EXCITATION, INHIBITION, AND DISCRIMINATION LEARNING IN A FREE - OPERANT AVOIDANCE SITUATION

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ABSTRACT

EXCITATION, INHIBITION, AND DISCRIMINATION LEARNING IN A FREE-OPERANT AVOIDANCE SITUATION

By

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Three groups of pigeons trained on a free-operant avoidance schedule were given auditory discrimination training. The birds were subsequently given two types of generalization tests, with and without avoidable shocks scheduled. Two of the groups, trained interdimensionally, produced excitatory and inhibitory generalization gradients along the tone frequency dimension. Two different predicted postdiscrimination gradients were computed from the algebraic summation of these gradients of excitation and inhibition. The predicted gradients were compared with the actual postdiscrimination gradient obtained from the third group of pigeons which had been given intradimensional discrimination training on the tone frequency dimension. The predicted postdiscrimination gradients agreed in shape with the empirical postdiscrimination gradient, but predicted a smaller area shift than found in the empirical postdiscrimination gradient. The results in general support Spence's gradient interaction theory and suggest that there is no basic dichotomy between stimulus generalization of avoidance and approach behavior.

EXCITATION, INHIBITION, AND DISCRIMINATION LEARNING IN A FREE-OPERANT AVOIDANCE SITUATION

By

Marty Klein

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To the females who made this work possible:
my wife, my mother, and my pigeons.

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I am happy to acknowledge my indebtedness to Dr. Mark Rilling whose suggestions and criticisms were instrumental in the preparation of this thesis. My sincere appreciation is also extended to my wife, Margaret, for her able assistance in the preparation of the manuscript.

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indicates the number of shocks received in the presence of the corresponding stimulus value. The filled triangles in the Group I and Group II gradients indicate the level of responding during the test to the white noise anchoring stimulus (see text for details). The numbers alongside the centerlines in the Group III (lower) gradients indicate the proportion of responses on each side of S+. Tones are spaced at approximately equal intervals along a log scale. Note the different ordinate scales.

Figure 5. (left) Relative gradients of excitation (closed triangles) and inhibition (squares). The excitatory gradient is the WSE gradient of Figure 3 (upper left). The inhibitory gradient is calculated from the WSE gradient of Figure 3 (center left). Details of the calculations are given in the text. The numbers in the square brackets alongside the vertical lines between the gradients represent the algebraic sum of the two points which the particular line connects. The numbers in parentheses alongside the same vertical lines were obtained by transforming the numbers in square brackets to a scale of 100. (right) Empirical (closed circles) post-intradimensional discrimination gradient (PDG) of relative generalization from Figure 3 (WSE), compared with PDGs derived from the calculations on the left. The values on Derived PDG 1 are from the square brackets on the left, while the values on Derived PDG 2 are from the parentheses on the left. 38

INTRODUCTION

Considerable theoretical attention has been directed at predicting an organism's response after it has learned to respond to one stimulus along a dimension and to withhold responding to another stimulus on the same dimension (intradimensional discrimination training). Almost all such studies have, however, been confined to procedures employing positive reinforcement. Generalization studies have been reported in a variety of paradigms (Hoffman, 1969; Siegel, 1967; Desiderato, 1969; Hearst, 1962), but only one investigator (Sidman, 1961), using monkeys, has reported generalization gradients in a free-operant avoidance situation.

Free-operant avoidance (Sidman, 1953a) is defined by two temporal parameters; the response-shock (RS) interval, the period of time that each response postpones the shock, and the shock-shock (SS) interval, the period of time between shocks in the absence of a response. Until recently, the use of pigeons in free-operant avoidance has been precluded by the difficulty in training the avoidance behavior (Hoffman and Fleshler, 1959; Rachlin and Hineline, 1967). Smith and Keller (1970) finally solved the methodological problems through use of a treadle response, and Klein and Rilling (1972) provided parameters of the response-shock interval and shock intensity which now make possible complex experiments with pigeons on an avoidance baseline.

Generalization studies on avoidance baselines should yield important data pertaining to Spence's (1937) theory of discrimination learning and Terrace's (1966) and Bloomfield's (1969) explanations of peak shift in appetitive conditioning. According to Spence (1937), a postdiscrimination gradient (PDG), obtained after intradimensional discrimination training, is the resultant of the interaction between excitation and inhibition. The number of responses to each test stimulus is the resultant of the algebraic summation of generalized inhibition to S- (associated with extinction) and generalized excitation to S+ (associated with reinforcement). Since inhibition and excitation are assumed to be opposite responses, the generalized inhibition to S- is subtracted from the generalized excitation to S+. One prediction of Spence's theory is that the maximum or peak of the generalization gradient will occur at a test stimulus which is displaced from S+ in a direction away from S-. This is the positive peak shift phenomenon.

Terrace, (1966, 1972) maintains that S- becomes "aversive" during discrimination training and that peak shift is a shift away from an aversive stimulus. Bloomfield (1969) argues that the main determinant of the peak shift is the change for the worse in one component of the multiple schedule. The change for the worse takes place during discrimination training. A change for the worse is operationally defined in a choice paradigm as a demonstrated preference for S+ over S-. Both Terrace (1972) and Bloomfield (1969) assert that the same conditions that produce peak shift also produce behavioral contrast, which is an increase in the response rate to S+ as the response rate to S- decreases during discrimination training. Many studies (Sidman, 1962; Verhave, 1962; Weisman and Litner, 1969; Lolordo, 1969; Baron and Trenholme, 1971; Emurian and Weiss, 1972) have shown that a stimulus correlated with time-out from avoidance has positive reinforcing properties. If peak shift and behavioral contrast are obtained following discrimination training with S+ associated with an avoidance baseline and S- associated with avoidance extinction (time-out), Terrace's and Bloomfield's theories will not explain the data. Gradient interaction theory, however, is supported by such a result since it makes no assumption about the functional "negativity" of S-; all that is required is the assumption that S- acts in a direction opposite to that of S+.

Hearst (1968, 1969a) conducted a set of experiments based upon Jenkins' and Harrison's (1962) interdimensional discrimination training technique. In interdimensional training, the S+ stimulus dimension is orthogonal to the S- stimulus dimension. Hearst obtained excitatory, inhibitory, and postdiscrimination (intradimensional) gradients from separate groups of pigeons in order to allow for meaningful comparisons between empirical PDG's and PDG's predicted by algebraically combining the empirical excitatory and inhibitory gradients. The results generally supported Spence's theory.

The present experiments, using a free-operant avoidance baseline, are based upon Hearst's (1968, 1969a) design. As an analogue to Hearst, Besley, and Farthing (1970), two types of generalization tests were employed: resistance to extinction, in which there were no scheduled shocks, and resistance to reinforcement, in which avoidable shocks were scheduled. The resistance to reinforcement procedure was employed in order to ensure above-zero response rates along the S- dimension since, frequently, there is very little responding along this dimension during generalization tests.

METHOD

Subjects: Twelve experimentally naive, white Carneaux pigeons were housed in individual home cages with free access to food and water. The subjects had stainless steel electrodes implanted through the pubic arch, and wore a leather harness with an electrical connector on the back (Azrin, 1959).

