TRANSFER OF STIMULUS CONTROL: MEASURING THE MOMENT OF TRANSFER[1]

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Three severely retarded boys acquired simple form discriminations errorlessly. Each was first taught to press a red key *versus* a simultaneously present white key. After this discrimination had been established, black figures were superimposed on the red and white keys. Each correct response affected the next trial by delaying the onset of the red stimulus an additional 0.5 sec. Transfer of stimulus control to the figures was indicated when the subjects responded correctly before the onset of the red stimulus. A series of errorless discrimination reversals was accomplished with this technique, during which the number of trials to transfer systematically decreased with successive reversals.

Numerous studies have reported the errorless or nearly errorless transfer of stimulus control (Moore and Goldiamond, 1964; Schusterman, 1966, 1967; Terrace, 1963*a*, *b*, 1966; Touchette, 1968; Westbrook and Miles, 1970). These studies used empirically developed programs of gradual stimulus change to eliminate responding to one or more stimuli and, in some cases, to provide subjects with a uniform training history. Such procedures do not reveal the point at which a subject comes under the control of the stimuli that will remain when training is complete. Schusterman (1967) reported data, collected on "probe" trials, that suggest that the point of stimulus control transfer during a graduated series of stimulus changes may differ markedly from one subject to the next. Variables that affect the point at which each subject comes under the control of the terminal stimuli during errorless discrimination training are of considerable interest as they relate to the refinement of instructional techniques.

The present study is concerned with the moment or point of stimulus control transfer. The term transfer, as used here, implies no process or conceptualization of activity in the central nervous system. It is used, as it was by Terrace (1963*b*), to refer to the acquisition of stimulus control by a set of stimuli that have been paired with an unrelated set of stimuli already having control over the response being measured. Terrace (1963*a*, *b*) transferred control across continua from brightness to color and from color to form. The procedures he employed, and those of subsequent experiments of this sort, involved compound stimulus displays that presented the stimuli currently controlling the subject's behavior in temporal and spacial contiguity with the stimuli to be transferred to. The importance of immediate history in determining the acquisition of stimulus control by various aspects of compound stimulus displays has been established (Johnson and Cumming, 1968; Ray, 1969). It is reasonable to expect that immediate history would have an effect on the point of stimulus control transfer during the course of errorless acquisition procedures that employ compound stimulus displays.

The present study used a procedure that permitted observation of the moment at which each subject began responding on a new basis. This procedure was used to observe directly the effects of immediate history on the point at which stimulus-control transfer occurred in individual subjects.

EXPERIMENT I

Subjects

Three severely retarded adolescent boys served. The boys had little expressive or receptive language. All had been institutional-

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ized for 10 or more years. Subjects CJ and AB had Down's syndrome and subject HJ displayed behavior consistent with his diagnosis of record, kernicterus. Most recent I.Q. scores for these boys were below 40 in each case. All of the subjects had participated in prior research.

Apparatus

Subjects sat before a panel containing two 3.75 in. (9.5 cm) square Plexiglas keys that served as stimulus display areas and response sensors. The keys were 3.75 in. (9.5 cm) apart and were hinged at the top, with heavy duty microswitches at their lower edges. Stimuli were presented from the rear by a Kodak Ektagraphic 35-mm slide projector, supplemented by two Bausch and Lomb Balmite single slide projectors. The Ektagraphic projector displayed form stimuli on both keys and illuminated the photocell decoder located at the rear of the response panel. Stimuli presented by this projector were turned on and off by means of a solenoid-controlled shutter. Each of the Balmite projectors could be turned on to illuminate a single key through a red filter. These projectors used 50-w BLR bulbs, which have an onset comparable to household incandescent bulbs, rather than the slow and gradual onset of higher wattage projection bulbs. For this reason they could be turned on or off electrically via a solid state switch, eliminating the need for a shutter and its resultant noise. Relative intensity of the stimuli was adjusted by a variable transformer that controlled the voltage delivered to the Ektagraphic projector bulb. Stimulus display, response recording, and reinforcement operations were arranged by solid-state switching circuits. Responses were recorded on a 20-channel Esterline-Angus operations recorder, which provided an account of the onset of trials, onset of additional cues, location of correct key, and the latency of all responses during and between trials. This recording apparatus was enclosed in a box insulated with sound-attenuating foam, located on the far side of a partition from the subjects.

