

PEAK SHIFT IN CONCURRENT SCHEDULES¹

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Pigeons were exposed to two keys, a main key and a changeover key. Initially non-differential training was given in which pecking the main key was reinforced on a variable-interval 2-min schedule when the key displayed the first stimulus, a black line on a blue background, and was reinforced on an identical but independent variable-interval 2-min schedule when the key displayed a plain blue stimulus. Later, differential training was given in which pecking the main key was reinforced on a variable-interval 2-min schedule when the first stimulus was displayed; and was reinforced on a variable-interval 10-min schedule when a second stimulus, a black line of another orientation on a blue background, was displayed. During non-differential and differential training, each peck on the changeover key changed the stimulus on the main key. Generalization tests were given before and after the differential training. These consisted of presentations on the main key of seven orientations of the black line on the blue background, including the first and second stimuli, with no reinforcements being given. Changeover-key pecks changed the stimuli on the main key. Generalization gradients were obtained using three measures: time spent, responses, and response rate in the presence of each test stimulus. Typically, maximum values on these measures occurred to stimuli away from the first in a direction opposite the second stimulus, and minimum values occurred to stimuli away from the second in a direction opposite the first.

Discrimination training, where different rates of responding to two or more stimuli are generated, often involves reinforcement of responding in the presence of one stimulus (S+) and not in the presence of another (S-). Generalization tests have been used to investigate control by S+ and S- following such training. In these tests, a number of stimuli in some physical dimension are presented, usually during extinction. If S+ and S- lie in the same physical dimension as the test stimuli, "peak shift" often occurs in the generalization gradient. Peak shift may be either positive or negative. Positive peak shift, where maximum responding occurs not to S+ but to a stimulus away from S+ in a direction opposite S-, has frequently been demonstrated (e.g., Hanson, 1959). Negative peak shift, where minimum responding occurs not to S- but to a stimulus away from S- in a direction opposite S+, has also been reported (Guttman, 1965). Other studies have shown that the presentation of

one stimulus during extinction is not necessary to produce peak shift. Both positive and negative peak shift have been demonstrated when two stimuli are each correlated with reinforcement, one with a lower frequency than the other (Guttman, 1959).

To date, peak shift has been demonstrated following training on multiple schedules, but not following on concurrent schedules. In multiple schedules, the training stimuli, each with its associated schedule of reinforcement, are alternated at a single locus by the experimenter. In concurrent schedules, the training stimuli are either simultaneously presented at separate loci, or alternated at a single locus by the behavior of the subject. Using pigeons, two-component concurrent schedules can be arranged by presenting each stimulus on simultaneously present keys (two-key procedure) or by presenting each stimulus on one key and having a peck to a second key change the stimulus (changeover-key, or CO-key, procedure). Honig (1962) investigated generalization gradients to stimuli to various wavelengths following discrimination training on multiple schedules and two-key concurrent schedules, in which one component was correlated with reinforce-

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ment and the other component with extinction. Two gradients were obtained from each test: one from presentations of a single stimulus value on both keys, and the other from presentations of one stimulus value on one key and the other stimulus value, 10 or 20 nm different, on the other key. For given training conditions, both gradients were of essentially similar form. Peak shift (positive) occurred only following the training on multiple schedules.

The present study investigated generalization gradients after discrimination training on CO-key concurrent schedules with unequal, but non-zero, reinforcement frequencies in each component. Generalization tests were given in which peaks on the CO key changed the test stimuli. This procedure has been used previously to demonstrate inhibitory generalization gradients following concurrent schedule discrimination training (Beale and Winton, 1970). Stimuli used during training and testing varied along a dimension of orientation of line.

METHOD

Subjects

Six experimentally naive White King pigeons were maintained at 80% ($\pm 15\%$) of their free-feeding weights. One subject became ill during the course of the experiment and had to be discarded.