Apparatus: The size of the experimental chamber was substantially reduced in comparison with the conventional pigeon chamber in order to increase the probability of a treadle response. The chamber was a Plexiglas box 11.5 in high by 8 in wide by 8.5 in deep (29.2 by 20.3 by 21.6 cm), with a foot treadle 2.5 in long by 3.5 in wide (6.1 by 8.9 cm). The treadle was centered on the front wall extending 2.5 in (6.1 cm) into the chamber with the edge nearer the pigeon 1 in (2.5 cm) lower than the distant edge, resulting in a 30° angle to the floor. A force of 50 g (0.5 N) and a downward displacement of 0.5 cm was required to operate a microswitch connected to the treadle. The box was mounted in a sound attenuating enclosure with a remote ventilating fan to minimize extraneous noise. Electromechanical equipment arranged the avoidance schedule and stimulus presentations, and a cumulative recorder was used to monitor the rate of responding.

A coiled cable, attached to a mercury swivel connected the shock source to the pigeon harness. The shock source was a 7.8v ac transformer, adjustable from 0 to 7.8 volts via a Variac. The duration of shock was 0.25 sec. The implanted electrodes were cleaned regularly to reduce changes in resistance. Cleaning was accomplished by rotating the implanted portion of the stainless steel loops into an exposed position, and scraping the deposits with a small knife blade. A Wheatstone bridge was used to measure internal resistance before each session, and the shock transformer voltage output was adjusted accordingly.

The auditory stimuli were generated by a Model 200 ABR Hewlett Packard audio oscillator and a model 901B Grason-Stadler noise generator. A Realistic Model SA-500 stereo amplifier was used to amplify the tones and noise to 85 dB as measured at the pigeons ear level on the A scale of a B&K Model 2204 sound pressure meter. The speaker was an 8 in (20.3 cm) Realistic 8 Ohm speaker, mounted at the pigeons ear level.

<u>Procedure</u>: Four subjects were trained in each group. Preliminary training consisted of two 30 min sessions of free-operant avoidance with a response-shock (RS) interval of 20 sec, a shock-shock (SS) interval of 5 sec, and a 4 mA shock of 0.25 sec duration. No auditory stimuli were presented. Beginning with the third session, session length was increased to 62.5 min and the shock intensity was increased to 8 mA. Training continued at these parameters for

an additional 20 sessions.

The discriminative stimuli were introduced during session 23 as outlined in Table 1, Column I (discrimination training). The stimuli, equated for intensity at 85 dB were presented for 2 min each in pseudo-random order, with a 5 sec timeout (blackout) between stimulus presentations. Thus, there were a total of 15 S+ and 15 S- presentations in each 62.5 min session. The positive stimulus (S+) was associated with the avoidance schedule, while the negative stimulus (S-) was associated with extinction of avoidance without shocks. Discrimination training continued for a minimum of 10 sessions, and continued until the rate of response to S- was less than 10% of that for S+ in three consecutive sessions.

The generalization test stimuli were 30 sec presentations of tones spaced at approximately equal intervals along a logarithmic scale (300, 450, 670, 1000, 1500, 2250, and 3400 Hz) and, in Groups I and II, white noise (Hoffman and Fleshler, 1961). The seven tone stimuli were presented in seven blocks (a block consisted of one presentation of each tone stimulus), making a total of 49 tone presentations during the test. The order of presentation was governed by 7x7 latin squares so that each stimulus appeared once in every ordinal position in the block.

There were two types of generalization tests: (A) extinction throughout the test, and (B) one avoidable shock (an SS interval as in training) programmed at 5 sec after the beginning of each test <u>tone</u> presentation. Each bird in each group received three generalization tests, with three sessions of discrimination training between tests. Thus, each group produced 12 generalization gradients. Table 1, Column VI (order of testing) gives the order of testing for each bird. Two birds in each group were tested in the order A-B-A, and two were tested in the order B-A-B. Each test session was preceded by seven S+ and seven S- presentations to allow for warm-up (Sidman, 1953b; Hoffman, Fleshler, and Chorney, 1961; Wertheim, 1964).

In Group I, pre-excitatory training, and in Group II, pre-inhibitory training, each 30 sec test stimulus presentation was followed by a 5 sec blackout and then by a 30 sec white noise presentation as in training. In Group III, intradimensional training, each 30 sec test stimulus presentation was followed by a 5 sec blackout. As in training, there were no white noise presentations in Group III. Thus, during those generalization tests with avoidable shocks programmed, the birds in Group I had shocks scheduled on the S+ dimension, the birds in Group II had shocks scheduled on the S- dimension, and the birds in Group III had shocks scheduled on the S+ - S- dimension.

Table 1. Column I gives the values of the discriminative stimuli for each group. Column III shows the mean percentage of shocks avoided over the last five sessions of prediscrimination training (sessions 18-22). Column IV shows the mean percentage of shocks avoided during the first session of discrimination training. Column V shows the number of sessions of discrimination training before the discrimination criteria were met. Column VI gives the order of generalization testing: (A) indicates tests conducted during no-shock extinction, (B) indicates tests with avoidable shocks programmed.

Table 1

GROUP	I Discrimination Training	II Subject	III Mean % Avoid. Sess.18-22 (predisc.)	IV % Avoid. 1st disc. Session	V Sessions to disc. Criterion	VI Order of Testing
Group I Interdimensional	S+ = 1000 Hz S- = white noise	200	93	90	11	A-B-A
		187	95	88	10	A-B-A
		1037	95	94	10	B-A
		1001	83	78	10	B-A-B
Group II Interdimensional	S+ = white noise S- = 1500 Hz	976	92	86	10	A-B-A
		931	97	86	14	A-B-A
		793	99	98	11	B-A-B
		403	81	81	10	B-A-B
Group III Intradimensional	S+ = 1000 Hz S- = 1500 Hz	504	95	92	19	A-B-A
		279	98	95	31	A-B-A
		589	99	99	38	B-A-B
		580	97	96	29	B-A-B

RESULTS

Table 1, Column III (mean % avoidance for sessions 18-22) shows that ten of the twelve birds were avoiding more than 90% of the scheduled shocks during the last five sessions of prediscrimination training. Only Bird 1001 (83%) and Bird 403 (81%) were avoiding less than 90% of scheduled shocks.

Discrimination training: Figure 1 presents the last five days of prediscrimination training (sessions 18-22) and demonstrates the acquisition of the discrimination for the birds in Groups I and II (interdimensional). The discriminative stimuli were introduced during session 23, which was the first day of discrimination training. For both groups, the response rate during S- dropped almost immediately to very low levels. Four birds (187,1001,404,976) ceased responding to S- almost completely during the first session of discrimination training. The other four birds (1037,200,793,931) showed a slightly slower decrease in responding to S-.

Figure 1 also shows that there were several different patterns of responding to S+ during discrimination training. Some birds showed slight increases, some slight decreases, and others showed no change. None of the birds showed unequivocal behavioral contrast. However, for almost all birds

Figure 1. The last five sessions of prediscrimination training (sessions 18-22) and the formation of the discrimination for Group I (upper panel) and Group II (lower panel). The solid lines show response rates during S+ and the broken lines show response rates during S-.