After each correct response, a Gerbrands solenoid-type dispenser, Model B, mounted to the right of the stimulus display, operated with a loud "thunk". Tokens or pennies, as appropriate, dropped into a glass jar at the base of the dispenser housing. The subjects were afforded ample opportunity to exchange tokens or money for tangible items and all did so promptly at the end of each session.

Procedure

A trial began when the keys were illuminated and ended when the subject closed the microswitch behind one of the keys. Reinforcement (token dispenser operation) followed each response on the correct key. Incorrect responses terminated the trial without operating the dispenser. An intertrial interval of 5 sec, during which the keys were dark, followed each correct response or error. No intertrial interval responses occurred and no simultaneous responses occurred.

Stimulus control baseline. Each subject was taught to press a red key *vs.* a simultaneously present white key with few or no errors (Touchette, 1968). All subjects had learned to discriminate the presence of red in a prior study. The red *vs.* white discrimination was used as a stimulus-control baseline, and was maintained while differential responding was established under the control of the black forms also presented on the keys. All subjects met a criterion of 10 correct responses in 10 consecutive trials on the red *vs.* white discrimination before any further training was begun.

Basic procedure. The first forms presented consisted of the letter E with legs pointing down (S+) and up (S−). The figures were 2 in. (5 cm) square and were composed of black lines 0.25 in. (6 mm) wide. On trial one of each series, the figures were presented simultaneously with the red stimulus. The positive stimulus was superimposed on the red, the negative stimulus on the white. A correct response on trial 1 affected the next trial by delaying the onset of the red stimulus an additional 0.5 sec. Thus, on Trial 2, both figures were presented on white backgrounds and after 0.5-sec delay, red was added to the correct key. On Trial 3, following a correct response on the preceding trial, red was added after 1 sec, *etc.*

The appearance of the keys during a trial that involved the delay of the red stimulus was as follows. At the end of the intertrial interval, black figures were presented on a moderately bright, white background at the sound of the solenoid operated shutter. After the appropriate delay, the correct figure became bright red while its background turned a less saturated red. No sound accompanied this change. Correct responses before or after the addition of the red stimulus terminated the trial and were reinforced.

Incorrect responses terminated the trial and reduced the delay on the following trial by 0.5 sec. It must be realized, however, that any significant number of errors would have indicated a loss of stimulus control by the specified aspects of the experimental environment and invalidated the errorless experimental design. No such problem occurred.

Reversal training. A series of discrimination reversals was arranged using the basic procedure described above. Each session consisted of two discrimination contingencies, the first to establish the original discrimination and the second to establish the reversal. There was a pause of 2 min between two series that were presented sequentially in a single session. At the start of each new series, the previously incorrect figure was designated as correct by pairing it with the red stimulus. Each reversal was accomplished by reintroducing the red stimulus and delaying its onset as before. The three subjects were taught serial reversals until their performances stabilized. The sequence of stimuli relating to reversal training are in Fig. 1, and specific procedural details are presented later.

Control procedures. Several variations in procedure were carried out to determine whether the stimuli designated by the experimenter were in fact controlling the reversal performance. These control procedures are described in conjunction with the results.

RESULTS

Basic procedure. The upper-left corner of Fig. 1 shows the data for CJ on his first exposure to the basic procedure. Correct responses are indicated by solid black lines whose heights specify the response latency in seconds. No errors occurred during this first series of trials. The edge of the shaded portion of the figure indicates the time when red was added on the correct key if a response had not been made. Subject CJ's response latencies were such that the red stimulus was added on each of the first 14 trials, reaching a delay of 6.5 sec. From Trial 15 on, however, CJ's response latencies were shorter than the delay. He continued to respond correctly and terminated each trial before the red stimulus was added. Control of responding was maintained throughout the run and the point at which CJ began to respond on the basis of the figures alone was indicated by a drop in response latencies, which occurred at a clearly identifiable point.