Apparatus

A standard two-key pigeon chamber was used (Grason-Stadler model E1184J). The operanda were two translucent keys 4 in. (10 cm) apart and 8 in. (20 cm) from the floor. Stimuli were projected to the left key by a rear-mounted multiple stimulus projector. The right key was illuminated by a 15-w bulb. A force of 15 g (0.14N) was sufficient to operate either key. General illumination was provided by a 10-w houselight at the right of the right of the right key. Reinforcement was 3-sec presentation of grain in a magazine halfway between and 6 in. (15 cm) below the two keys. The chamber was enclosed in a refrigerator cabinet. A blower provided ventilation and masking noise. Stimulus events and response dependencies were automatically scheduled. Responses were recorded on counters and a cumulative recorder.

Procedure

Sessions were usually conducted six days a week, each session lasting approximately 45 min.

Preliminary training. The birds were trained to feed from the magazine and then to produce the magazine by emitting behaviors successively approximating a peck on the left key. Each of the first 40 pecks on the left key was reinforced. The left key was white; the right key was dark and ineffective.

Concurrent non-differential training. Beginning in the third session, the birds were trained on concurrent schedules with identical interval schedules of reinforcement in each component. In these schedules, reinforcement was arranged for the first response following either a fixed time interval (FI) or varying time intervals with some specified mean (VI). The stimuli correlated with the two components were a black line 3 mm wide on a blue key and a plain blue key. For three birds (B1, B2, B3) the line was 60° from vertical and for the other birds (B4, B5) the line was 30° from vertical. A peck on the right key (changeover or CO key) switched components. During all concurrent training and during testing, the CO key was illuminated by white light. A changeover delay (COD) of 1.5 sec specified the minimum duration between a peck on the CO key and the availability of reinforcement for a peck on the main key. The third session arranged reinforcement in each component every 30 sec (*conc* FI 30-sec FI 30-sec) and the fourth session arranged reinforcement in each component every 1 min (*conc* FI 1-min FI 1-min). The fifth session arranged reinforcement after varying intervals with a mean of 1 min (*conc* VI 1-min VI 1-min) and was followed by 10 sessions of variable-interval reinforcement with a mean of 2 min (*conc* VI 2-min VI 2-min). The variable-interval schedules used were based on a distribution of intervals that produces fairly uniform responding (Fleshler and Hoffman, 1962).

Generalization test 1 (G1). In the sixteenth session, each bird was given the first generalization test (G1). During the test, seven orientations of the black line on the blue background were presented on the main key according to four random series. The lines were 0°, 15°, 30°, 45°, 60°, 75°, and 90° from vertical. Each peck on the CO key produced a stimulus change.

No responses were reinforced. A test was terminated following the completion of the series of seven line orientations that the bird was in at approximately 30 min. This allowed each test stimulus to be presented an equal number of times to a subject. The test was preceded by a 10-min warm-up on *conc* VI 2-min VI 2-min, during which conditions were as for the concurrent non-differential training. During a brief timeout that intervened between warm-up and test, the houselight was out and the keys dark.

Concurrent differential training. Following G1, one further session on *conc* VI 2-min VI 2-min was given and then differential reinforcement training sessions began. In these sessions, the birds were given concurrent schedules with a VI 2-min schedule of reinforcement in one component and a VI 10-min schedule of reinforcement in the other (*conc* VI 2-min VI 10-min). For each bird, the lined stimulus used during the concurrent non-differential training (S_1) was correlated with the VI 2-min component, *i.e.*, the 60° line for B1, B2, B3, and the 30° line for B4, B5, and the lined stimulus used during the concurrent non-differential training by the group of birds exposed to the other lined stimulus (S_2) was correlated with the VI 10-min component, *i.e.*, the 30° line for B1, B2, B3 and the 60° line for B4 and B5.

Generalization test 2 (G2). Each bird reaching a criterion during differential training was given a generalization test (G2) in the next session. The criterion was that at least 84% of the total responses emitted in one session of differential training occurred during the VI 2-min component, *i.e.*, the relative rate of responding matched the relative rate of reinforcement. G2 was identical to G1 in all respects except that during the warm-up, the *conc* VI 2-min VI 10-min schedules used during differential training were in force.

Generalization test 3 (G3). In the session after 60 sessions training on *conc* VI 2-min VI 10-min, each bird was given a generalization test (G3). G3 was identical to G2.