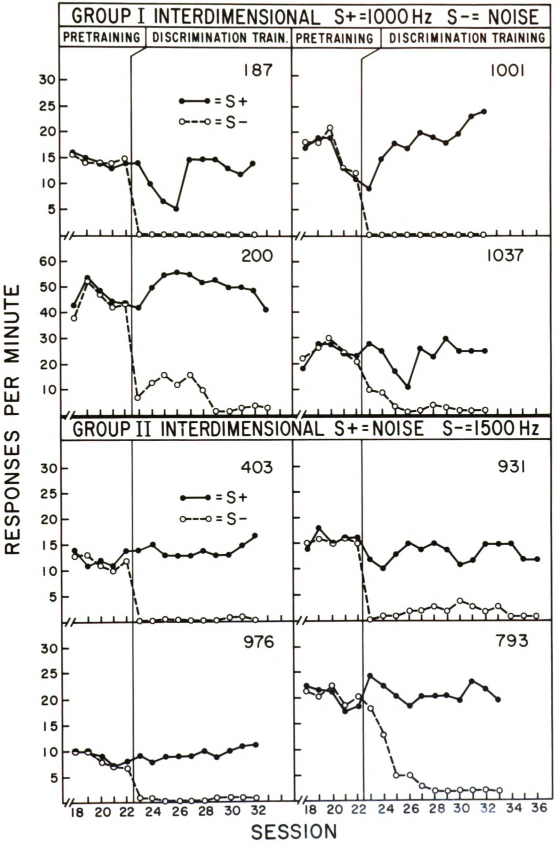
GROUP I INTERDIMENSIONAL S+=1000 Hz S-= NOISE
PRETRAINING
DISCRIMINATION TRAIN.
PRETRAINING
DISCRIMINATION TRAINING
187
1001
200
1037
●—● = S+
○--○ = S-
GROUP II INTERDIMENSIONAL S+ = NOISE S-=1500 Hz
403
931
976
793
RESPONSES PER MINUTE
SESSION
5
10
15
20
25
30
40
50
60
18
20
22
24
26
28
30
32
34
36

Figure 1.

in Groups I and II, the avoidance performance during S+ deteriorated during the first session of discrimination training. Table 1, Column IV (% avoidance, 1st discrimination session) shows that seven of the eight birds in Groups I and II had decreased avoidance percentages during this session. A mean of 2.4 sessions was required for the avoidance behavior to return to the previous higher levels of avoidance.

Figure 2 presents the last five days of prediscrimination training (sessions 18-22) and demonstrates the acquisition of the discrimination for the birds in Group III (intradimensional). Acquisition of the discrimination for this group was quite different from Groups I and II. Instead of an abrupt drop in rates to S- (1500 Hz) as in Groups I and II, the birds in Group III showed gradual decreases in rates, and required many more sessions to reach the discrimination criteria. Table 1, Column V (sessions to discrimination criteria) shows that the birds in Group III required between 19 and 38 sessions, or an average of 29 sessions, to reach criterion. This compares with an average of 10.7 sessions for Groups I and II. Thus, the difficulty of discrimination was inversely related to the physical difference between S+ and S-.

Figure 2 also shows that, as in Groups I and II, the birds in Group III did not show unequivocal behavioral contrast. However, the initial change in response rates to S+ was more consistent for Group III, where the initial rates to S+ tended to be slightly higher than during

Figure 2. The last five sessions of prediscrimination training (sessions 18-22) and the formation of the discrimination for Group III. The solid lines show response rates during S+ and the broken lines show response rates during S-.

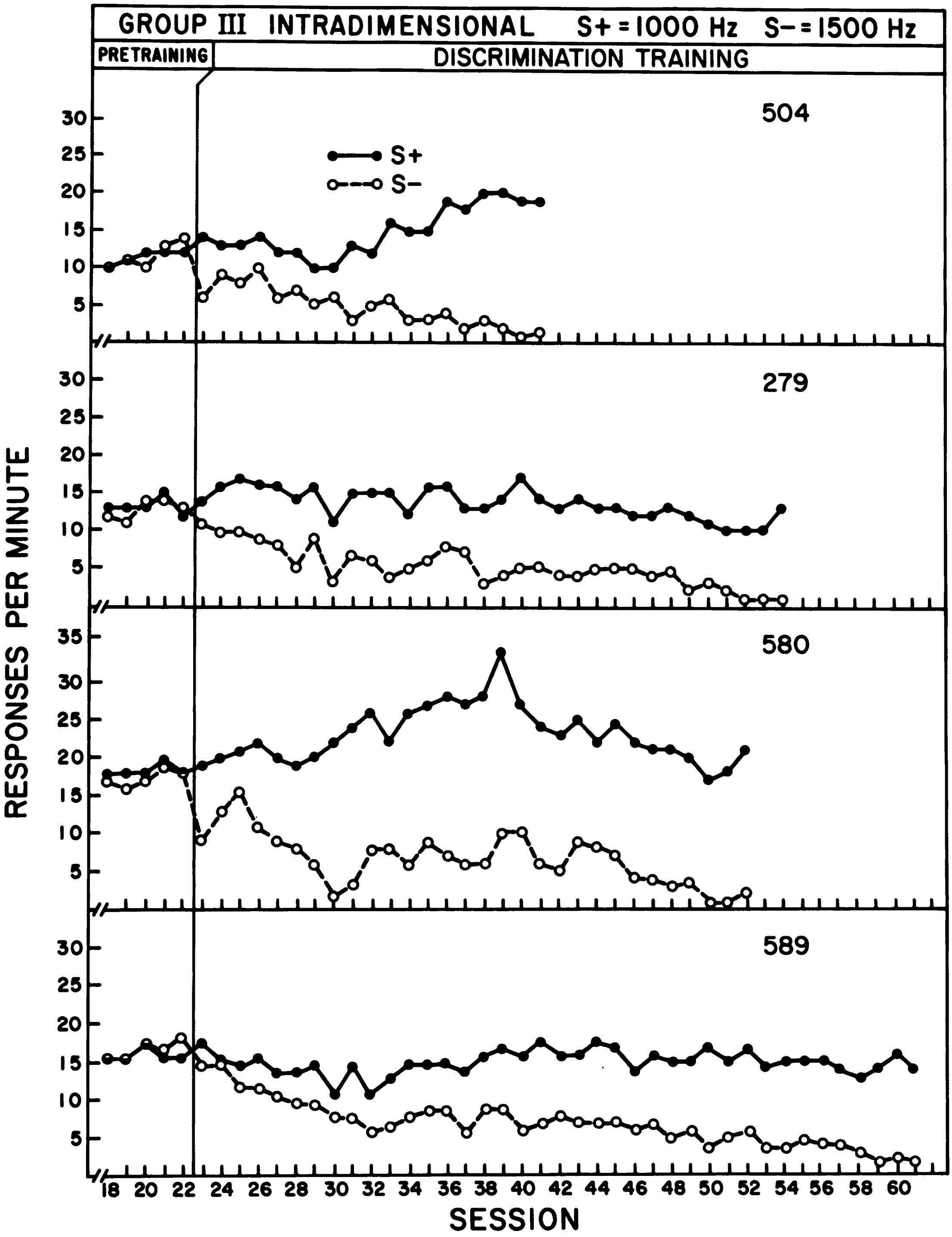
GROUP III INTRADIMENSIONAL S+ = 1000 Hz S− = 1500 Hz
PRETRAINING
DISCRIMINATION TRAINING
504
279
580
589
S+
S−
RESPONSES PER MINUTE
SESSION
5
10
15
20
25
30
35
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60

Figure 2.

prediscrimination training. As in Groups I and II, three of the four birds showed decreased avoidance percentages during the first session of discrimination training (Table 1, Column IV). The birds in Group III required a mean of 7.5 sessions to return to the previous higher avoidance percentages.

