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Generalization of a Relational Discrimination

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GENERALIZATION OF
A RELATIONAL DISCRIMINATION

by

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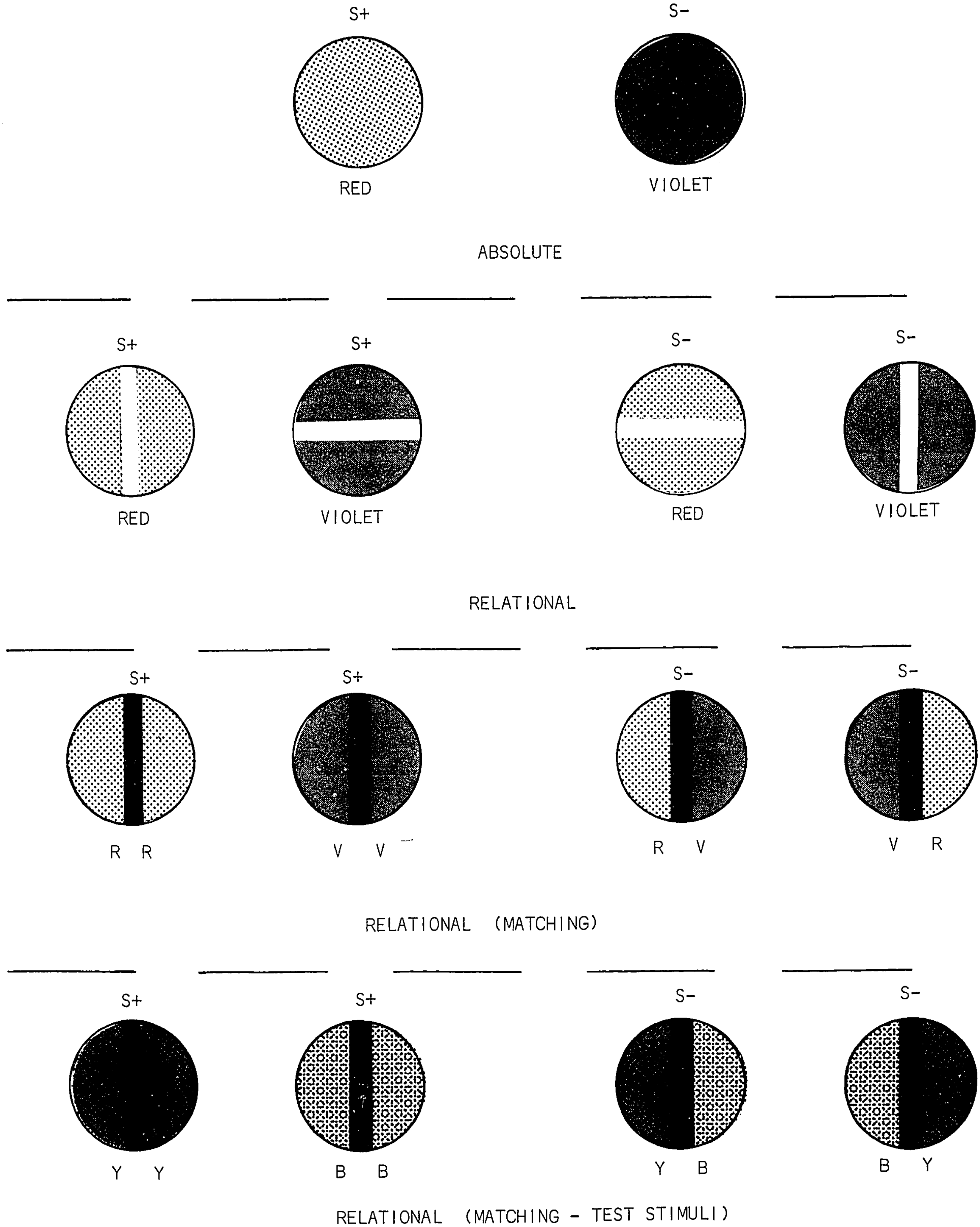
Discriminations fall into one of two categories: absolute (simple) discriminations (a in Fig. 1) and relational (complex or conditional) discriminations (b in Fig. 1). Absolute discriminations are based on differences in one stimulus aspect (typically along a single stimulus dimension), such as wavelength or line angle. Relational discriminations are based on differences in two or more stimulus aspects. The defining characteristic is that the discrimination must be based on a relation between the various aspects (such as wavelength and line angle) of the stimulus.

