^\circ$, and 90° . This ranking of number of responses in the order of size of deviation from vertical was not apparent in Group 4. The responses to $\pm 22.5^\circ$ were at a high level as in the other three groups, but it is difficult to distinguish $\pm 45^\circ$, $\pm 67.5^\circ$, and 90° in terms of initial tendency to respond. Apparently, the animals' history of rejecting more remote tilts effectively reduced their initial tendency to respond to each new tilt until $\pm 22.5^\circ$ lines were introduced.

White-Black Discrimination Training

All but one of the seven animals trained on the simple white-black discrimination mastered it within 10 days. Monkey R14 took about 20 days. Monkey R7, which had not learned the criterion discrimination in 43 days, took 10 days to learn the white-black discrimination. Compared to training on the criterion procedure, the white-black discrimination gained faster control over responding with all animals but one, reaching criterion accuracy within 10 sessions.

Superimposing Line on Correct Key

After the animals had learned the white-black discrimination, a vertical line was suddenly added to the white key. Superimposing this line temporarily increased errors by several of the subjects. The tendency to pick dark keys increased for Subjects R7, R9, R10, R11, and R14 as soon as the black vertical line was added to the correct choice. The effect disappeared in one or two sessions. Monkeys R15 and R12 did not show an increase in errors when the line was added to the correct key.

Eliminating the Brightness Cue for Correct Choice

As long as the incorrect keys remained black, the animals had two bases for making

a correct choice: (a) the presence of the vertical line on the correct keys, and (b) the brightness difference between the correct and incorrect choices. During the gradual change of the incorrect keys from black to white, the tendency to press keys which did not contain a line gradually increased. The maximum number of errors per session made by each animal covered a wide range. The maximum values expressed as a percentage of 60 trials, were as follows: R7—7%, R9—32%, R11—90%, R12—70%, R14—17%, and R15—68%. Monkey R12 made so many errors, during the transition and after, that control by the stimuli on the keys appeared to have been lost. Stimulus control reappeared four days after the transition had been completed. A rapid increase in errors by Monkeys R11 and R15, during progressive brightening of the incorrect keys, suggested that stimulus control would disappear when the keys were fully bright, as it had for R12. Therefore, the progression was reinitiated for this pair of animals. The second series of brightness increases produced fewer errors than had the first. This suggested that the behavior of Monkeys R11 and R15 had been modified to some extent by the first progressive brightening of the incorrect keys.

The increase in errors made by all animals as the brightness increased on the incorrect keys, indicated that brightness remained an important cue to the animals even after the vertical line was available as a basis for choice. This was not surprising, since the animals had been taught to discriminate brightness in their initial training. Although it produced errors, equalizing the brightness of all the keys transferred stimulus control to the line.

Progressive Darkening of Nonvertical Tilts on Incorrect Keys

Nonvertical alternatives were gradually introduced in Groups 3 and 4 by darkening the lines on the white background. For Group 3, all nonvertical alternatives were introduced simultaneously; for Group 4, only the horizontal alternative was introduced by progressive contrast changes. When only the horizontal alternative was introduced progressively (Group 4) during the transition, Monkey R12 made a maximum of two errors per session and Monkey R15 a maximum of 17 errors per session to the horizontal alternatives. When all seven nonvertical tilts were introduced pro-

gressively (Group 3) during the transition, Monkey R7 made a maximum of 38 errors and R11 a maximum of 32 errors per session.

Progressive Introduction of Tilts Closer to Vertical

After the discrimination between horizontal and vertical was well established (Group 4), the abrupt introduction of $+67.5^\circ$ on two keys and -67.5° on two keys failed to disrupt responding to vertical. Figure 11 shows that Monkey R12 did not respond at all to $+67.5^\circ$ or -67.5° when they were introduced. Figure 12 shows that Monkey R15 made a few responses to these new lines, and continued to respond to them at a low level for the following 13 days.

When $+45^\circ$ lines were introduced on two keys and -45° lines on two keys, Monkeys R12 and R15 made a few responses to these new alternatives (Fig. 11 and 12). However, both animals continued to respond to vertical and rarely, if at all, responded to lines which deviated from vertical by more than 45° . Apparently the initial horizontal-vertical discrim-

ination, followed by the discrimination among $+67.5^\circ$, -67.5° , 90° , and vertical lines provided the animals with a basis for the finer discrimination; it was not necessary to introduce the $+45^\circ$ and -45° lines gradually.