The concurrent non-differential training was given to build up a high level of CO-key responding and also to provide a baseline from which to compare control by S_1 with that following differential training. In order to facilitate control by the line-orientation aspect of S_1 and S_2 , during non-differential

training and for the first 33 sessions of differential training, the brightnesses of the stimuli were varied irregularly. From the thirty-fourth session of differential training, the brightnesses of S_1 and S_2 were approximately equated. The brightnesses of the stimuli used in the generalization tests were approximately equated and were held constant for all tests.

RESULTS

Three behavior measures were used: responding to a stimulus, time spent in the presence of that stimulus and absolute rate of responding (obtained by dividing responses to the stimulus by the time spent in the presence of that stimulus) to that stimulus.

During concurrent non-differential training, no consistent preference was shown for either training stimulus on any of the behavior measures, except that B5, in the last few sessions, made fewer responses to the lined stimulus (S_1), and spent less time in that stimulus. No consistent preference was shown by this subject in absolute rate. CO-key pecks showed a general increase and in the session before G1 all subjects gave at least 100 pecks. The behavior of each subject in the non-differential training session immediately after G1 was not markedly different from that in the session immediately before G1.

In the differential training sessions, the values on all three behavior measures tended to be greater in the presence of S_1 than in the presence of S_2 . However, the changes made to the brightnesses of S_1 and S_2 during the first 33 sessions frequently resulted in an initial decrease, and even an occasional reversal of this divergence. This provided evidence of at least partial control by the brightnesses aspect of these stimuli. From the thirty-fourth session of differential training, after the brightness of S_1 and S_2 were approximately equated, a consistent divergence occurred on all measures, with greater values occurring in the presence of S_1 for all subjects. Four subjects (B1, B2, B3, B5) reached the criterion for G2 before the completion of sixty days differential training: B1 after 43 days; B2 after 39 days; B3 after 42 days; and B5 after 44 days. B4 had not reached the criterion at the end of differential training and therefore was not given G2. The number of CO-key pecks made by each subject varied widely throughout differential