Generalization: Figures 3 and 4 present the results of the generalization tests. The gradients displayed in Figure 3 are relative gradients for each group. The total responses of the group to each tone stimulus is expressed as a percentage of the total responses to all test stimuli on the tone dimension. The gradients in Figure 4 are the absolute gradients obtained from each individual generalization test. In both Figures 3 and 4, the results of tests conducted with scheduled shocks are displayed as two gradients. The solid lined gradients (WSE) include all responses to each tone stimulus, while the broken lined gradients (W/OSE) exclude shock-elicited responses, which were defined as all responses that occurred within 3 sec after a shock. Note that the ordinate scales are different for gradients within each figure.

The upper gradients in Figure 3 are the results for Group I of tests conducted with scheduled shocks (upper left) and without scheduled shocks (upper right). The upper left-hand gradients (WSE and W/OSE) are based on five individual tests for the birds in Group I (Bird 1037 died before the final test).

Both the WSE and W/OSE gradients for this group were

Figure 3. Group I (upper panel), Group II (center panel), and Group III (lower panel) relative generalization gradients. Total responses of the group to each tone stimulus is expressed as a percentage of the total responses to all test stimuli on the tone dimension. The gradients on the left are the results of tests conducted with avoidable shocks. In these gradients, the solid-lined gradients (WSE) include shock-elicited responses, while the broken-lined gradients (W/OSE) exclude shock-elicited responses. The gradients on the right are from tests conducted without scheduled shocks. The numbers alongside the centerlines in the Group III (lower) gradients indicate the proportion of responses on each side of S+. Tones are spaced at approximately equal intervals along a log scale. Note that the ordinate scale on the Group I (upper right) no-shock gradient differs from the other ordinate scales.

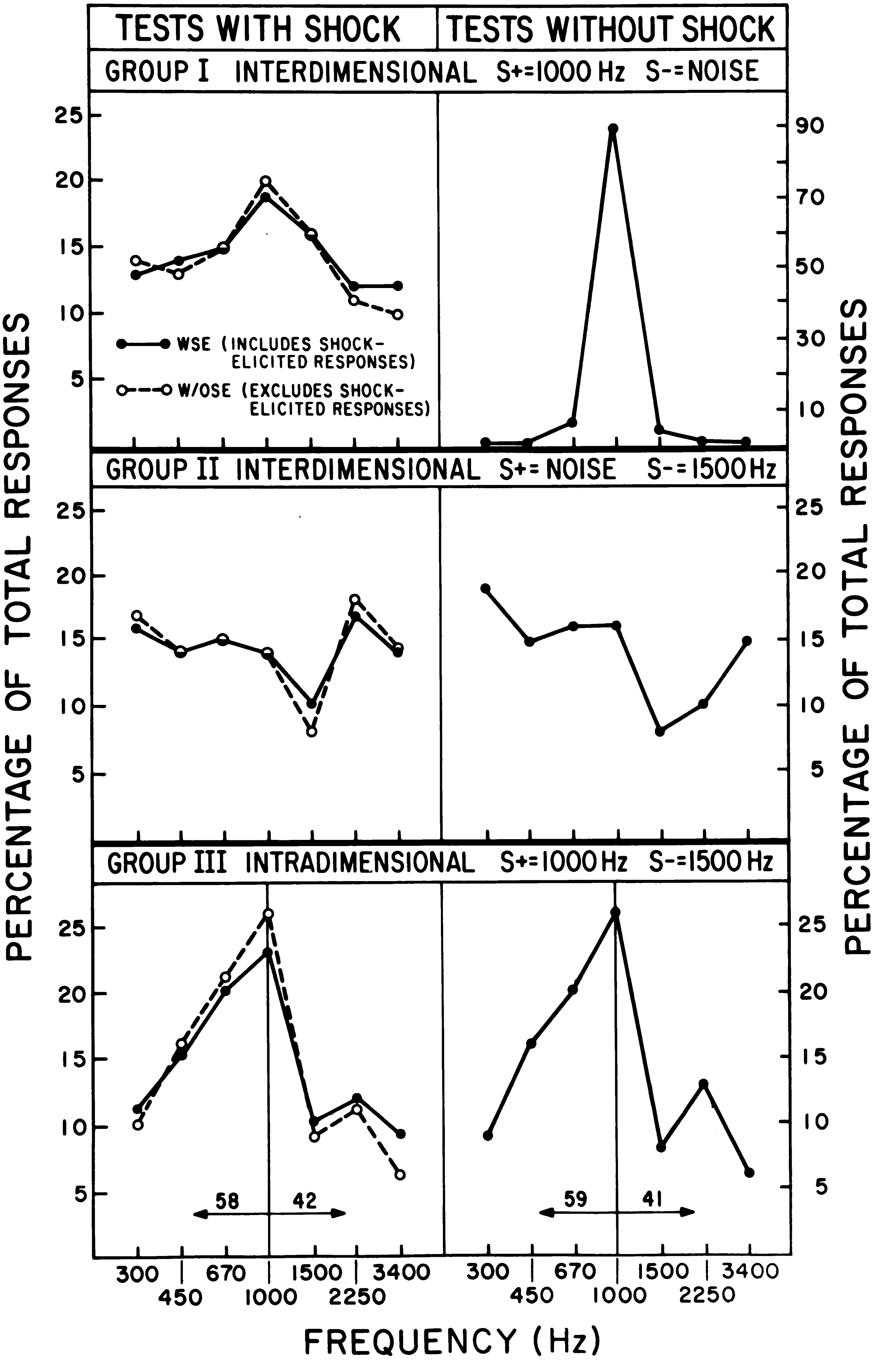
TESTS WITH SHOCK
TESTS WITHOUT SHOCK
GROUP I INTERDIMENSIONAL S+=1000 Hz S-=NOISE
GROUP II INTERDIMENSIONAL S+=NOISE S-=1500 Hz
GROUP III INTRADIMENSIONAL S+=1000 Hz S-=1500 Hz
WSE (INCLUDES SHOCK-ELICITED RESPONSES)
W/OSE (EXCLUDES SHOCK-ELICITED RESPONSES)
PERCENTAGE OF TOTAL RESPONSES
5
10
15
20
25
10
30
50
70
90
58
42
59
41
300
450
670
1000
1500
2250
3400
FREQUENCY (Hz)

Figure 3.

quite symmetrical and showed maximum responding at S+. The subtraction of shock-elicited responses from the WSE gradient (solid line) had very little effect on the percentage of responses to each stimulus, and thus had little effect on the shape of the relative W/OSE gradient (broken line).

