EARLY AND LATE INTRODUCTION OF PROBES AND STIMULUS CONTROL ACQUISITION IN FADING

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College students learned to name Braille patterns presented visually using a fading procedure in which Braille patterns were superimposed on letter names after which letter names were attenuated. Measurement of acquisition was accomplished by presenting probes—consisting of the Braille stimuli only—throughout fading. Effects of probes upon acquisition were assessed by introducing probes early or late in fading. Fewer fading levels were needed for Braille elements to acquire control when probes were introduced early rather than late. When probes were introduced late, all subjects learned to name the Braille elements as the letters were being faded out. When probes were introduced early, however, most subjects learned to name the Braille elements as they were being faded in. Since virtually no errors occurred during compound-stimulus presentations, the probe procedure did not induce errors during acquisition. Quantitative analysis of probe data suggested that inclusion of probes enhanced the control acquired by the Braille elements during compound-stimulus presentations. The reported effects may have been due to differences in the relative frequency of reinforcement presented during compounds and probes.

Key words: stimulus-control transfer, errorless learning, discrimination learning, Braille stimuli, fading, probes, reinforcement predictability, verbal naming, humans

Stimulus fading refers to a procedure in which new stimuli that do not control responding are superimposed on another set of original stimuli that do control responding. Thereafter, the originals are gradually attenuated and eventually eliminated (Terrace, 1963). Since differential responding occurs in the presence of the new stimuli alone after the originals have been eliminated, the new stimuli must have acquired control of responding during the fading operations. Theoretically, acquisition could have occurred at any point after superimposing the new stimuli on the originals but before the originals reached detection threshold. The point of acquisition, however, cannot be ascertained while fading is being conducted, since error rate—the usual measure of acquisition—is nearly always at a zero level (Sidman, 1977). To measure acquisition

of control by the new stimuli, fading procedures have been modified by the insertion of probes consisting of the new stimulus elements presented alone at various points in fading (Doran & Holland, 1979; Fields, 1978; Fields, Bruno, & Keller, 1976; Lazar, 1977; Moore & Goldiamond, 1964; Schusterman, 1967; Sidman & Stoddard, 1967; Touchette, 1971). Responding to the probes has been used to trace the acquisition of control by various dimensions of the new stimuli during fading.

Although probes permit measuring the acquisition of control by new stimuli in fading, they may also influence the acquisition process itself. Such influences were not assessed in any of the studies cited, however. Additionally, comparing the results of those studies does not clarify the issue since each used different sets of probe parameters, baseline procedures, and subjects. The effects of probes upon acquisition were addressed by Fields (1979), who used pigeons as subjects. Fading was used to transfer control from colors to line orientations. After establishing an original discrimination between colors, the initial intensity of the colors was set at a very low level, lines were superimposed on colors at low intensity and were faded in. Thereafter, colors were faded out. Probes were introduced at the beginning

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of the line fade in (early) or at the beginning of the color fade out (late). Early introduction of probes induced somewhat earlier acquisition of control by lines and increased the degree of control acquired by the lines as they were being faded in. These effects, however, may have been limited to the special conditions that prevailed with respect to the starting intensity of the original controlling stimuli and the nonreinforcement of probe responding. In the following experiment, the generality of the effects of introducing probes early and late in fading was examined by setting the starting intensity of the original controlling stimuli at a high level, which is more typical of stimulus fading. Additionally, probe responses were differentially reinforced.

METHOD

Subjects

Sixteen volunteers were drawn from the College of Staten Island student body.

Apparatus

Subjects were seated in a room at a table facing a portable motion picture screen that was 2 m ahead. A reinforcement counter (Scientific Prototype) was on the table facing the subject. A cardboard strip, 7.5 cm high and 30 cm long, containing the letters that were the available response alternatives for each part of the experiment was placed to the left of the reinforcement counter. The visual stimuli were presented by two Kodak Carousel projectors located behind the subject. A shutter controlled stimulus durations.

The stimuli consisted of English capital letters and their Braille equivalents, presented in black against a white background. Letters and Braille symbols were presented alone or were superimposed and presented as compounds in various parts of the experiment. When projected, the stimuli covered a field on the screen that was 42 cm high and 34 cm wide. The Braille patterns consisted of 1 to 6 dots (5 cm in diameter) presented in a 2 by 3 array centered on the field. The distance between the centers of the dots was 17 cm. Letters, also centered on the projection area, were 34 cm high, and the width varied depending on the letter.