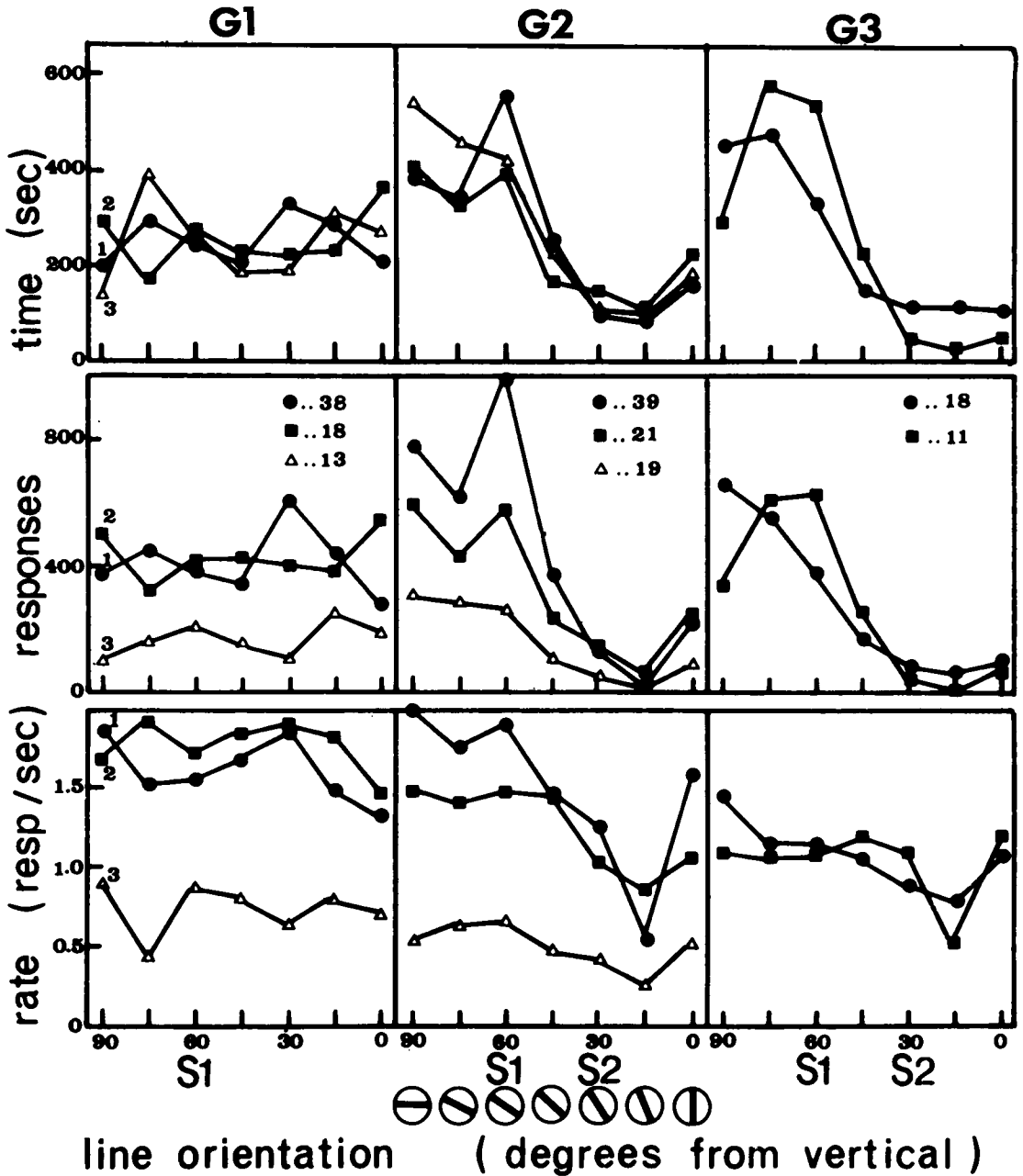


Fig. 1. Individual generalization gradients based on time spent in each stimulus, responses to each stimulus, and absolute rate of responding to each stimulus for B1, B2, and B3. Absolute rates were obtained by dividing responses to each stimulus by time spent in that stimulus. The 60° stimulus (S_1) was correlated with VI 2-min reinforcement during non-differential and differential training. The 30° stimulus (S_2) was correlated with VI 10-min reinforcement during differential training. The numbers above each response gradient are the times each test stimulus was produced by each bird during that test.

training. There was an overall decrease, with each subject making fewer responses on the last session of differential training than during the session of non-differential training im-

mediately before G1. However, except for B3 the decrease was not large, each subject making at least 95 responses on the last day of differential training.