The upper right-hand gradient in Figure 3 is the Group I relative gradient for the six tests conducted without scheduled shocks. In this case, practically all responses (90%) occurred in the presence of S+, with only a few responses in the presence of the stimuli immediately adjacent to S+. This result is in sharp contrast to the gradients obtained in the tests with scheduled shocks (upper left-hand panel), where many responses occurred in the presence of each test stimulus.

The top panel of Figure 4 presents the eleven individual absolute gradients which produced the relative gradients in the upper panel of Figure 3. The five generalization tests conducted with scheduled shocks are again represented by double gradients (WSE and W/OSE). The numbers above the data points on the WSE gradients indicate the number of shocks received in the presence of the corresponding stimulus during the test. The general effect of the shocks during the tests was to nondifferentially raise the entire gradient. Subtracting shock-elicited responses from the WSE gradients produced W/OSE gradients almost identical in shape to the WSE gradients. There was no evidence of a correspondence between the number of shocks received in the

Figure 4. Group I (upper panel), Group II (center panel), and Group III (lower panel) individual absolute gradients. There were four birds in each group, and the results for each bird's three generalization tests are presented in the order in which the tests were given (Bird 1037 in Group I died prior to test 3). In the gradients from tests with scheduled shock, the solid-lined gradient includes shock-elicited responses, while the broken-lined gradient excludes shock-elicited responses. The number above each data point on these gradients indicates the number of shocks received in the presence of the corresponding stimulus value. The filled triangles in the Group I and Group II gradients indicate the level of responding during the test to the white noise anchoring stimulus (see text for details). The numbers alongside the centerlines in the Group III (lower) gradients indicate the proportion of responses on each side of S+. Tones are spaced at approximately equal intervals along a log scale. Note the different ordinate scales.

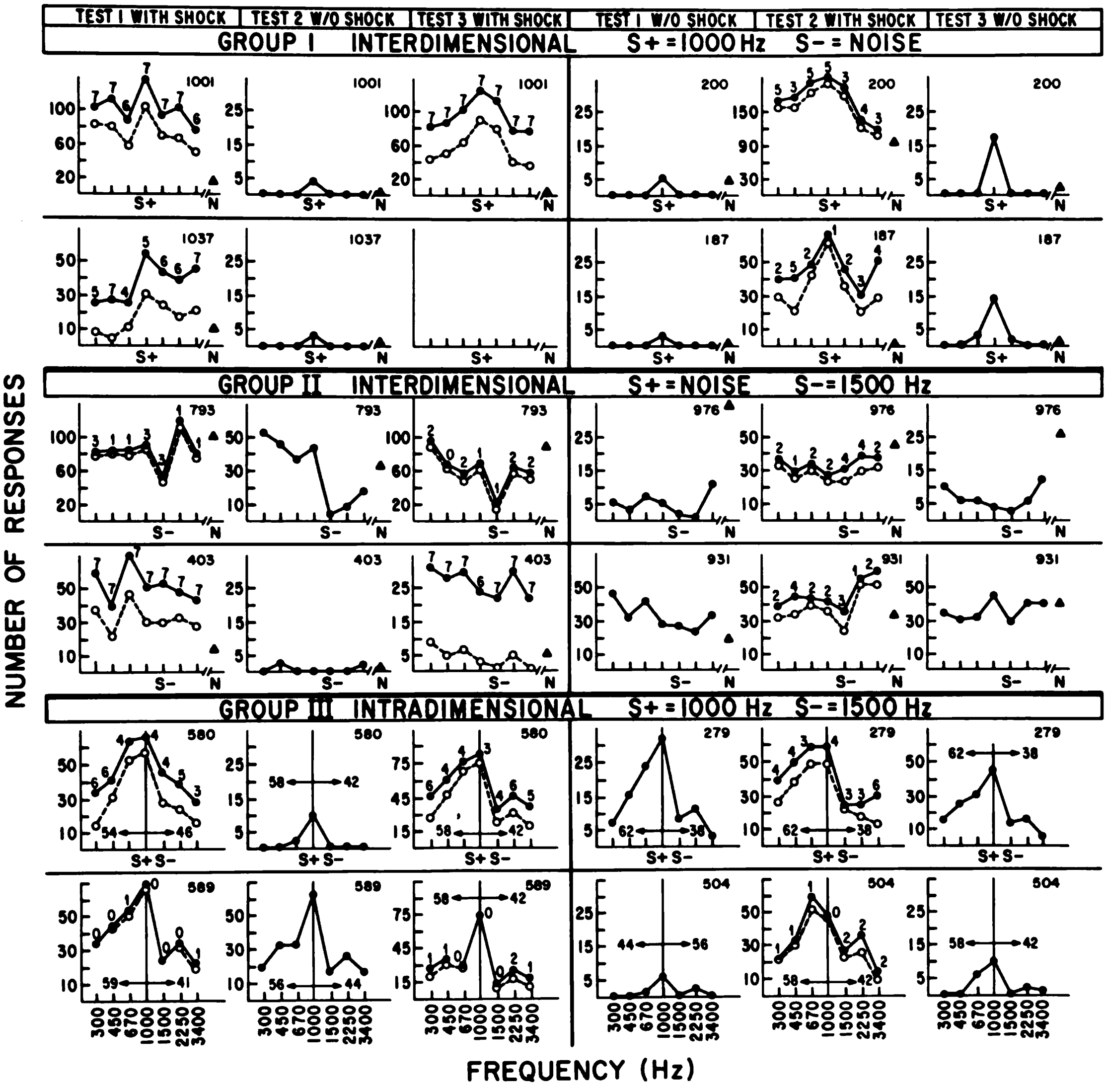
TEST 1 WITH SHOCK
TEST 2 W/O SHOCK
TEST 3 WITH SHOCK
TEST 1 W/O SHOCK
TEST 2 WITH SHOCK
TEST 3 W/O SHOCK
GROUP I INTERDIMENSIONAL S+ = 1000 Hz S- = NOISE
GROUP II INTERDIMENSIONAL S+ = NOISE S- = 1500 Hz
GROUP III INTRADIMENSIONAL S+ = 1000 Hz S- = 1500 Hz
1001
1037
200
187
793
403
976
931
580
589
279
504
S+
S-
N
NUMBER OF RESPONSES
300
450
670
1000
1500
2250
3400
FREQUENCY (Hz)

Figure 4.

presence of a stimulus and the number of responses in the presence of that stimulus. For example, during test 3, Bird 1001 received seven shocks (the maximum) at each stimulus value and still produced a typical excitatory gradient with a peak at S+. Bird 187 (test 2) received only one shock in the presence of S+ where maximum responding occurred. The bird received more than one shock in the presence of every other test stimulus. Bird 200 (test 2) received five shocks at S+ where maximum responding occurred. The bird also received five shocks at 300 and 670 Hz, and fewer than five shocks in the presence of the other test stimuli.