The uppermost row of graphs in Fig. 1 shows the responses of all three subjects on the first exposure to the procedure. The response latencies of all subjects initially increased, then sharply decreased. The transition point is clearly indicated in each case. Once a subject had responded correctly on the basis of the figures alone, he always responded before the red light was displayed. Transitions from one basis for responding to the other were abrupt and stable.

Reversal training. Each subject was taught a series of errorless reversals to determine the effect of this training history on tne point of stimulus control transfer. The data collected during the reversal series are presented in the remainder of Fig. 1.

Run 2 was the first reversal of the original discrimination. Subject CJ's transfer point changed only slightly, while subject HJ showed a large reduction in number of trials to transfer. Subject AB required an increased number of trials before he began to respond on the basis of the figures alone.

As the number of reversals increased, the crossover point occurred earlier in each run. The extremes are represented by Subjects CJ and HJ. Subject CJ showed a gradual reduction in tendency to wait for the addition of the red stimulus. Subject AB's tendency to increase response latencies in accordance with the delay of the red stimulus was reduced somewhat more rapidly and erratically. His performance stabilized after six runs. Subject HJ's response latencies did not follow the delay on Run 2 and were stable through Run 3. Taken as a whole, Fig. 1 shows that the change in transfer point followed a different course for each subject. The first and last runs taken alone, however, are quite similar across subjects.

During reversal training, three patterns of responding emerged. Responses were made before the onset of the red light, after its onset, and at the onset of the red stimulus. The latter responses occurred within 0.5 sec after the red stimulus was added to the correct key.