Stimulus matching is an example of a relational discrimination. In stimulus matching, as studied by Malott and Malott (1967), responses are reinforced when both halves of the response key are the same color, and they are not reinforced when each half is a different color (c in Fig. 1). To discriminate between matching and nonmatching stimuli, it is necessary to repond on the basis of the relation between the colors on the two halves of the key.

Recently, Malott and Malott (1967), demonstrated generalized stimulus matching using a single-response free-operant procedure. In that study, key peck responses were reinforced when both halves of the key were red or both halves of the key were violet; responses were not reinforced when the nonmatching combinations of red and violet were present (c in Fig. 1). Subsequent generalization tests with yellow and blue resulted in higher response rates when both halves of the key were yellow or both halves were blue than when one half of the key was blue and the other half was yellow (d in Fig. 1). The matching behavior had generalized to novel colors.

Figure 1. Examples of (a) an absolute discrimination, (b) a relational discrimination, (c) relational discrimination (stimulus matching) stimuli used in training by Malott and Malott (1967), and (d) stimulus matching stimuli used in a generalization test by Malott and Malott (1967).

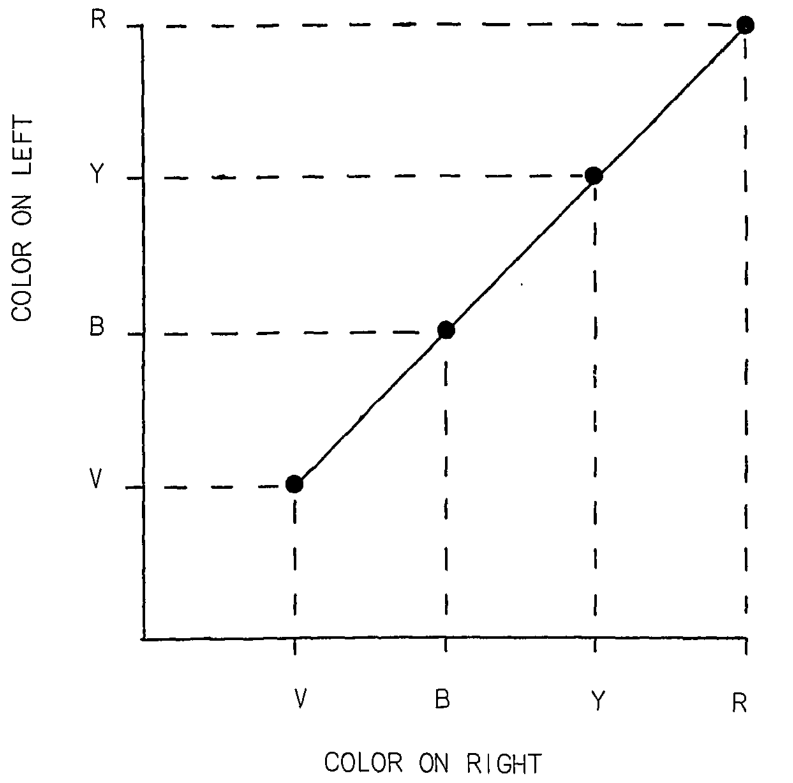

S+
S-
RED
VIOLET
ABSOLUTE
S+
S+
S-
S-
RED
VIOLET
RED
VIOLET
RELATIONAL
S+
S+
S-
S-
R R
V V
R V
V R
RELATIONAL (MATCHING)
S+
S+
S-
S-
Y Y
B B
Y B
B Y
RELATIONAL (MATCHING - TEST STIMULI)