The top panel of Figure 4 also shows that the results of the six tests conducted without scheduled shocks were different from those conducted with scheduled shocks. In particular, there were very few responses in the tests without shocks. However, all of the gradients had peaks at S+, where almost all responding occurred. Only Bird 187 (test 3) responded to stimuli other than S+, and then responded only five times to stimuli immediately adjacent to S+.

The single data point (N) on each graph in Figure 4 is a function of the number of responses in the presence of white noise during the test, and was computed by dividing the number of responses in the presence of white noise by seven. This transformation was performed because the white noise "anchor stimulus" alternated with every test stimulus presentation, and thus total exposure time to white noise was seven times as long (24.5 min) as the total exposure

time to each test stimulus (3.5 min).

For Group I, white noise was S- during discrimination training. During the generalization tests, responding in the presence of white noise was quite low and sporadic. Figure 4, upper panel, shows that there were very few responses in the presence of white noise during the tests without scheduled shocks. Figure 4 (upper panel) also shows that response levels to white noise were higher during the tests with scheduled shocks than during the tests without scheduled shocks. However, in four of the five tests conducted with scheduled shocks, there were fewer responses to white noise than to any of the test stimuli. Only Bird 1037 (test 1) responded to white noise at a slightly higher rate than to two of the test stimuli.

The gradients in the center of Figure 3 are the results for Group II of tests conducted with scheduled shocks (left-hand) and without scheduled shocks (right-hand). The center left-hand gradients (WSE and W/OSE) are based on six individual tests for the birds in Group II.

Both the WSE and W/OSE gradients for Group II were incremental, with minimum responding at S- (1500 Hz). As in Group I, the subtraction of shock-elicited responses from the WSE gradient (solid line) had little effect on the percentage of responses to each stimulus, and thus had little effect on the shape of the relative W/OSE gradient (broken line).

Figure 3, center right, shows the Group II relative gradients for the six tests conducted without scheduled shocks. In contrast to the results for Group I, this gradient is quite similar to the gradients obtained with scheduled shocks (center left). For Group II, the largest difference between the gradients obtained with and without scheduled shocks occurred at 2250 Hz (adjacent to S-). In the tests with shocks, 17% of total responses occurred in the presence of 2250 Hz, while in the tests without shocks, only 10% occurred in the presence of 2250 Hz.

The center panel (horizontal) of Figure 4 presents the twelve individual absolute gradients which produced the relative gradients in the center panel of Figure 3. The six generalization tests conducted with scheduled shocks are again represented by double gradients (WSE and W/OSE). As in Group I, subtracting shock-elicited responses from the WSE gradients produced W/OSE gradients very similar in shape to the WSE gradients. Also as in Group I, the general effect of the shocks during a test was to nondifferentially raise the entire gradient. There was no evidence of a correspondence between the number of shocks received in the presence of a stimulus and the number of responses in the presence of that stimulus. For example, during test 3, Bird 403 received seven shocks at every stimulus value except one (1000 Hz) and still produced an inhibitory gradient with a minimum at S-. Bird 793 (test 3) received only one shock in the presence of S- where minimum responding occurred. The bird received zero and one shock at 450 and 1000 Hz

respectively, and more than one shock in the presence of each other test stimulus. Bird 931 (test 2) received three shocks in the presence of S- where minimum responding occurred. The bird received four shocks at 450 Hz, and fewer than three shocks in the presence of the other test stimuli.

The center panel of Figure 4 also shows the results of the six tests conducted without scheduled shocks. Four of the six gradients showed minimum responding at S-, while the remaining two gradients (Bird 976, test 1; Bird 931, test 1) showed minimum responding at 2250 Hz, a stimulus adjacent to S-. Unlike Group I, which had almost zero responses during the tests without shocks, the birds in Group II, with the exception of Bird 403 (test 2), responded to every test stimulus. Indeed, during the tests without shocks, Bird 931 responded at levels very near those during the test with shock.

For Group II, white noise was S+ during discrimination training. In four of six tests with scheduled shocks, the birds responded at about the same rates to white noise and the test stimuli (Figure 4, center panel). Only Bird 403 (tests 1 and 3) responded consistently less to white noise than to the test stimuli. However, most of Bird 403's responses to the test stimuli were shock-elicited, as indicated by the relatively large differences in magnitude between the WSE and W/OSE gradients, and by the number of shocks received at each stimulus. Also, in the test without shock (test 2), Bird 403 extinguished almost completely in the presence of all stimuli. In the other five gradients obtained in tests without scheduled shocks, the birds responded to white noise at about the same rate or higher than to the test stimuli.

The lower gradients in Figure 3 are the results for Group III (intradimensional) of tests conducted with scheduled shocks (left) and without scheduled shocks (right). The lower left-hand gradients (WSE and W/OSE) are based on six individual tests for the birds in Group III.

Both the WSE and W/OSE gradients for Group III showed maximum responding at S+ (1000 Hz), and relatively little responding at S- (1500 Hz). While the group relative gradients did not show peak shift, area shifts in the predicted direction were obtained. In an area shift more than 50% of the area under the gradient lies on the side of S+ away from S- (Terrace, 1966; Hearst, 1969a). Figure 3 lower left, shows that 58% of Group III's test responses were on the side of S+ away from S-, while 42% were on the side of S+ toward S-. These results were not due to a preference for low frequency stimuli, since the upper panel of Figure 3 shows symmetrical gradients. As in Groups I and II, the subtraction of shock-elicited responses from the WSE gradient (solid line) had little effect on the percentage of responses to each stimulus, and thus had little effect on the shape of the relative W/OSE gradient (broken line).

Figure 3, lower right, shows the Group III relative gradients for the six tests conducted without scheduled shocks. As in Group II, and in contrast to Group I, this gradient was quite similar to the gradient obtained with scheduled shocks (lower left). Even the area shift was similar to the gradients obtained with scheduled shocks, with 59% of the test responses on the side of S+ away from S-.

The lower panel of Figure 4 presents the twelve individual absolute gradients which produced the relative gradients in the lower panel of Figure 3. The six generalization gradients obtained with shocks are again represented by double gradients (WSE and W/OSE). As in Groups I and II, subtracting shock-elicited responses from the WSE gradients produced W/OSE gradients very similar in shape to the WSE gradients. Also as in Groups I and II, the general effects of the shocks during a test was to nondifferentially raise the entire gradient. There was no evidence of a correspondence between the number of shocks received in the presence of a stimulus and the number of responses in the presence of that stimulus. For example, during test 1, Bird 589 received zero shocks at S+ where maximum responding occurred. The bird received one shock in the presence of 670 and 3400 Hz, and zero shocks in the presence of the other test stimuli. Bird 580 (test 3) received three shocks in the presence of S+ where maximum responding occurred. The bird received <u>more</u> than three shocks in the presence of the other test stimuli. Bird 279 (test 2) received four shocks in the presence of S+ where maximum responding occurred. The bird received four or <u>fewer</u> shocks in the presence of the other test stimuli, with the exception of 3400 Hz, where six shocks were received.

During the tests with shocks, only Bird 504 (test 2) produced unequivocal peak shift, while Bird 279 (test 2) produced an equivocal peak shift. However, all of the birds produced area shifts in these tests, ranging from 54% to 62%.