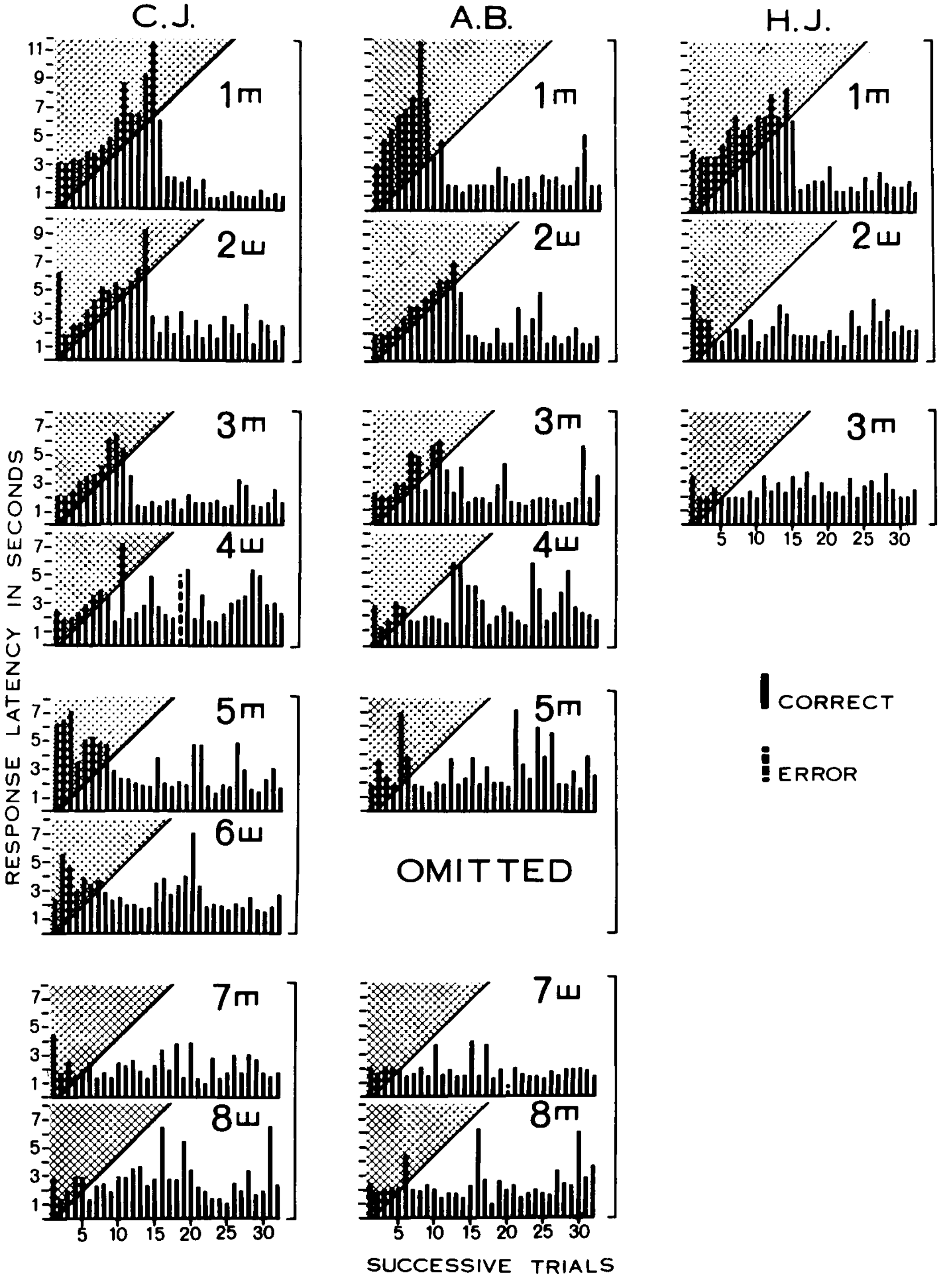

Fig. 1. Response latency for each trial during serial errorless reversals. Each column shows the data from a single subject whose initials appear at the top of the column. Correct responses are indicated by black bars whose heights represent latency. Errors are represented by broken bars. The edge of the shaded portion of each graph shows the point at which the red stimulus was added if no response had been made. Brackets indicate a session and each graph is a complete run. The positive stimulus is shown beside the run number.

Subject AB responded at the onset of the red stimulus on Trials 8 and 9 of his first run (Fig. 1). Later during Run 4 Subject AB again responded twice just at the onset of the red light. Visual observations revealed that these extremely short latencies occurred when the subject had placed his hand in front of the correct key when the figures alone were displayed, but waited for the onset of the red stimulus before pressing.

Control procedures. The data collected during the control runs indicated that the procedure used during the reversal series did not generate control of the reversal performance by spurious or undesirable aspects of the experimental environment.

The first control variation was the omission of Run 6 for Subject AB (Fig. 1). If the original discrimination was being cued by the start of each session rather than by the red light, and the reversal by the start of the second run at mid-session, he should have made errors at the beginning of Runs 7 and 8. He did not. Runs 7 and 8 show no signs of disruption for Subject AB, even though the usual sequence within a session was reversed.

Further control procedures were instituted for Subjects CJ and AB, who had experienced the greatest number of reversals (Fig. 2). Run 9 for both subjects was a nonreversal instead of the usual reversal that occurred on alternate runs. With the same contingencies in effect as in the prior run, the red stimulus was added to the display and delayed as usual. If reversals were being cued by the onset of the red stimulus regardless of what it was paired with, or by the start of a new session, Run 9 should have caused errors. It did not.

On Run 10, the red stimulus was not added and no reversal was required. Neither subject made errors, indicating that the 2-min pause at mid-session did not, by itself, control the reversal.

Figure 3 shows the results of the last reversal, which was scheduled without the red stimulus. All three subjects made a single error and then proceeded through the run without further disruption. These data indicated that control of the reversal performance could be transferred from the red light to the events contingent on an error. The uniformity of the result made it clear that the red stimulus had allowed errorless reversals to occur. During all of the reversal and control procedures, these were the only errors that occurred on the first trial of a run.