The greatest behavioral change occurred when lines of $+22.5^\circ$ and -22.5° were introduced. It can be seen from Fig. 11 and 12 that Monkeys R12 and R15 responded to these lines, considered together, almost as often as they responded to vertical. With continued training, Monkey R12 responded progressively less often to $+22.5^\circ$ and -22.5° . Monkey R15, on the other hand, continued to respond to these lines at the same rate for a longer period of time. Both animals tended to increase slightly their choices of more remote non-vertical tilts as long as their errors to $\pm 22.5^\circ$ continued.

SUMMARY AND DISCUSSION

Discrimination among Stimuli Differentiated by More than One Aspect (Group 1)

Group 1 had learned to discriminate between stimuli differentiated by (a) background brightness (white *versus* black) and (b) presence and absence of a black vertical line. The line itself had several aspects to which the animals might have attended, for example, tilt, length, width, color, *etc.* Monkey R10's

Fig. 11. Errors produced by each of the nonvertical tilts as they were introduced in Group 4. Monkey R12.

Fig. 12. Errors produced by each of the nonvertical tilts as they were introduced in Group 4. Monkey R15.

gradient was slightly peaked at vertical (Fig. 4), indicating that tilt was one aspect of the positive stimulus which had gained control of its behavior. Monkey R12 failed to demonstrate any tilt discrimination in six days on the criterion procedure (Fig. 4). The generalization gradients from this group confirmed Reynolds' (1961) finding that subjects may not use all available aspects to discriminate among stimuli.

A difference in the performance of animals R10 and R12 was apparent when the vertical line was abruptly added to the white choice during earlier training. Monkey R10 made 13 errors and Monkey R12 made only one. For Monkey R10 this constituted an increase in its error rate; for Monkey R12 it did not. The fact that Monkey R10 temporarily switched to picking black keys suggests that some aspect of the line exerted control over its behavior since introduction of the line changed its behavior. These errors may have been an earlier indication of a tilt discrimination that was later confirmed in the generalization test, or they may have indicated control by some other aspect of the line, such as its black "color", which later developed into control by line tilt. The fact that adding the line did not change the behavior of Monkey R12 might have predicted the flat generalization gradient later obtained from this animal during the generalization test. The failure of Monkey R12's to make errors, however, does not preclude the possibility that the line served to control its behavior.

*Discrimination among Stimuli
Differentiated by Presence versus
Absence of a Form (Group 2)*

Procedure for these animals differed from that in Group 1 in only one respect: the brightness cue for correct choice was removed by gradually brightening the incorrect keys to white after the vertical line had been superimposed on the correct choice. Their behavior indicated that they discriminated the presence of the line on the correct key, but at this point there was no way to know what aspects of the line accounted for the control. During the later generalization test (Fig. 5) both animals demonstrated that line tilt exerted some control over their behavior, but the flatness of their gradients compared to those from Groups 3 and 4 may indicate additional sources of

control by other aspects irrelevant to the tilt discrimination.

Eliminating the brightness cue by gradually increasing the brightness of the black keys did transfer control to the line, but not without many errors by some of the subjects. Those which made many errors indicated a clear difference between these results and those reported by Terrace (1963a), who used a similar progressive procedure to teach pigeons a red-green discrimination. Terrace trained pigeons to peck a red key and not to respond when the same key was dark. By gradually changing the negative stimulus from dark to green, Terrace was able to establish a red-green discrimination without errors. It should be pointed out that changing the negative keys from black to white, in the present study, introduced a previously positive stimulus on the incorrect alternatives. The green light in Terrace's study had not been encountered by his subjects during previous training in the experimental chamber. This difference may account for the failure to achieve an errorless transfer in the current study.