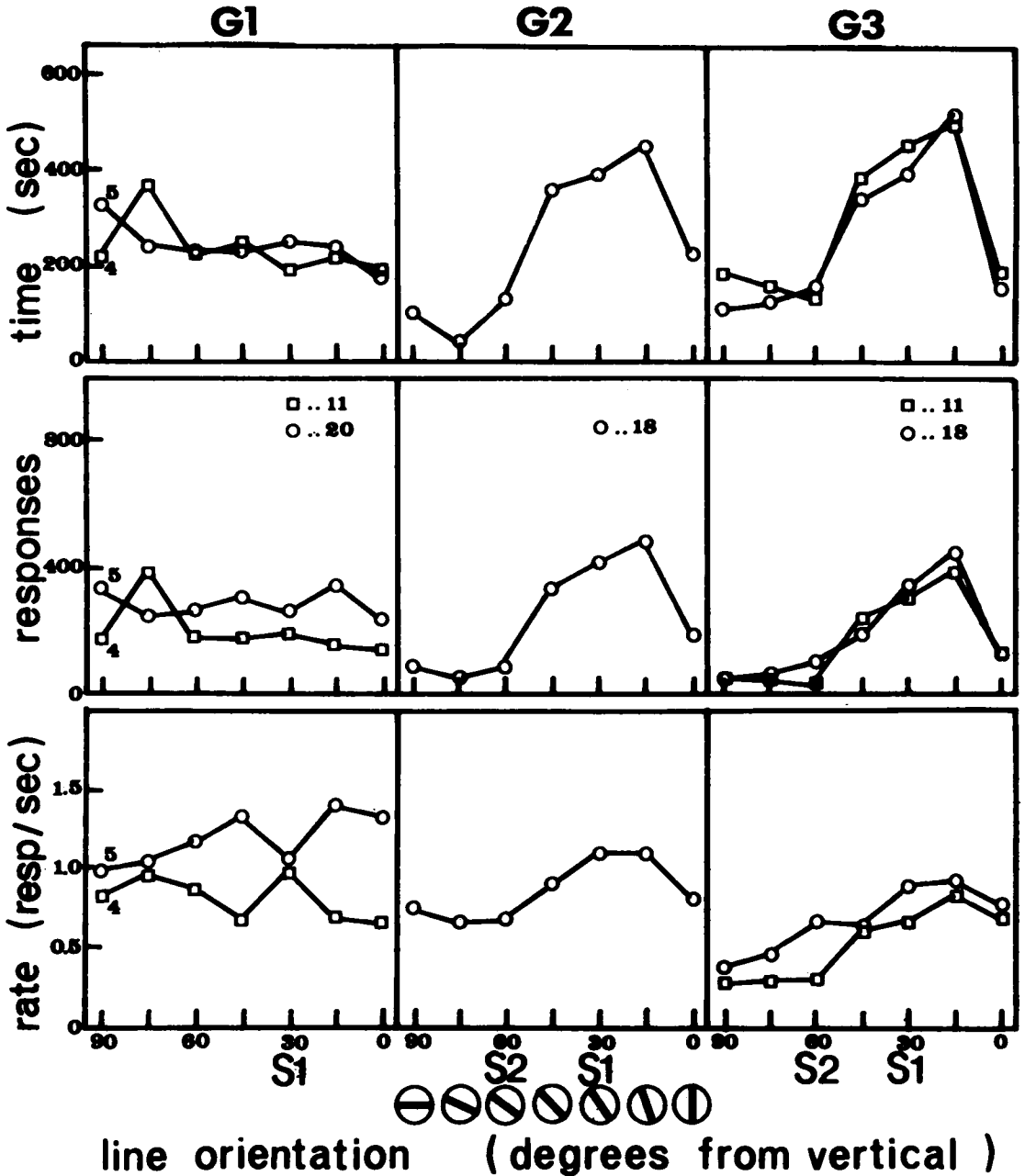


Fig. 2. Individual generalization gradients based on time spent in each stimulus, responses to each stimulus, and absolute rate of responding to each stimulus for B4 and B5. Absolute rates were obtained by dividing responses to each stimulus by time spent in that stimulus. The 30° stimulus (S₁) was correlated with VI 2-min reinforcement during non-differential and differential training. The 60° stimulus (S₂) was correlated with VI 10-min reinforcement during differential training. The numbers above each response gradient are the times each test stimulus was produced by each bird during that test.

The data obtained from the generalization tests are shown in Fig. 1 and 2. These are based on the full test period. Test periods varied in length between 28 and 32 min because each

bird had to be presented each test stimulus an equal number of times. Figure 1 shows the performances by B1, B2, and B3 on each of the behavior measures to each test stimulus. No

G3 gradient is shown for B3 because during G3, this subject hardly ever switched stimuli and did not produce each stimulus even once. Figure 2 shows the performance by B4 and B5 on each of the measures to each test stimulus.

The G1 gradients show that no systematic control was exerted by any test stimulus over responding by all subjects. Maximum and minimum values on each measure showed considerable variation among subjects. The time gradient is similar in shape to the response gradient and both tend to differ in shape from the rate gradient for each subject, especially for B1, B2, and B3.