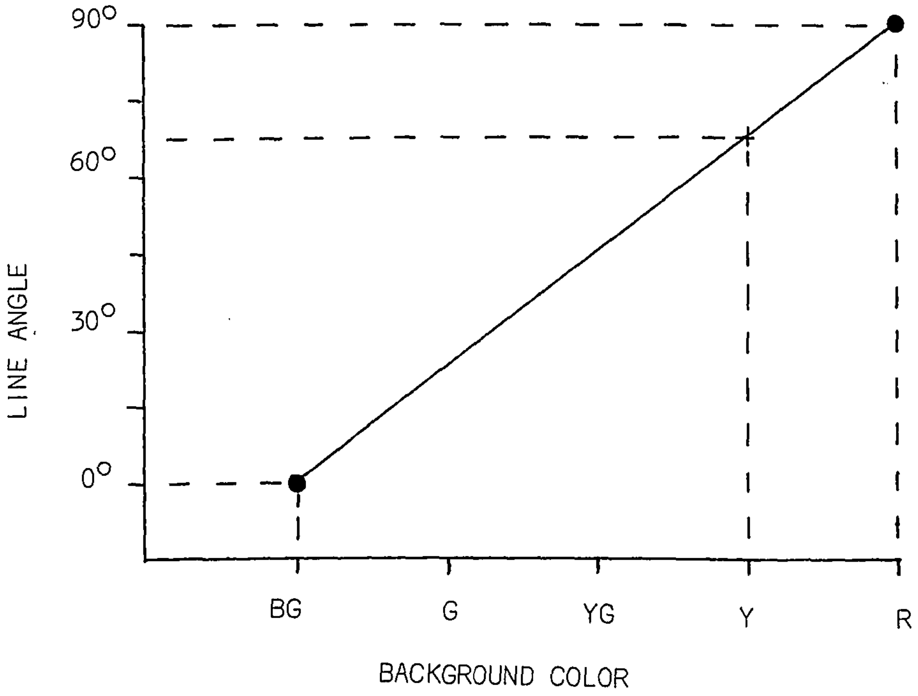
The stimuli in stimulus matching can be functionally transformed from colors on both halves of the key to colored backgrounds and line angles as follows: Given the matching stimuli in c of Fig. 1, let the functions of red on the right be performed by a 90° line (vertical) and violet on the right by a 0° (horizontal) line. The color of the background will perform the function of color on the left half of the key. By doing this, red-red is logically equivalent to a 90° line on a red background, red-violet to a 0° line on a red background, violet-red to a 90° line on a violet background, and violet-violet to a 0° line on a violet background. Such changes do not alter the fact that the discrimination is relational, only the specific stimuli are changed.

If the formal equivalence is also a behavioral one, the results of the Malott and Malott (1967) matching study have interesting implications for the relational discrimination. If two different stimulus aspects (for example, angle of white line and color of background) were used instead of two separate but identical stimulus aspects (such as color of the right side and color of the left side of the key), would similar results be obtained? It seems reasonable to predict that, if the relational discriminaton were based on line angle and background color, in testing with novel stimuli, the subjects would also respond in keeping with the relation between aspects present during training.

Extrapolating from the Malott and Malott study, if in a generalization test for stimulus matching, one half of the response key were always red and the color on the other half were varied, response rate should be highest when the color on the varied half were also red. In

Figure 2. Top: a theoretical equal response contour showing the relation between the colors on each half of the key in stimulus matching. Bottom: a theoretical equal response contour showing the relation between line angle and background color in the relational discrimination involved in the present experiment.