Each Braille and letter equivalent was used in only one of the two conditions in the ex-

periment. Their assignment to each condition (A and B) was random with the restriction that an equal number of Braille stimuli having three or four dots was used in each condition. Thus, the Braille patterns for D, G, O, and W were used in Condition A, and H, L, P, S, T, and Z were used in Condition B.

When fading was used, stimuli were faded in and faded out by changing the focus of the projector from which they were being generated (Acker, 1968). Eleven levels of defocusing were used for each portion of the fading procedure, where each level was measured in terms of degrees of rotation of the focusing knob of the projector.

Procedure

Preliminary training. After a subject was seated in the experimental room, the experimenter described and illustrated the types of stimuli to be presented, the responses to be made, and the feedback provided for correct and incorrect responses. Finally, the subject was told that stimuli might be changed during the experiment. Questions were answered by rereading the relevant portion of the instructions once. Then, the room light was dimmed.

Condition A. The strip containing the allowable response letters for Condition A was placed next to the reinforcement counter, and traditional discrimination training began. Each trial consisted of presenting a fully focused Braille stimulus for 5 sec or until the subject responded by saying a letter name, after which the trial terminated. Ten seconds later the next trial was presented. If the correct name of the Braille symbol was said, the response was reinforced by adding one point to the number on the reinforcement counter. Stimuli were presented in random order with the restriction that each occurred once within each block of four presentations. Training continued until each stimulus was identified correctly twice in a row. Subjects were then matched by grouping them in terms of the numbers of trials needed to learn the Condition A discrimination. Thereafter, matched subjects were randomly assigned to each experimental group (I and II).

Condition B. After completion of Condition A, the strip containing the allowable letter names for stimuli to be used in Condition B replaced that used during Condition A. The

six stimuli in Condition B were presented as compounds. Each compound was presented for 5 sec or until the subject said a letter name, after which the trial terminated. Ten seconds later, the next trial was presented. If a stimulus was correctly named, the number on the reinforcement counter was increased by one point. The compounds were presented in blocks of six trials in which each appeared once in a random order.

Initially, each compound stimulus consisted of a fully focused letter and a fully defocused Braille equivalent. If a subject responded correctly to six stimuli consecutively, the focus of the Braille components was increased by one step. As soon as one error occurred, the fading level was restarted with a different random series of the six stimuli. If a second error occurred, beginning with the next trial, the compounds were presented at their previous focus level. Thus, one error resulted in a "reset," a second error resulted in a "backup," and six consecutive correct trials resulted in an "advance." Once the Braille stimuli were completely focused (faded in), they remained so for the rest of Condition B, and the letter components were systematically defocused using the same criteria just described for focusing Braille components.

Probe procedure. The probe procedure used in fading was designed to minimize the number of unreinforced trials while permitting assessment of stimulus control acquisition in fading. Prior to each change in the focus of letters or Braille patterns, each of the fully focused Braille stimuli was presented alone, as a probe. Responding in the presence of the probes was used to assess the degree to which they controlled responding. The six Braille probes were presented in random order without replacement. Each was presented for 5 sec or until a letter-naming response occurred. Each correct response was reinforced. If the six probes occasioned correct responses, a second randomized series of probes was presented. If the second series was completed correctly, the session terminated. In contrast, if any probe occasioned an incorrect response, the probe trial terminated without reinforcement and the remaining probes in the group of six were not presented. Instead, the compound stimuli were presented at the next scheduled fading level.

Early/late introduction of probes. To de-

termine whether the point of introducing probes influenced acquisition, each subject was assigned to one of two experimental groups. In Group I (early introduction), probes were used after every fading level while focusing Braille and defocusing letters. In Group II (late introduction), probes were not used while Braille elements were being focused. Rather, they were used after every fading level as letters were being defocused.

RESULTS

Graphs in Figure 1 depict the course of acquisition by Braille elements during fading for each of the subjects in the experiment. Data for two of the subjects were deleted due to equipment malfunctions. In each graph, the number of probe trials evoking correct responses was plotted as a function of fading level. The dotted vertical line on each graph was drawn at the last level at which Braille elements were faded in. Thus, all data to the left of the vertical line were obtained while fading in Braille elements, and all data to the right were obtained while fading out letters. Graphs in the upper half of Figure 1 portray data obtained when probes were introduced late, while those in the lower half portray data obtained when probes were introduced early.