During G2, negative peak shift was shown on all measures by the four subjects tested (B1, B2, B3, B5), except by B3 in time and by B5 in rate. Positive peak shift was shown clearly in responses and time by two subjects (B3, B5). A third subject (B2) did show a higher value in time and responses to a stimulus away from S1 on the side opposite S2 (90°), but the values on these two measures were lower to the stimulus between S1 and the 90° stimulus (75°). The other subject tested (B1) gave a higher response rate to the 90° stimulus than to S1, but again, the value to the 75° stimulus was lower. In general, gradients in responses and time are similar in shape for each subject. Gradients in rate are less similar in shape to the other two gradients for each subject, but are more similar than during G1.

During G3, negative peak shift was shown on all three measures by two subjects (B2, B5), in responses and rate for one subject (B1), and in rate only for the other subject (B4). Positive peak shift was shown on all three measures for three subjects (B1, B4, B5) and in time only for the other subject (B2). Again, time and response gradients are similar in shape for each subject, and usually more similar to each other than to the rate gradient.

Both G2 and G3 gradients were obtained from three subjects (B1, B2, B5). B1 showed positive peak shift in time and responses during G3 but not during G2, although the peak in time during G3 was 15° from S1 while the peak in responses was 30° from S1. For this subject, a positive peak in rate occurred 30° from S1 during both G2 and G3. However, the peak during G3 was more convincing as there was no drop in rate to the 75° stimulus as occurred during G2. The negative peak was less steep during G3 on all measures. The G3

gradients in time and responses for B2 are steeper than the G2 gradients in time and responses, and the positive peak in time shifted from 30° from S1 to 15° from S1. Overall rate to the test stimuli was generally lower during G3 than G2 for this subject. No consistent change occurred in the negative peak between the two tests. For B5, the positive peak in time and responses occurred 15° from S1 during both G2 and G3. The response rate to the 15° stimulus, relative to the rate to S1, increased slightly during G3. The negative peak on all three measures shifted for this subject from 15° from S2 during G2 to 30° from S2 during G3. Overall rate to the test stimuli was lower during G3 than during G2.

During the generalization tests, each subject, except B3 during G3, made at least 70 CO-key pecks, *i.e.*, presented each stimulus on the main key at least 10 times, and in most cases switched more than 120 times. All subjects made some multiple pecks in rapid succession on the CO key without any responses on the main key between these pecks, but these were usually subjects emitting large numbers of CO-key pecks.

DISCUSSION

Positive and negative peak shift were demonstrated following differential training on concurrent schedules with all three dependent variables: time, responses, and response rate in the presence of the lined test stimuli. During G2 and G3, orderly generalization gradients were obtained with all dependent variables from all subjects. Peak shift was shown by all subjects but not with all dependent variables by all subjects. The similarity of the G2 and G3 gradients indicates their reliability, even though multiple CO-key pecks in quick succession could result in the test stimuli being responded to on an unequal number of occasions. It is possible that variability could have been reduced by making such multiple pecks ineffective, either by requiring a response on the main key or introducing some delay, before allowing a second CO-key peck to be effective.

In the Hanson (1959) study, the generalization gradients obtained after discrimination training to an S+ and S- were compared with those of a control group trained to S+ alone. He showed that after training to S+ alone,

peak responding usually occurred to S+, whereas after discrimination training, the peak responding was to a stimulus away from S+ in a direction opposite S-. Terrace (1966) has used the term "peak shift" to describe similar-shaped generalization gradients after discrimination training to an S+ and S-, but without demonstrating that the peak occurred to the S+ after non-differential training. A problem with this is that it does not provide evidence of a shift in the peak from the S+. It is possible that the test stimulus responded to maximally after differential training would have been responded to maximally after non-differential training. For instance, two subjects in the Hanson (1959) study did respond maximally to a stimulus away from S+ in the direction opposite the stimulus used as S- during differential training, after training to S+ alone. In the present experiment, maximum values of the dependent variables never occurred to S₁ during G1 for any subject. However, the procedure used to eliminate control by the brightness aspect of each stimulus clearly had not done so. This was evidenced by the marked changes that occurred on all dependent variables, following variations in the brightnesses of S₁ and S₂ during the first 33 sessions of differential training. During G1, Birds B2, B3, and B5 showed some preference for a stimulus away from S₁ in a direction opposite the stimulus used as S₂ during differential training, but this preference was not marked and occurred only on one dependent variable for each subject: in rate for B2 and B5, and in time for B3. During G2, Birds B2 and B5 did not show positive peak shift in rate, and although B3 showed positive peak shift in time, it was to a different stimulus than that in which it spent most time during G1. The use of two groups of subjects having S₁ and S₂ of opposite values provides further evidence that the gradients obtained were due to differential training and not due to stimulus-specific effects.