R
Y
B
V
COLOR ON LEFT
V
B
Y
R
COLOR ON RIGHT

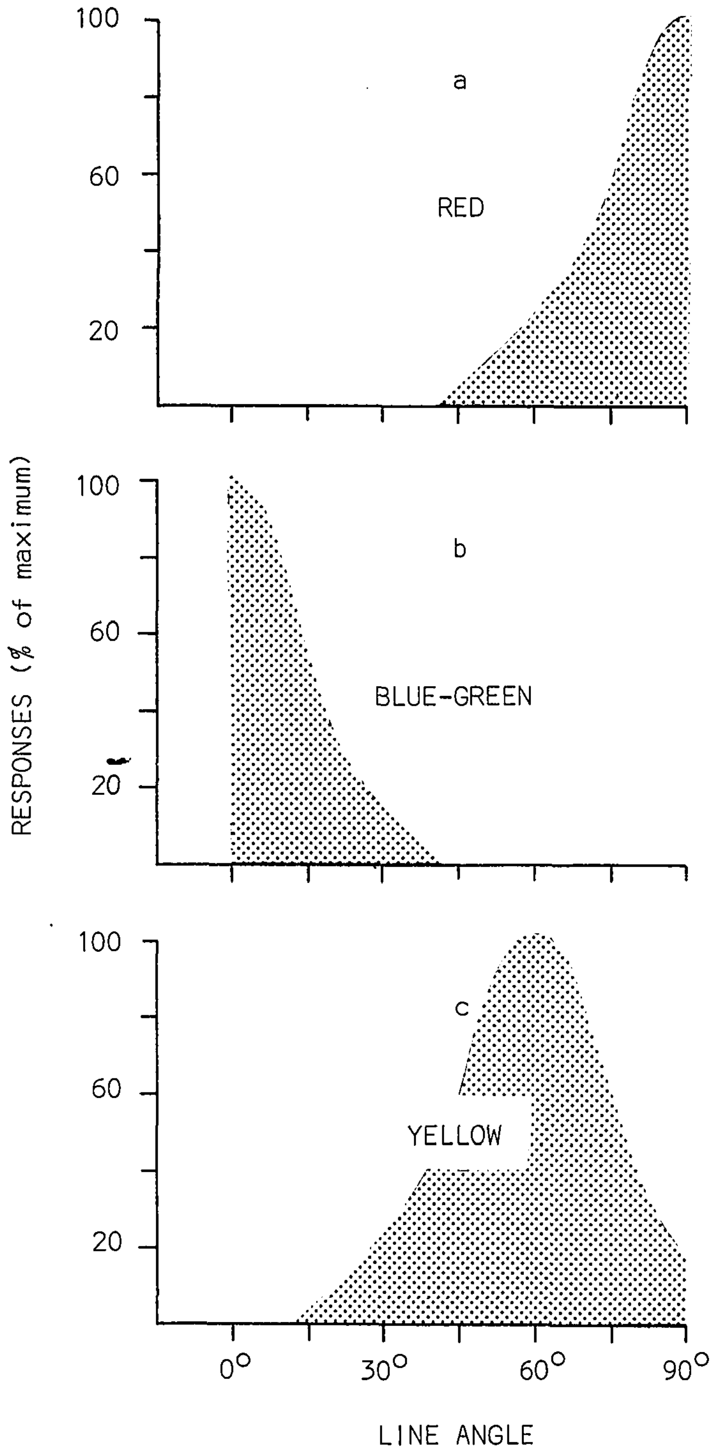

90°
60°
30°
0°
LINE ANGLE
BG
G
YG
Y
R
BACKGROUND COLOR

another generalization test, if violet were used as the constant half of each stimulus and the color of the other half were varied, response rate should be highest when the color on the varied half were also violet. The top half of Fig. 2 shows the expected relation between the color of the right half and the color of the left half of the key. This is an equal response contour. This particular contour was constructed by plotting the peaks of several hypothetical generalization gradients. This was done in the following manner. Given the training with violet and red, the peaks of the generalization gradients when violet and red are a part of each stimulus would have to be at violet and red. However, when yellow or blue is a part of each stimulus the peak would not have to occur at yellow or blue. It could well appear at red, for example. In that case the point plotted on the equal response contour would be yellow-red.