When probes were introduced early, a minimal number of probes evoked correct responding at the start of fading, indicating that Braille elements had not acquired control when initially superimposed on letters. Correct responding to probes remained at a low level and was then followed by a rapid increase to criterion level as fading progressed, indicating acquisition of control by all Braille elements. An average of 10.16 fading levels were needed for Braille elements to acquire control when probes were introduced early. Additionally, the Braille stimuli acquired control of responding as they were being faded in for two-thirds of the subjects.

When probes were introduced late, a minimal number of probe stimuli evoked correct responding upon their first presentation, with the exception of two subjects. For these two, the higher level of correct probe responding implied that some of the Braille stimuli had acquired control while being faded in. The number of correctly labeled probe stimuli increased rapidly, thereafter, for all subjects. An

Fig. 1. Number of probes occasioning correct responses as a function of fading level. Each graph contains data for one subject. Vertical lines on each graph indicate the last level at which Braille elements were faded in. Data to the left of the vertical lines were obtained while fading in the Braille elements, and data to the right were obtained as letters were faded out. Graphs above the horizontal line contain data obtained when probes were introduced late, whereas those below the line were obtained when probes were introduced early. Data presented in a given column were obtained from subjects who had learned the Condition A discrimination within a range of trials indicated at the top of each column.

average of 13.75 fading levels were needed for Braille stimuli to acquire control when probes were introduced late. For all subjects, Braille stimuli acquired control while letters were being faded out.

Based on the averages mentioned above, 27% more fading levels were needed by Braille stimuli to acquire control when probes were introduced late rather than early, a difference that was statistically significant ($t = 3.49$, $df = 12$, $p < .005$). This relationship was also evaluated by comparing data obtained from individual subjects in each group who were matched in terms of the number of trials needed to learn the first discrimination. Acquisition data for subjects who had learned the first discrimination in an equivalent num-

ber of trials appear in each of the columns in Figure 1. (The range of trials needed to learn the Condition A discrimination is listed at the top of each column.) Thus, the effects of early and late introduction of probes could be evaluated by comparing data in a given column. In general, more probes evoked correct responding at a given fading level for subjects run with early rather than late introduction of probes.

Individual subject comparisons were then summarized in Figure 2 by plotting the number of fading levels needed for each subject to learn the Condition B discrimination as a function of number of trials needed to learn the first discrimination. Data for equivalent subjects were clustered as in Figure 1. For

Fig. 2. Number of fading levels needed to reach criterion in fading for each subject when probes were introduced early and late in fading, plotted as a function of the number of trials need to learn the Condition A discrimination.

subjects who learned the initial discrimination in an equivalent number of trials, the Braille elements acquired stimulus control in fewer fading levels when probes were introduced early rather than late. Thus, individual subject comparisons corroborated the conclusion drawn from a statistical comparison of group data.

In addition to influencing the number of fading levels needed for Braille elements to acquire stimulus control, early and late introduction of probes also influenced the number of probe stimuli presented in fading. The data in Figure 1 indicated that more probe trials occurred when probes were introduced early rather than late in fading. On average, 19.83 probes were presented when they were introduced early, and 6.88 were presented when they were introduced late, a statistically significant difference ($t = 3.76$, $df = 12$, $p < .01$). This relationship was also evaluated for individual subjects by comparing the number of probes presented to subjects who had learned the first discrimination in an equivalent number of trials and was depicted in Figure 3.

When equivalent subjects were compared, more probes were presented when probes were introduced early rather than late.

Finally, the error rate in the presence of the compound stimuli in both experimental conditions was negligible. In each group, only one subject responded incorrectly to one stimulus presentation throughout fading.

DISCUSSION

The major finding of this experiment was that new stimuli acquired control of responding in fewer fading levels when the use of probes began early rather than late in fading. Additionally, acquisition occurred as the new elements were being faded in when probes were introduced early, and occurred as the original elements were being faded out when probes were introduced late. Both results replicated, in a single experiment, those reported by Fields (1978, 1979) and extended their generality since the present experiment differed from the earlier ones in terms of the salience of the original controlling stimuli at the start

Fig. 3. Number of probe stimuli presented during acquisition for each subject when probes were introduced early and late in fading, plotted as a function of the number of trials needed to learn the Condition A discrimination.

of fading, the reinforcement contingencies that prevailed in the presence of the probe stimuli, the basic discrimination training procedures, stimuli, responses, reinforcers, probe procedures, and subjects used.