The lower panel of Figure 4 also shows the results of the six tests conducted without scheduled shocks. All of the gradients thus obtained showed maximum responding at S+. As in Group II, the birds in Group III responded to almost every test stimulus. For example, during the test without shocks, Bird 589 responded at levels very near those during the tests with shocks.

None of the birds in Group III produced peak shift during the tests without shocks. However, five of the six gradients thus obtained showed area shifts ranging from 56% to 62%. Only Bird 504 (test 1) failed to produce area shift, with 44% of responses on the side of S+ away from S-. In the two subsequent tests however, Bird 504 produced a 58% area shift.

DISCUSSION

Sidman (1966) argued that it is often difficult to train a discrimination in an avoidance situation because a well trained animal rarely pauses longer than the RS interval, and therefore receives few shocks. Consequently, it may be difficult for the animal to learn that avoidance is unnecessary during an S- (extinction) component of a multiple schedule. Hearst (1962) encountered difficulties in attempting to train free-operant avoidance discrimination when the physical properties of the controlling stimuli did not differ much. Hearst (1969b) noted that keen discriminations between stimuli are impaired under stress and the precision of stimulus control often decreases.

The results of the present experiment imply, however, that as in appetitive situations (Hearst, 1968, 1969a), the major variable affecting the formation of a discrimination in an avoidance situation is the physical difference between S+ and S-. In Groups I and II, where S+ and S- were on different stimulus dimensions, the discrimination was learned very rapidly (Figure 1). In Group III (Figure 2), where S+ and S- were on the same stimulus dimension, it took considerably longer for the birds to learn the discrimination. Appel (1960) using rats in free-operant avoidance, found

that with S+ = tone and S- = no-tone, the discrimination was learned in five to seven sessions.

In contrast to appetitive situations, when a novel stimulus is presented during free-operant avoidance behavior, it is likely to have a facilitating effect on the behavior (Stone and MacLean, 1963). In the present study, it appears that the introduction of novel stimuli had a slight depressing effect on the avoidance behavior, and the resulting decrease in response rates allowed the birds to encounter the new (extinction) contingencies during S-. If the introduction of novel stimuli had had a facilitating effect on the avoidance behavior, it would have taken considerably longer for the birds to encounter extinction during S- (since most birds were avoiding over 90% of scheduled shocks), and increased rather than decreased avoidance percentages during S+ would have occurred.

Relaxation theory (Denny and Adelman, 1955; Denny, 1971) seems to best explain the way in which the present discriminations were formed. First, the novel S- stimulus depressed the behavior enough for the birds to encounter the extinction schedule. Then, according to relaxation theory, the birds initially experienced short-latency relief, and later, long-latency relaxation, which is a consummatory response (UCR) for a frightened animal when a fearful stimulus is absent for a period of time. The relaxation then carried over to the S+ component, where it competed with fear, which is the animal's innate response to a frightening situation, and

resulted in the lower avoidance percentages during the early sessions of discrimination training. Since relaxation and fear are competing responses, discrimination performance should be impaired if the cues for fear are similar to the cues for relaxation. Thus, Groups I and II learned the discrimination in much less time than Group III, because the cues for relaxation and fear were much more dissimilar in Groups I and II (interdimensional) than in Group III (intradimensional).

Sidman (1961), using monkeys in free-operant avoidance, obtained intradimensional generalization gradients (PDG's) along the click frequency dimension. In some generalization tests the negative stimulus (6 clicks/sec) alternated with each test stimulus, and in other tests the positive stimulus (2 clicks/sec) alternated with each test stimulus. No shocks were delivered during the generalization tests. The results of Sidman's (1961) experiments were as follows: (1) The slopes of the obtained gradients were of the same order of magnitude as those obtained in appetitive generalization tests (Hanson, 1959). (2) All of the gradients showed less responding as the test stimulus diverged form S+ and approached S-, where S+ and S- were the opposite extremes of the test stimuli. (3) The gradients were steeper when S+ was the "anchoring" stimulus (i.e. alternated with each test stimulus) than when S- was the anchoring stimulus. Sidman (1961) also studied the effects of response-shock interval and shock duration, and concluded that the shape of the generalization gradient was independent of these variables, and in general, independent of variables that altered the subjects' rate of avoidance responding.

In the present study, Group I had an S- anchoring stimulus and Group II had an S+ anchoring stimulus during generalization testing. Figure 4 shows that Group I responded at substantially lower rates than Group II during tests conducted without shocks. This result is contrary to appetitive situations where more responses are usually obtained during the excitatory tests than during inhibitory tests (Hearst, Besley, and Farthing, 1970). The effect seems to be due to the value of the anchoring stimulus. In terms of relaxation theory (Denny and Adelman, 1955; Denny, 1971), during discrimination training for Group I, relaxation became conditioned to white noise (S-) and fear was conditioned to the 1000 Hz tone (S+). In Group II, relaxation was conditioned to the 1500 Hz tone (S-), and fear was conditioned to the white noise (S+). During the generalization tests, Group I was presented with the S- anchor stimulus before and after each test (tone) stimulus. Since this stimulus (S-) was the same value as during discrimination training, and the test stimuli were different from S+ on 86% of test presentations, there was more generalization decrement on the test dimension than to the anchoring stimulus. Thus, the predominant response tendency throughout the test (without shocks) was relaxation, which competed with the avoidance response. A similar argument leads to the conclusion that the predominant response tendency throughout Group II's generalization tests without shocks was fear, which competed with the relaxation to the test stimuli. The fact that five of the six tests without shock for Group I showed zero responding to all stimuli except S+, and five of six tests for Group II showed above zero responding to all stimuli including S- lends support to this interpretation.

It also appears that we can now extend Sidman's (1961) finding that the shape of the generalization gradient is independent of variables that alter the subject's rate of avoidance responding. The results of the present study suggest that the avoidable shocks during the generalization tests had little effect on the shape of the gradients. Subtracting shock-elicited responses from the WSE gradients produced W/OSE gradients almost identical in shape to the WSE gradients. In addition, the Group III area shifts in tests with scheduled shocks were very similar to the area shifts in tests without scheduled shocks (Figures 3 and 4).

The shocks during the generalization tests did, however, affect the magnitude of the gradients. Compared with the no-shock gradients, the gradients obtained with shocks generally showed much higher response levels. It appears that the shocks elevated the entire gradient nondifferentially. Thus, the data suggests that the wings of the no-shock gradients from Group I were hidden by the low magnitude of response which resulted from the S- anchoring stimulus (a floor effect).

Terrace (1966, 1972) argues that, during discrimination training, S- becomes aversive as a result of nonreinforced responding and thus accounts for peak shift and behavioral contrast. Bloomfield (1969) maintains that the main determinant of the peak shift and behavioral contrast is the change for the worse in one component of the multiple schedule, and that the change for the worse takes place during discrimination training. The results of the present study support neither theory. Terrace (1972, p.233) says "... those training procedures which produce contrast also produce peak shift and vice-versa." Apparently, the "vice-versa" does not hold in avoidance situations since none of the birds in Group III showed unequivocal contrast, but two birds showed peak shift and all showed area shifts during generalization tests.