An S+ is a positive stimulus associated with reinforcement and an S- is a negative stimulus associated with extinction. Assume that discrimination training were given with the two S+s of a red background with vertical white line and a blue-green background with horizontal white line; and the two S-s of a red background with horizontal white line and a blue-green background with vertical white line. If this were done, it would seem the general requirements for establishing a relation between line angle and color would be present.

The generalization gradients resulting from such a procedure could have any of several hypothetical forms. Holding the background color constant at red or blue-green and varying the line angle would theoretically result in gradients similar to a and b of Fig. 3, where

Figure 3. Hypothetical generalization gradients, (a) red background constant, vary line angle. The peak is at 90°. (b) blue-green background constant, vary line angle. The peak is at 0°. (c) yellow background constant, vary line angle. The peak is at approximately 60°.


100
60
20
a
RED
100
60
20
b
BLUE-GREEN
100
60
20
c
YELLOW
RESPONSES (% of maximum)
0°
30°
60°
90°
LINE ANGLE

the peak occurs at the test stimulus aspect which was paired with the constant stimulus aspect to comprise an S+. The same testing procedure could be used holding line angle constant and varying the background color. The question now arises, what will happen when the background color is held constant at yellow and line angle is varied? Based on the equal response contour and sensory scaling analysis made earlier, the prediction would be a gradient with a peak at approximately 60°, for example, such as c in Fig. 3. This line angle is arbitrary in that the relation would not have to be a straight line.

The bottom half of Fig. 2 represents a theoretical equal response contour of line angle and color. This might also be considered a sensory scale, mapping one stimulus aspect on another. It generally indicates the relation between two stimulus aspects, given the particular past history of the organism from which it was obtained. This scale seems reasonable since, if a red background-90° line were an S+, one would expect a peak at 90° when the background in a test was red and the angle of line was varied. The same reasoning would predict a point at blue-green-0°. Assume that these two points would be obtained and a relation between background color and line angle could be established during training. In this case, the predicted result of a generalization test with the background constant at yellow and line angle varied would be a peak at a line angle other than 90° or 0°.

The question under investigation was, given the above training, will testing with a novel colored background and line angle varied result in a generalization gradient with the peak at a line angle that was not used in training.

METHOD

Subjects

The subjects were six experimentally naive White Carneaux barren hen pigeons housed in individual cages. They were fed at the end of each experimental session, or once daily when sessions were not conducted, to maintain them at 70% of their free-feeding weight at the beginning of each session. Purina Pigeon Grains were used to maintain weight and also served as the reinforcer. Grit and water were continuously available in the home cage.

Apparatus

A Lehigh Valley Electronics pigeon test chamber #1519c was used with the houselight off at all times. Only one response key was present; it consisted of a transparent plastic paddle in back of a hole 1¼ in. in diameter. Visual stimuli were presented behind the paddle with an Industrial Electronics Engineers, Inc. one-plane readout model #10-3043-1815L and G.E. 47 lamps. Kodak Wratten Filters were used to provide background stimuli. Wavelengths are specified in terms of nanometers (nm) which are the same as millimicrons. Their numbers were: #65 for 501.3 nm (blue-green), #74 for 538.0 nm (green), #99 for 554.6 nm (yellow-green), #73 for 576.0 nm (yellow), and #72-B for 605.7 nm (red). White lines 1/8 in. wide and 1 1/8 in. long, were centered on the background stimuli. The line angles could be varied from 0° (horizontal) to 90° (vertical) in 15° increments. Masking noise was presented through a speaker in the chamber. A fan provided ventilation and additional masking noise.

Programming during training was done automatically with solid state digital switching circuitry. During generalization tests, the stimuli were manually controlled. Responses and reinforcements were recorded with electro-mechanical equipment.