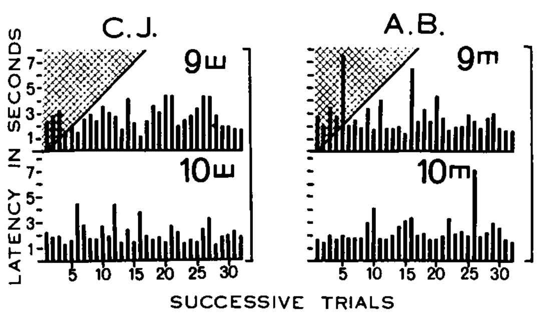

Fig. 2. Response latencies for each trial during nonreversal control procedures. Each column shows the data from a single subject whose initials appear at the top of the column. Correct responses are indicated by solid black bars whose heights represent latency. The edge of the shaded portion of the graphs indicates the point at which the red stimulus was added if no response had been made. The positive stimulus is shown beside the number of each run. During Runs 9 and 10, the positive form was the same as it had been during the previous run. At the initiation of Run 9, the red stimulus was added to the display and delayed as usual. On Run 10, the red stimulus was not added and no reversal was required.

EXPERIMENT II

In the first experiment, all subjects readily learned to respond on the basis of the figures during the course of the first sequence, and acquisition data were similar across subjects (Fig. 1 top). In Exp. II, new figures were presented for transfer, lines tilted at 45° and 135°. These stimuli had been found to generate high intersubject variability during acquisition (Touchette, 1969) and to form the basis for a discrimination that has been difficult to establish under anything less than optimal conditions (Jeffrey, 1966; Rudel and Teuber, 1963). Would the technique of delaying the red stimulus result in transfer to these "difficult" stimuli? Would intersubject variability increase?

The three retarded subjects were presented with the new stimuli, using the basic procedure described. Red was paired with the positively tilted line. Each correct response delayed the onset of the red stimulus an additional 0.5 sec. The lines were black, 2.75 in. (66 mm) long, and 0.25 in. (6 mm) wide.

The results of this experiment are shown in Fig. 4. Subject CJ rapidly responded before the onset of the red light. He responded on

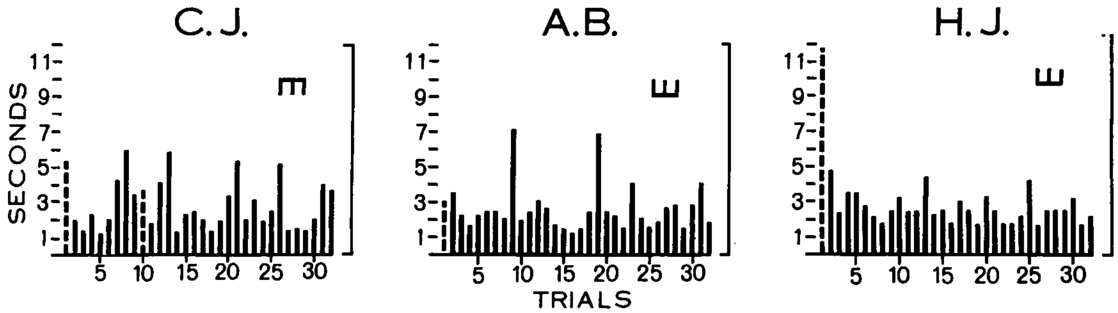

Fig. 3. Response latencies during reversal without visual cue, run after all other reversal and control procedures. Each graph represents the data from a single subject whose initials appear above the graph. Correct responses are designated by solid black bars whose heights indicate latency. Errors are represented by broken bars. The positive stimulus is shown in the upper right of each graph.

the basis of the tilted lines alone on Trials 8 and 10, then continued to respond correctly before the addition of red.

Subject AB's pattern of response latencies resembled those that all three subjects had displayed in their initial exposure to the basic procedure (Fig. 1 top). His responses followed the delayed onset of the red light until Trial 15, after which he responded in the presence of the tilted lines alone.