*Progressive and Simultaneous
Introduction of a Range of Nonvertical
Alternatives (Group 3)*

With the gradual introduction of alternative stimuli that narrowed the basis for discrimination down to tilt (Monkeys R7 and R11), sharp control was established by the tilt dimension. This is consistent with previous findings that generalization gradients are more sharply peaked after differential reinforcement along a dimension than after training with single stimuli from the dimension (Pierrel, Sherman, and Fischman, 1963; Hanson, 1957; Reinhold and Perkins, 1955). However, the progressive introduction of nonvertical alternatives established, in three sessions, a degree of control by line tilt that took many more sessions to establish after these same alternatives were abruptly introduced (compare Fig. 5 and 6). The animals responded to nonvertical lines as these were gradually introduced, but at all times the distribution of responses was sharply peaked at vertical. The progressive and simultaneous introduction of nonvertical alternatives transferred control to the tilt dimension and the transfer cannot be attributed to the extinction of inappropriate responding.

In analyzing the advantages that a progres-

sive procedure for transferring stimulus control may have over an abrupt procedure, two differences seem especially noteworthy. First, the progressive procedure provides the subject with a stimulus difference that controls responding when a new dimension of stimulus difference is introduced. This is also true when stimuli are superimposed that differ in both a controlling and a new dimension. Secondly, the gradual attenuation of a controlling stimulus difference may work to enhance the probability of a new difference gaining control of responding. Terrace (1963*b*) found that superimposing horizontal and vertical bars on the red and green stimuli of an established discrimination facilitated transfer to a discrimination of horizontal and vertical. The transfer was effected without errors, however, when the red and green stimuli were removed gradually instead of abruptly. As the red and green stimuli became less intense, a point may have been reached where behavior came under the control of both aspects of the composite stimuli.

Sharpening Line-Tilt Discrimination by Progressively Narrowing Tilt Difference between Alternatives (Group 4)

Responses to nonvertical alternatives were reduced when the tilt discrimination was established using a large tilt difference (90°) and then progressively reducing the size of the difference between the correct choice and alternatives.

The animals in Group 4 (Monkeys R12 and R15) learned to discriminate vertical from horizontal by the progressive transfer method used in Group 3. The procedure was effective, as it had been in Group 3, in transferring control of their behavior from stimuli distinguished by the presence and absence of a line, to stimuli distinguished by tilt of line (Fig. 7). Alternatives were then added which required a progressively finer discrimination of tilt. The small number of initial responses to $\pm 45^\circ$ (Fig. 10) indicated that a history of rejecting tilts more remote from vertical reduced the probability of responding to $\pm 45^\circ$ before they were actually introduced. This result agrees with findings of Baker and Osgood (1954), Lawrence (1952), Schlosberg and Solomon (1943), and Pavlov (1927), who all found that gradually reducing the difference between discriminative stimuli along a continuum was

more effective in teaching a fine discrimination than starting with a small difference at the beginning of training.

The errors to $\pm 22.5^\circ$ were not reduced in either Group 4 or Group 3. If the progressive procedures had any effect on the initial errors to $\pm 22.5^\circ$, it was to increase them compared to Groups 1 and 2 (Fig. 10). This suggests that the animals had a sharp tilt discrimination, but that $\pm 22.5^\circ$ lines were treated as positive stimuli. Since all animals eventually ceased to respond to $\pm 22.5^\circ$, the effect cannot be attributed to their inability to discriminate between 0° and $\pm 22.5^\circ$. In Group 4, initial errors to $\pm 45^\circ$ were reduced, compared to Group 3, by a history of rejecting more remote tilts. It is possible that initial errors to $\pm 22.5^\circ$ would have been similarly reduced by a history of rejecting tilts very close to $\pm 22.5^\circ$, but slightly more remote from vertical. The inclusion of values between $\pm 45^\circ$ and $\pm 22.5^\circ$ should reduce errors to $\pm 22.5^\circ$ in Group 4 as a result of the animals' discrimination history. The inclusion of these same values in Group 3 should not reduce errors to $\pm 22.5^\circ$, since all of the alternatives were introduced at the same point in the animals' discrimination history.