Procedure

Using standard operant conditioning procedures, the subjects were trained to eat from the food magazine and to peck the reponse key illuminated by the yellow light. The yellow light was used in shaping to avoid differential responding to the S+s due to the initial key peck training. The yellow light was a positive stimulus (S+) associated with reinforcement. Reinforcement consisted of 3 sec access to grain with the magazine light on. After the key peck response was established, the next 50 responses were reinforced on a continuous reinforcement schedule (CRF). A key-light off condition, which was an S-, was then introduced. The key-light on S+ and key-light off S- training constituted phase one. This and subsequent phases employed a continuous reinforcement schedule unless otherwise stated. The S+ periods were terminated by reinforcement and the next stimulus was the S-. It was present until no key peck responses occurred for a 30 sec period. When this condition was met, the S- was terminated and the next S+ was presented. Sessions lasted 50 min or 50 reinforcements, whichever came first, and were conducted six times per week. This procedure was used in all subsequent phases. Discrimination training continued until the number of S- responses per S- period had stabilized as determined by visual inspection of the graph of S- responses per S- period as a function of sessions. The same criterion was used in all subsequent phases. At this point, yellow and key off were eliminated as training stimuli and were not used in any further training phases.

In an effort to facilitate learning of the potentially difficult discrimination, a series of progressively more complex phases was used with three subjects, Group I. For comparison, three additional subjects, Group II, were introduced to the final discrimination immediately following the training with yellow and key light off.

For Group I, in the second phase, one S+ and one S- were used and in each phase thereafter one stimulus was added until the final discrimination problem was present. Table 1 summarizes the S+s and the reinforcement schedule in each phase. In the second phase of training, the S+ was a red background with a vertical line and the S- was a red background with a horizontal line. In the third phase a blue-green background with a horizontal line (S+) was added to the end of the stimulus sequence used in phase two. In the fourth phase, a blue-green background with a vertical line (S-) was added to the stimulus sequence used in phase three. Thus the final discrimination problem was red-vertical (S+), red-horizontal (S-), blue-green-horizontal (S+), and blue-green-vertical (S-).

For Group II, the second and third phases were not used; otherwise their training was identical to Group I.

For both groups, when the subjects' behavior had reached criterion on the final discriminaton problem with CRF, the response requirement was gradually increased to a RI-64 sec schedule (a type of variable interval schedule) where the probability of reinforcement

Table 1

Summary of the S+s, S-s, and reinforcement schedule in each phase. Phases 2 and 3 were not used with Group II.

Phase	S+	S-	Order of Presentation	Schedule in S+
1	yellow	blank	yellow blank	CRF
2	red-90°	red-0°	red-90° red-0°	CRF
3	red-90° blue-green-0°	red-0°	red-90° red-0° blue-green-0°	CRF
4	red-90° blue-green-0°	red-0° blue-green-90°	red-90° red-0° blue-green-0° blue-green-90°	CRF
5	same as the fourth phase			RI-64

for the first response in each 4 sec period was 1/16. This constituted the fifth phase. After 15 sessions of training with this schedule, the first generalization test was conducted.

Ten min of warm-up exactly like the fifth phase preceded each generalization test. The first generalization test consisted of an extinction session in which the test stimuli were line angles from 0° to 90° in 15° increments, all with a yellow background. Table 2 summarizes the stimuli used in each generalization test. Stimulus presentations lasted 20 sec and were separated by 10 sec periods of complete darkness. The stimuli were presented in 14 randomized blocks with each stimulus appear once per block for a total of 98 stimulus presentations. Testing and recording procedures were identical for all generalization tests. The number of responses was recorded in each stimulus presentation. Generalization tests were separated by 15 training sessions identical to the fifth phase. In the second generalization test, the stimuli were the same as in the first generalization test except that yellow-green was used in place of yellow as the background color. The third generalization test was identical to the first and second generalization tests except red and blue-green were used as background colors, thus giving a total of 14 stimuli instead of 7. In this test, there were 7 presentations of each stimulus instead of 14 as in the other tests. The fourth generalization test was exactly like the first one.