Subject HJ did not respond correctly in the presence of the tilted lines alone. In order to give him more opportunity, his run was extended to 40 trials. The delay reached 17.5 sec with no correct responses before the addition of red to the display. Two errors caused the delay to be reduced by 0.5 sec on Trials 15 and 20. Subsequently, the original "E" discrimination of Exp. 1 was reestablished using the same procedure. During this run, HJ made no errors and responded correctly to the figures alone on Trial 6 and all subsequent trials. This successful transfer to the figures used in Exp. 1 demonstrated that HJ had not learned to wait for the red stimulus under all conditions.

Ray and Sidman (1970) and Schusterman (1967) suggested that in order for transfer of stimulus control to occur, both of the stimuli must control the measured response simulta-

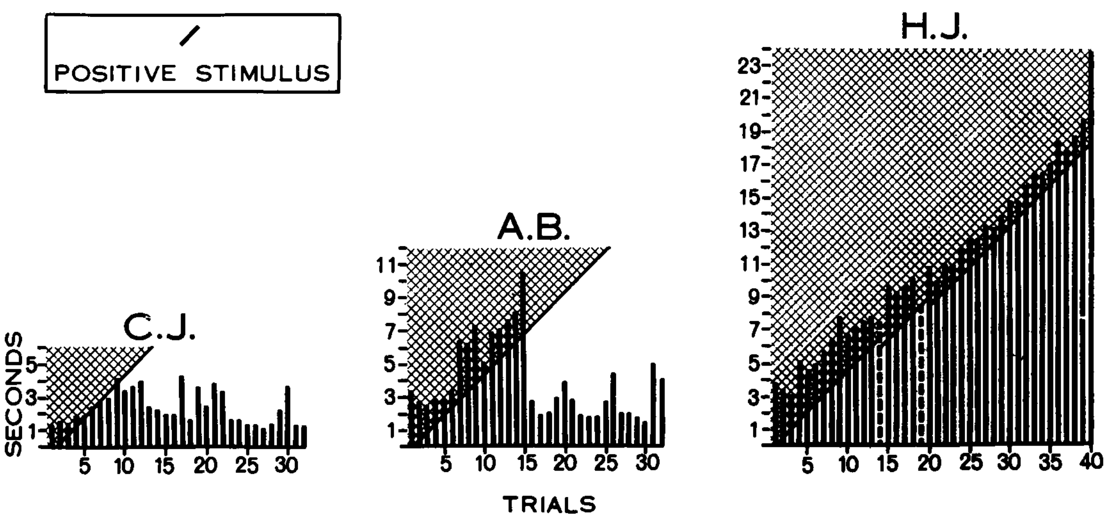

Fig. 4. Response latencies during the first exposure to lines tilted at 45° and 135°. Each graph represents the data from a single subject, whose initials appear above the graph. Correct responses are indicated by solid black bars whose heights represent latencies. Errors are shown as broken bars. The edge of the shaded portion of each graph indicates the point at which the red stimulus was added if no response had been made. The two errors in subject HJ's performance each resulted in a 0.5-sec reduction of the delay.

neously at some point. HJ was under excellent control by red but showed no indication of being controlled by line tilt. To determine whether the presence of control by both red and line tilt in the subject's immediate history constituted a sufficient condition for transfer to occur, the following procedure was carried out. HJ was taught to respond differentially to 45° and 135° lines by a fading program that gradually introduced the negative stimulus (*cf.* Ray, 1967; Terrace, 1963*a*). Materials were sheets of white paper with lines 80 mm long and 2 mm wide, not identical to those on the experimental apparatus. The reinforcer was pennies, delivered by hand each time HJ touched the correct line. He met a criterion of 10 correct responses in succession after having completed the fading series without error.

HJ was again presented with the tilted lines on the experimental apparatus. Contingencies were identical to those under which he had previously failed to respond to the tilts alone. There was reason to expect that the recently acquired tilt discrimination might not be available under the experimental conditions that varied in many ways from those conditions under which the discrimination had been learned. HJ, however, responded correctly in the presence of the tilted lines alone on Trial 6 and continued to do so. No errors occurred during this run. This successful transfer of stimulus control lends some support to the notion that cross-continuum transfer occurs only when both stimuli that form the compound, control the measured response simultaneously.