Bloomfield's theory (1969) in particular has difficulty explaining the present results since many studies have shown that a stimulus correlated with time-out from avoidance has positive reinforcing properties (Sidman, 1962; Verhave, 1962; Weisman and Litner, 1969; Lolordo, 1969; Baron and Trenholme, 1971; Emurian and Weiss, 1972). Thus, introduction of an S- component associated with avoidance extinction cannot readily be construed as a change for the worse. Terrace (1972), who maintains that peak shift is obtained following discrimination training in which unreinforced responses to S- occur, has a similar difficulty. It would be difficult to argue that the Group III birds' responses to

S- were unreinforced, particularly early in discrimination training. With the birds avoiding effectively in S+ components, responses in S- components had the same consequences; e.g. a period of no shocks.

Gradient interaction theory (Spence, 1937), which predicts the obtained peak and area shifts, is supported by the present results since it makes no assumptions about the functional negativity of S-. The only assumption is that S- acts in a direction opposite to that of S+. For example, in the present experiment, relaxation to S- and fear to S+ (Denny, 1971) appear to have been the predominant response tendencies in the presence of the discriminative stimuli.

According to Spence, the number of responses to each test stimulus is the resultant of the algebraic summation of generalized excitation to S+ and generalized inhibition to S-. In the present study, Group I demonstrated excitatory stimulus control and Group II demonstrated inhibitory stimulus control since the gradients for these groups had non-zero slopes (Terrace, 1972). Thus, due to the experimental design (Hearst, 1968, 1969a), Spence's theory (1937) predicts that the algebraic summation of the Group I gradient and the Group II gradient will be the Group III gradient (Hearst, 1968, 1969a).

Following Hearst (1968, 1969a), the values of the empirical WSE relative gradients of excitation and inhibition in Figure 3 were used to plot the summation curves shown in the left panel of Figure 5 (the no-shock gradients were not

Figure 5. (left) Relative gradients of excitation (closed triangles) and inhibition (squares). The excitatory gradient is the WSE gradient of Figure 3 (upper left). The inhibitory gradient is calculated from the WSE gradient of Figure 3 (center left). Details of the calculations are given in the text. The numbers in the square brackets alongside the vertical lines between the gradients represent the algebraic sum of the two points which the particular line connects. The numbers in parentheses alongside the same vertical lines were obtained by transforming the numbers in square brackets to a scale of 100. (right) Empirical (closed circles) post-intradimensional discrimination gradient (PDG) of relative generalization from Figure 3 (WSE), compared with PDGs derived from the calculations on the left. The values on Derived PDG 1 are from the square brackets on the left, while the values on Derived PDG 2 are from the parentheses on the left.

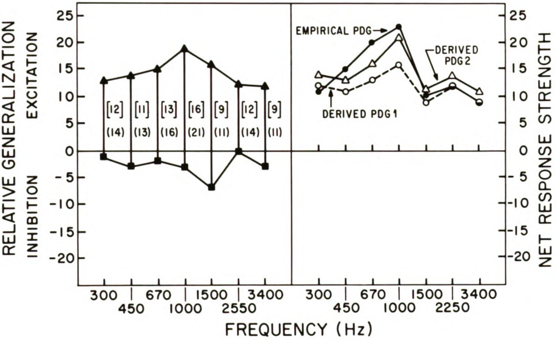
RELATIVE GENERALIZATION
EXCITATION
INHIBITION
25
20
15
10
5
0
-5
-10
-15
-20
[12]
(14)
[11]
(13)
[13]
(16)
[16]
(21)
[9]
(11)
[12]
(14)
[9]
(11)
300
450
670
1000
1500
2550
3400
EMPIRICAL PDG
DERIVED PDG 2
DERIVED PDG 1
300
450
670
1000
1500
2250
3400
FREQUENCY (Hz)
NET RESPONSE STRENGTH

Figure 5.

used because almost all responses were to S+ in Group I). The excitatory gradient (filled triangles) was plotted in the same way as in Figure 3 (upper left). The empirical inhibitory gradient of Figure 3 (center left) was displaced downward along the ordinate to yield the values in Figure 5; maximum responding was arbitrarily set at zero and, by subtraction, the other points in the Figure 3 inhibitory gradient were converted to negative values (Hearst, 1968, 1969a).

The gradients (Figure 5, left) were then algebraically summed, yielding the numbers in the square brackets alongside the vertical lines between each set of points. The broken line postdiscrimination gradient (Derived PDG 1) on the right in Figure 5 was plotted according to the values obtained by this summation. The agreement between the shape of Derived PDG 1 and the empirical gradient from Group III (filled circles) was fairly good, since four of the seven points (300, 1500, 2250, 3400) match almost exactly, and a 54% area shift to the left was predicted (as compared with 58% for the empirical gradient).

While the gradient produced by this summation procedure (Hearst, 1968, 1969a) supports Spence's theory (1937), the summation procedure itself makes it almost impossible to exactly fit derived gradients to relative empirical postdiscrimination gradients. The sum of the points on a relative postdiscrimination gradient is 100, since the gradient is plotted according to proportions of total responding. On the other hand, the differences between the points on the

excitatory and inhibitory gradients do not necessarily sum to 100. When the derived values do not sum to 100, it is impossible to map them to a same sized set of points which do sum to 100.

In the present study, the derived values summed to 82 (Figure 5, left), and this accounts for Derived PDG 1 being almost everywhere lower than the empirical PDG (Figure 5, right). However, when the derived values (square brackets) were converted to proportions of the total, as was done in computing the empirical relative postdiscrimination gradient, the fit of the gradients was improved considerably. The numbers in parentheses (Figure 5, left) alongside the vertical lines represent the percentage of the total (82) for each derived value in square brackets. The open triangle gradient (Derived PDG 2) on the right in Figure 5 was plotted according to these transformed values from Derived PDG 1. While there was less agreement between the individual points on Derived PDG 2 and the empirical postdiscrimination gradient, the shape of Derived PDG 2 is a considerable improvement over the shape of Derived PDG 1. The 54% area shift to the left in Derived PDG 2 was the same as for Derived PDG 1.

Miller (1959, 1961) maintained that there is a fundamental difference between stimulus generalization of avoidance and approach behavior. For Miller, control by external stimulus dimensions is assumed to be greater for avoidance behavior than for approach behavior, and runway tests with rats have supported this assumption by producing approach

gradients which are flatter than avoidance gradients. On the other hand, Hearst (1969b) argued persuasively that there is no compelling reason for assuming that external cues are more important in avoidance behavior than in approach behavior. He attributed the differences in gradient shapes to procedural differences. "By proper manipulation of certain experimental conditions, one can produce a steep approach gradient or a flat approach gradient, a steep avoidance gradient or a flat avoidance gradient." (Hearst, 1969b, p.263). Hearst concluded that fundamental differences between the stimulus generalization of approach and avoidance will probably not emerge.

The present avoidance results support both Hearst and Spence, since, except for the absence of behavioral contrast during discrimination training, they are comparable in almost every aspect to the results of similar studies conducted in appetitive situations (Hearst, 1968, 1969a; Marsh, 1972). Therefore, it appears that there is no basic dichotomy between stimulus generalization of avoidance and approach behavior.

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