The use of reinforcement in both components during differential training supports Guttman's (1959) finding that extinction in one component is not necessary to produce peak shift. Presenting reinforcement in each component also helps maintain switching behavior in concurrent schedules, especially during generalization testing. Beale and Winton (1970) found that after training on con-

current schedules with extinction in one component, several subjects reliably switched between test stimuli only during the first half of a 30-min generalization test similar to those given in this study. All present subjects, except B3 during G3, switched frequently throughout each 30-min generalization test. In the differential training session before G3, the CO-key responses by B3 had declined markedly, and in the session immediately before G3 this subject made only one CO-key peck (changing from S₂ to S₁).

Two problems interfere with the unequivocal demonstration of negative peak shift. One is that when one of the training stimuli is presented during extinction, responding to it during testing may be so low that clear evidence of less responding to another stimulus is difficult. Such was the case in the Hanson (1959) study, where evidence of negative peak shift was provided by some subjects, but not others, and the effect was usually small. The use of reinforcement in both components can maintain greater than zero responding to each training stimulus, allowing for clearer evidence of the existence or non-existence of negative peak shift. A second problem is that less responding may occur to a stimulus away from S- (or S₂) in a direction opposite that of S+ (or S₁) simply because responding declines to stimuli away from S+ rather than because of an interaction of the control by S- with the control by S+. The gradients shown by Terrace (1968) in Exp. I after training on multiple schedules in VI 1-min reinforcement in the presence of one stimulus (S₁) and VI 5-min reinforcement in the presence of another stimulus (S₂), show that responding to all stimuli away from S₂ in a direction opposite S₁ is much less than to S₂ and shows no consistent increase to stimuli further away from S₂. The present study frequently showed that the values on the dependent variables to the stimulus 30° away from S₂ on the side opposite S₁ were often as great or greater than to S₂, even though the values to the stimulus 15° from S₂ on the side opposite S₁ were lower than to S₂.

Several differences distinguish the present study from that of Honig (1962) in which no peak shift was obtained after training on concurrent schedules. Honig used a two-key procedure with stimuli of various wavelengths displayed on one or both keys. Preliminary training consisted of presentations of a 550-nm

stimulus for 60-sec periods either on one key, with presentations on the two keys being alternated randomly, or simultaneously on both keys. This was followed by a generalization test in which 11 wavelengths were presented, ranging from 490 to 610 nm in 10-nm steps, with the 500- and 600-nm stimuli omitted. During the test, each stimulus was presented simultaneously on both keys nine times and with another stimulus on the other key nine times for 30-sec periods. Each stimulus was presented only with a stimulus of the same wavelength or a wavelength adjacent to it on the continuum. Two group gradients were obtained, one based on responding in the presence of identical stimuli and one based on responding in the presence of different stimuli. Both gradients were of similar form and were peaked at 550 nm with responding decreasing fairly systematically to stimuli of greater or lesser wavelength. During differential training on concurrent schedules, the 550- and 560-nm stimuli were presented simultaneously for 60-sec periods, one on each key, with the presentations alternated randomly. Responding to the 550-nm stimulus was reinforced on a VI 1-min schedule. Responding to the 560-nm stimulus was never reinforced. Subjects that met a criterion of no responding to the 560-nm stimulus during five consecutive 60-sec periods were given a second generalization test identical to the first. The gradients based on single-stimulus responding and two-stimulus responding were again fairly similar in form, neither showing a shift in the peak from 550 nm. Birds given similar preliminary training but with discrimination training on a multiple schedule, with responding to the 550-nm stimulus reinforced on a VI 1-min schedule and responding to the 560-nm stimulus not reinforced, produced gradients with the peak at 540 nm, *i.e.*, with a positive peak shift.