Table 2

Stimuli used in generalization tests.
The background color was a part of each stimulus presented.

Test No.	Line Angles	Colors
1	0°, 15°, 30°, 45°, 60°, 75°, 90°, no line	yellow
2	same as test 1	yellow-green
3	same as test 1	red blue-green
4	same as test 1	yellow

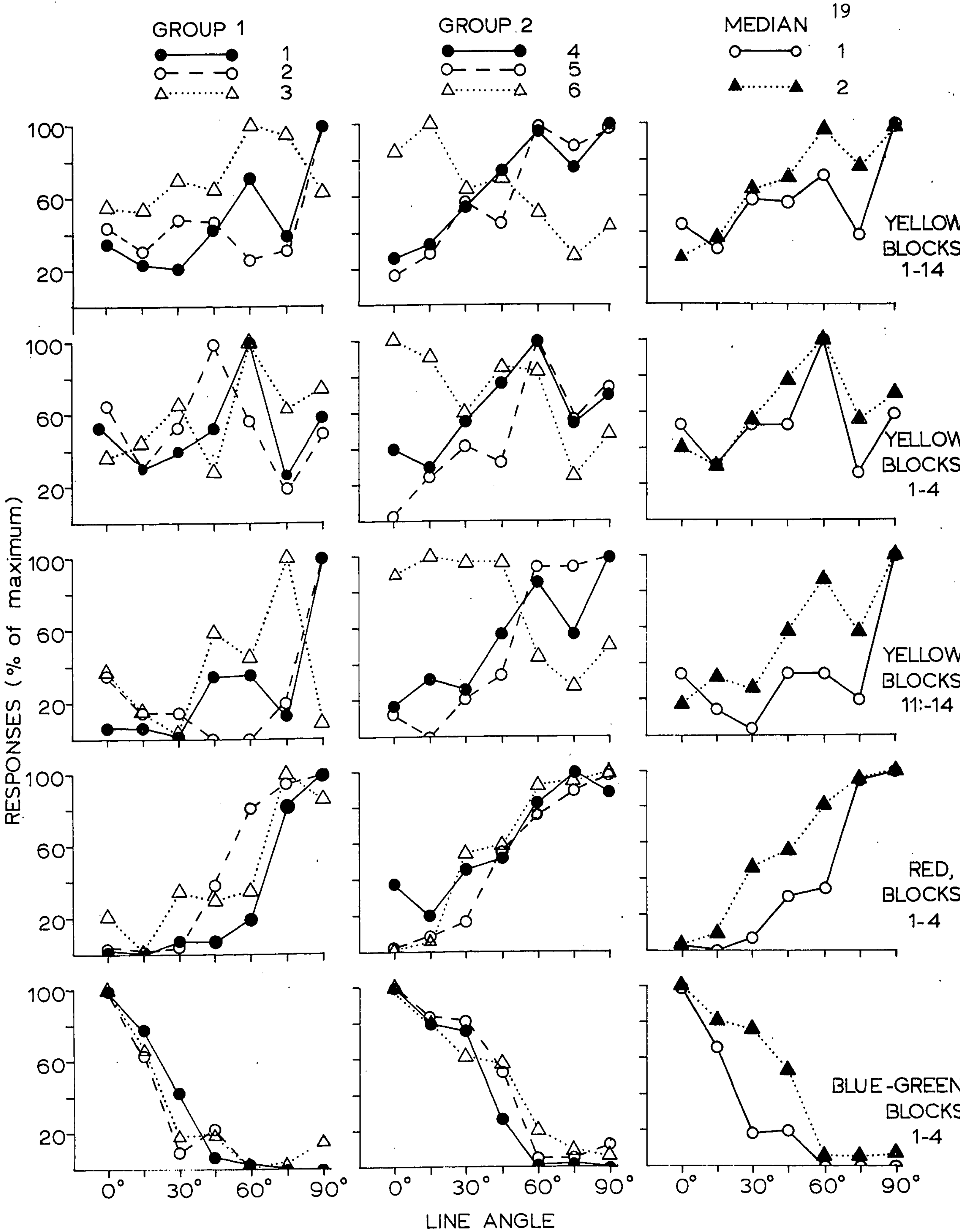
RESULTS

The data showing the rates of acquisition of the two groups will not be presented here. Those data will be presented in a separate paper. Suffice it to say that all indications are that the abrupt introduction of the complex discrimination problem results in more rapid acquisition than does the gradual introduction of the final discrimination problem.