Although the abovementioned effects were functionally related to the point at which probes were introduced, the mechanisms producing these effects need clarification. One possibility entails explaining the results in terms of the direct reinforcement of responding to probe stimuli. Probe responding was used to assess the control acquired by new stimuli during compound stimulus presentations. But, since probe responding was also reinforced differentially, responding to probes may have reflected the direct strengthening effects of that reinforcement alone. It follows that fewer fading levels would have occurred when probes were introduced early because the probes would have begun to gain control of responding upon their introduction. The plausibility of this explanation can be assessed by considering some of its logically necessary inferences and comparing them to the data obtained in the experiment. If probe responding reflected only the direct effects of the reinforcement contingencies that prevailed during probe presentations, an equal number of probe stimuli should have occurred in each group

for the Braille stimuli to acquire a criterion level of stimulus control. In fact, more than three times the number of probes occurred when they were introduced early rather than late. Since the obtained data differed considerably from the predicted results, the plausibility of explaining the obtained results in terms of differential reinforcement of probe responding alone can be discounted. These results also imply that Braille elements must have gained control of responding during compound-stimulus presentations, an implication confirmed by the fact that many probes evoked correct responding upon their first presentation for two subjects in the late introduction group. Finally, probe responding must have reflected the control acquired by Braille elements during compound stimulus presentations, as well as any direct strengthening effects produced by reinforcement of probe responding.

The preceding logical and quantitative analysis indicated that reinforcement of probe responding could not explain the results described above. Fields (1978, 1979) also found that early introduction of probes resulted in earlier acquisition of control by new stimuli in fading even though probe stimuli were presented under extinction conditions, further supporting the notion that reinforcement of

S+ probe responding per se was neither necessary nor sufficient to account for the reported effects. How, then, can these results be explained? Whatever processes are postulated would have to operate equally well when S+ probe responding was reinforced or extinguished, and would also have to explain how the introduction of probes enhanced the control acquired by the stimulus elements during compound stimulus presentations.

One plausible explanation can be developed by considering the differences in reinforcement signaled by compounds and probes during the early stages of fading, the dual process nature of discrimination learning, and generalization between probes and compounds. One of the conditions for establishing discriminative control is that stimuli have to signal different reinforcement densities. In the present experiment, shortly after probes were introduced, the compound stimuli signaled reinforcement with a likelihood approximating 1.0, whereas the probes signaled reinforcement with a much lower likelihood, thus satisfying the conditions needed for compounds and probes to acquire control. When stimuli acquire control, however, subjects first learn to attend to relevant stimuli, and then learn to emit the reinforceable operant in the presence of the relevant stimuli (Fields, 1980; Hamlin, 1975; Zeaman & House, 1963). In the current experiment, then, when probes were introduced, subjects would learn to attend to dot patterns during probe presentations, but would not necessarily learn to emit the reinforceable operant in their presence. Since the probes were similar to dot patterns in compounds, by generalization, attention to dot patterns would be enhanced during compounds. This, in turn, would increase the likelihood that subjects would be attending to the Braille elements while emitting the reinforceable responses, thereby facilitating the control of responding acquired by the Braille elements during compound stimulus presentations. The same argument is also applicable when probes are presented under extinction conditions as reported by Fields (1978, 1979) since the compounds and probes also signaled different reinforcement densities. It appears, then, that the combination of processes described above accurately predicts the acceleration of stimulus control induced by early introduction of probes, whether probe re-

sponding was differentially reinforced or extinguished, and also accounts for these results in terms of enhancement of control acquired by the new cues during compound stimulus presentations. Further research is required, however, to substantiate the plausibility of this explanatory model.

In summary, early introduction of probes resulted in early acquisition of control by the new stimuli in fading. In some cases, acquisition occurred as the new stimuli were being introduced or "faded in." These effects may have been due to the differences in reinforcement signaled by probes and compounds when the probes were initially introduced, which enhanced the control acquired by new stimuli during compound stimulus presentations. The stimuli used to measure the acquisition of discriminative control, then, influenced the course of acquisition, albeit indirectly.

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