A distinction often made between two-key concurrent procedures and multiple schedule procedures is that the former procedures involve simultaneous presentation of the training stimuli and the latter involve successive presentation. For example, Bloomfield (1969, p. 229) interprets the results of Honig's experiment as showing that successive differential training is a necessary condition for the production of peak shift. With respect to this distinction, the CO-key concurrent procedure can be considered more like the multiple-schedule

procedure than the two-key concurrent procedure. However, as Catania (1966, pp. 219-220) pointed out, if concurrent operants are to be independent they must not be able to be emitted simultaneously, and when they can occur successively only, then the two-key and CO-key procedures are equivalent. Catania, in the same paper, cites data showing equivalent functional relations with the two concurrent procedures.

Even if the simultaneous *versus* successive presentation of the two stimuli is an important difference between Honig's procedure and the present one, it remains to explain how the two procedures produce differential effects. Catania (1966, pp. 247-248) outlined one possible account for the different results with simultaneous and successive training in Honig's study. This is that the simultaneous differential training affected "not only the tendency to peck either key, but also the likelihood of COs between the keys." The successive differential training did not involve any CO response. This possibility cannot account for the present results where, although the stimuli were presented successively, a CO response was involved. Bloomfield (1969, p. 229) explains Honig's data in terms of whether responding to the no-reinforcement stimulus was inhibited or not. He suggests that in simultaneous training, the animal has only to develop a preference for the reinforcement stimulus over the no-reinforcement stimulus. Because of the constant availability of the reinforcement stimulus, there is no inhibition of responding to the no-reinforcement stimulus. Again, this explanation cannot account for the present results because the birds could develop a preference for S_1 without inhibition of responding to S_2 , since S_1 was always available.

Apart from this difference, the Honig study varied in procedure from the present study in a number of ways. Honig presented stimuli during training and testing for fixed periods, and during testing, the stimuli presented together were always similar in value. Although an earlier part of his experiment showed that presentation of other combinations of stimuli during testing produced comparable results, this was done only after the preliminary training. In the present experiment, each stimulus was preceded and followed by a number of stimuli, due both to the explicit arrangement of four random series, and also because multi-

ple pecks emitted in rapid succession on the CO key produced non-explicitly arranged sequences of stimuli. Further, the stimulus on the main key could be changed at any time without any restriction. Honig found that for a given differential training procedure, the part of the test in which different stimuli were presented successively, and the part of the test in which different stimuli were presented simultaneously, produced similar gradients. It might be that because the choice provided by the simultaneous presentation procedure was restricted, peak shift was not obtained. Evidence on the importance of choice in test procedure is provided by a previous study in which two test procedures were used following differential training on concurrent schedules (Beale and Winton, 1970). One procedure was similar to that in the present study and the other procedure differed only in that changes in the stimulus on the main key occurred after fixed intervals independent of the subject's responding. Only the procedure providing choice produced reliably systematic gradients. Other differences from the present study include use of stimuli on the wavelength continuum, no COD (although subjects showing noticeable interaction of control by the two schedules during differential training were discarded), use of extinction in one component, and a much smaller number of days of differential training (five days). Further experimentation is required to assess whether these differences had any crucial effect on the shape of the generalization gradients.

The Beale and Winton study investigated control around an S-, using the present generalization test procedure, after discrimination training on concurrent schedules with an S+ and an S- lying in orthogonal dimensions. The U-shaped generalization gradients obtained, with time as the dependent variable, were interpreted as evidence of inhibitory control by S-. The present study provides support for interpreting generalization gradients in time, after training on concurrent schedules, as analogous to gradients in responses, after training on multiple schedules using the standard generalization test (e.g., Guttman and Kalish, 1956). The gradients in time and in responses are very similar and are often quite similar to the gradients in response rate.

These results are consistent with increasing evidence that time spent in the presence of stimuli presented in concurrent schedules is a sensitive dependent variable (Brownstein and Pliskoff, 1968; Baum and Rachlin, 1969).

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