Number of Different Alternatives

In Group 4, the number of different alternative tilts was increased gradually from two (0° and 90°) to eight (0° , $\pm 22.5^\circ$, $\pm 45^\circ$, $\pm 67.5^\circ$, and 90°). In Group 3, the increase was abrupt from two choices (line and white keys) to eight (0° , $\pm 22.5^\circ$, $\pm 45^\circ$, $\pm 67.5^\circ$, and 90°). Data from a pilot experiment have shown that a multi-valued discrimination may deteriorate when the number of values presented simultaneously is increased. In the pilot study, a monkey learned to discriminate a vertical line from all of the nonvertical lines used in this study. The various tilts were, however, programmed somewhat differently. One key on the response matrix contained a vertical line on every trial. The position of the correct choice was varied. Only one other key was white and contained one of the seven possible nonvertical lines. The position of the nonvertical alternative was varied. The remaining six keys were dark.

The subject learned to press the key containing the vertical line and to reject each of the nonvertical tilts when they appeared as the alternative. Under these conditions, the ani-

mal was discriminating vertical with about 75% accuracy. At this point, the monkey was tested with all eight tilted lines presented simultaneously. Accuracy dropped to about 33%, as indicated by the first pair of bars in Fig. 13. Later, the discrimination was reestablished with only one nonvertical alternative presented on a trial. Accuracy rose to about 95%. The number of alternatives presented simultaneously was again increased, this time to two. Accuracy dropped to 58%. Performance gradually improved to 98% accuracy and the number of simultaneous alternatives was then increased to three. Accuracy dropped to 84%. Further increases in the number of keys containing nonvertical lines continued to produce an initial increase in errors until a total of five negative keys contained lines. Additional increases to six and seven alternatives failed to affect accuracy.

One possible explanation for the disrupting effect of increasing the number of alternatives presented simultaneously may lie in the behavior necessary to scan a number of different alternatives effectively. A wide-angle lens allowed observation of the animals during various phases of training. Casual observation revealed that the monkeys rarely moved their heads about in front of the matrix when all seven negative keys contained the same stimulus. On the criterion procedure, however, a monkey would frequently inspect several different keys before making a choice. It is reasonable that the pattern of scanning the alter-

natives in a simultaneous discrimination would affect accuracy, since the scanning would determine not only whether all alternatives were observed, but also which alternatives were directly compared.

The fact that the number of different alternatives was increased somewhat gradually in Group 4 may have been a factor in establishing effective scanning behavior and thereby reduced errors in this group.

Discrimination Training with No Programming of Stimulus Changes (Control Group)

The outstanding feature of discrimination acquisition for this group appeared to be its unpredictable time course. Monkey R8 began to respond on the basis of tilt after 25 sessions and reached criterion accuracy after 47 sessions. Monkey R7 responded without regard to line tilt (generalization gradient of zero slope) for 43 sessions, at which point training was discontinued.

A closer examination of the monkeys' behavior during training indicated why Monkey R8 developed a tilt discrimination and Monkey R7 did not. Both animals developed a preference for the response keys closest to the feeder tray. This pattern of responding was occasionally reinforced when the vertical line appeared in one of these positions. Throughout training, Monkey R7 responded to at least three key positions in a session. Temporary imbalances in the distribution of reinforcements among the three keys possibly caused position to compete with line tilt for control of responding.

Monkey R8 eventually responded to a single key position for one entire session. Responding to a single key limited differential reward to the dimension of line tilt. In the following session, Monkey R8 made a few responses to other keys and the significance of these responses was immediately reflected in the shape of the generalization gradient. The gradient was of nonzero slope and centered around 0° (Fig. 9). In succeeding sessions, Monkey R8 responded to keys progressively more remote from the initially preferred position until it responded only to 0° and distributed its responses equally among the eight key positions. In a sense, this animal had successfully programmed its own training conditions. Its behavior implied that had the various tilts been

Fig. 13. Data from a single monkey showing the proportion of trials correct as a function of increases in the number of keys containing a nonvertical alternative. The solid bars indicate the proportion of trials correct in the session before the increase; the broken bars indicate the proportion of trials correct in the session after the increase.

sequentially presented on a single key, a tilt discrimination might have developed more quickly. Its behavior further indicated that the transfer to an eight-keyed simultaneous discrimination would have developed control by key-position, at least temporarily.