DISCUSSION

The present delay procedure was developed to measure the point at which control of a response is transferred from one set of stimuli to another. The data collected during these two experiments indicate that the point of transfer may vary greatly. Inter- and intra-subject differences were observed in the point at which responding to the forms alone was initiated. In Exp. I, the course of change in transfer point was different for each subject, although the number of trials to transfer decreased systematically with successive reversals in every case. Experiment II demonstrated that transfer may occur quickly or not at all under apparently identical contingencies. This experiment also revealed that the subject who acquired the reversal performance most readily in Exp. I (HJ) was the only subject who failed to acquire the tilt discrimination in Exp. II. The probability that control of a subject's behavior can be transferred from one set of stimuli to another cannot be stated in general terms, without regard for the subject's history with the particular stimuli. Future experiments will reveal whether results such as those in Exp. II reflect the subject's prior history with the stimuli to which transfer was attempted.

Although little is known about the conditions that limit the transfer of stimulus control, the above findings come as no great surprise. They bear out Skinner's (1966) contention that "no two organisms embark on an experiment in exactly the same condition nor are they affected in the same way by the contingencies in an experimental space" (p. 20).

Schusterman (1967) reported data collected during a series of "probe" trials inserted at several points in a fading program that was used to effect nine errorless reversals of a form discrimination. These data suggested that subjects differed in the point at which they transferred from a size cue to the reversed forms. The present study lends support to that observation. Schusterman, however, interpreted the summarized data of individual subjects as indicating a gradual shift of control from size to form over the course of fading. The data from Exp. I, summarized and plotted in a manner similar to Schusterman's, would also suggest a gradual transition. The transfer for each reversal was abrupt, but, because the transitions occurred on different trials, an average across trials would produce the appearance of a smooth curve. Summarized data from a series of discrete events can falsely suggest a continuous process (Migler 1964; Voeks, 1954).

Stimulus control transfer procedures such as those used by Schusterman (1966, 1967) and Terrace (1963*b*) commenced training with both sets of stimuli present at their maximum value. The stimuli that initially controlled the subject's behavior were then gradually "faded out". This approach allows, and may encourage, the subject to continue under the control of the gradually disappearing stimuli. Terrace (1966) noted that during repeated failures of a procedure to transfer stimulus control from brightness to line orientation, errors typically occurred only in the final few steps of fading. This observation, which has frequently been made but rarely reported, suggests that the subjects continued under the control of the dimension that was being removed, rather than coming under the control of the desired dimension. Delaying the onset of the stimuli that initially control key pressing rather than fading them out may, in some cases, prevent this problem. In Exp. I, it was noted that subjects sometimes responded within a fraction of a second after the onset of the red stimulus. Visual observations revealed that these responses occurred when the subject had placed his hand in front of the correct key before the onset of the red stimulus. This observation suggests that the onset of red may have served to reinforce a controlling relation between behavior not measured as part of the experiment (anticipatory hand movements) and the transfer stimuli. The delay procedure makes it likely that unmeasured behaviors will come under the control of the transfer stimuli, since these stimuli precede the onset of the stimuli that control the measured response, key pressing. Like fading, however, the delay procedure only encourages the transfer of stimulus control.

Hively (1962) offered the following analysis of the failure of stimulus control transfer during fading. "No matter how carefully one designs a sequence of correlations between the *occurrence* of stimuli and the *availability* of reinforcement, the actual contingencies of reinforcement in a given case depend upon what the subject observes, which in turn depends upon the individual subject's history" (p. 292). More recently, Johnson and Cumming (1968) and Ray (1969) demonstrated the importance of immediate history in determining selective attention within a compound display. The present data also suggest that immediate history is important in the facilitation of the transfer of stimulus control. To determine how training history variables limit transfer, the moment of transfer must be directly observed.

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