In general, the course of acquisition of the line-tilt discrimination was more unpredictable in the Control Group than in Groups 3 and 4. In the Control Group, it was left largely to the animals to discover patterns of behavior that would lead to reinforcement, and patterns *e.g.*, position habits, developed which made inefficient contact with the reinforcement contingencies. In Groups 3 and 4, the training program was designed to maintain control of appropriate behavior as acquisition progressed.

The results from the Control Group show that an animal may not learn to discriminate line tilt after fairly prolonged training involving differential reinforcement of responding to tilted line stimuli. The results from the Experimental groups show that the responses made when an animal learns to discriminate line tilt depend on the animal's discrimination history. An animal's history will determine whether responses to nonvertical stimuli are extinguished by determining whether these responses occur. In the case of an animal taught to discriminate stimuli differing in more than one aspect, it is not possible to predict which aspect or aspects will gain control for an individual animal (Group 1). For an animal taught to discriminate the presence of a form, a single dimension of the form, like line tilt, may exert only weak control, if any at all (Group 2). The transfer from control by the presence of a line to control by tilt of the line is facilitated when lines that vary in tilt are introduced gradually rather than abruptly (Groups 3 and 4). It is presumably crucial in the gradual procedure that control by line tilt develop before all other cues to correct choice have been eliminated.

REFERENCES

Baker, R. A. and Osgood, S. W. Discrimination trans-

- fer along a pitch continuum. *J. exp. Psychol.*, 1954, **48**, 241-246.
- Butter, C. M. Stimulus generalization along one and two dimensions in pigeons. *J. exp. Psychol.*, 1963, **65**, 339-346.
- Ferster, C. B. The effect on extinction responding of stimuli continuously present during conditioning. *J. exp. Psychol.*, 1951, **42**, 443-449.
- Ganz, L. and Riesen, A. H. Stimulus generalization to hue in the dark-reared macaque. *J. comp. physiol. Psychol.*, 1962, **55**, 92-99.
- Hanson, H. M. Discrimination training effect on stimulus generalization gradient for spectrum stimuli. *Science*, 1957, **125**, 888-889.
- Jenkins, H. M. and Harrison, R. H. Effect of discrimination training on auditory generalization. *J. exp. Psychol.*, 1960, **59**, 246-254.
- Lawrence, D. H. The transfer of a discrimination along a continuum. *J. comp. physiol. Psychol.*, 1952, **45**, 511-516.
- Newman, F. Stimulus generalization of angular orientation following non-differential and differential conditioning. M. A. Thesis, Kent State University, 1963.
- Pavlov, I. P. *Conditioned reflexes*. (Translated by G. V. Anrep). London: Oxford University Press, 1927.
- Peterson, N. Effect of monochromatic rearing on the control of responding by wavelength. *Science*, 1962, **136**, 774-775.
- Pierrel, Rosemary; Sherman, J. G., and Fischman, Marion W. Generalization of auditory intensity as a function of small amounts of discrimination training. *J. exp. Anal. Behav.*, 1963, **6**, 545-548.
- Ray, B. A. The course of acquisition of a line tilt discrimination by rhesus monkeys. Unpublished doctoral dissertation. Columbia University, 1966.
- Reinhold, D. B. and Perkins, C. C. Stimulus generalization following different methods of training. *J. exp. Psychol.*, 1955, **49**, 423-428.
- Reynolds, G. S. Attention in the pigeon. *J. exp. Anal. Behav.*, 1961, **4**, 203-208.
- Schlosberg, H. and Solomon, R. L. Latency of response in a choice discrimination. *J. exp. Psychol.*, 1943, **33**, 22-39.
- Skinner, B. F. *The behavior of organisms*. New York: Appleton-Century-Crofts, 1938.
- Terrace, H. S. Discrimination learning with and without "errors." *J. exp. Anal. Behav.*, 1963a, **6**, 7-27.
- Terrace, H. S. Errorless transfer of a discrimination across two continua. *J. exp. Anal. Behav.*, 1963b, **6**, 223-233.
- Terrace, H. S. Stimulus control. In W. K. Honig (Ed.), *Operant Behavior: Areas of Research and Application*. New York: Appleton-Century-Crofts, 1966, 271-344.
- Warren, J. M. Additivity of cues in a visual pattern discrimination by monkeys. *J. comp. physiol. Psychol.*, 1953, **46**, 484-486.

Received July 11, 1966