The first row of gradients in Fig. 4 are the results of the first generalization test when yellow was the background. In Group I, the peaks of the gradients for birds 1 and 2 were at 90°; for bird 3, it was at 60°. In Group II, the peaks for birds 4 and 5 were at 90°; for bird 6, it was at 15°. The median gradients both have the peak at 90°. In all gradients that peak at 90°, there is an obvious rise near the middle of the gradient. It seemed appropriate to examine the changes in the gradients that occurred as testing progress.

The first four presentations of each stimulus were used to construct the gradients shown in the second row. For all six subjects, the peak of the gradient was not at 90°. For one subject the peak was at 0°, for four the peaks were at 60°, and for one it was at 45°. In every case where the peak did not occur in the 45°-60° range, there is a subpeak at 45° or 60°. The median gradients both peak at 60°. This effect disappears with continued testing as can be seen by examination of the third row of gradients which were constructed from the last four presentations of each stimulus. For four of the subjects, the gradients peak at 90°, for one at 75°, and for one at 15°. The median

Figure 4. Row 1 - Generalization gradients representing all of the presentations of each stimulus with the yellow background. Row 2 - Gradient representing the first 4 presentations of each stimulus with the yellow background. Row 3 - Gradient representing the last 4 presentations of each stimulus with the yellow background. Row 4 - Gradients representing the first 4 presentations of each stimulus with the red background. Row 5 -Gradient representing the first 4 presentations of each stimulus with the blue-green background.


GROUP 1
1
2
3
GROUP 2
4
5
6
MEDIAN
1
2
YELLOW BLOCKS 1-14
YELLOW BLOCKS 1-4
YELLOW BLOCKS 11-14
RED, BLOCKS 1-4
BLUE-GREEN BLOCKS 1-4
RESPONSES (% of maximum)
100
60
20
0°
30°
60°
90°
LINE ANGLE

gradients both peak at 90°. By the end of the generalization test, the effects of continued testing are quite pronounced, thus masking any possible effects of the interaction of the stimulus aspects. Since the phenomenon disappears or is masked as testing progresses, only gradients constructed from the first four presentations of each stimulus can be used in the subsequent analysis.

In the second generalization test with yellow-green as the background enough responses did not occur to construct reliable generalization gradients. The criterion for constructing a gradient was 50 or more responses to one of the stimuli.

The third generalization test was with red and blue-green as the background color. The data presented in the fourth and fifth rows are from the first four presentations of each stimulus. All peaks with the red background were at 90°; with the blue-green background, the peaks were at 0°. The variability between subjects within a group observed in the first test was noticeably less on the third test.

The fourth generalization test also failed to produce enough data to construct generalization gradients.

In the generalization tests with the yellow and yellow-green backgrounds, the response rates were quite low and the effects of extinction became pronounced very rapidly. In a generalization test, when two stimulus aspects are simultaneously changed, the resulting response probability has been described as the product of the response probabilities of each aspect (Butter, 1963). Such a multiplicative process results in a larger response decrement due to stimulus change than occurs in a simple generalization test where a single aspect is changed. Therefore, at the onset of a multi-aspect generalization test, the response rates are low and decrease rapidly as the stimulus aspects are varied.

Figure 5 shows the median generalization gradients for the combined data of both groups. This is a summary function of all gradients for the first 4 blocks of each test. It is the median gradient for the six subjects combined. The mean generalization gradients have been constructed and look the same as the median gradients. The differences between the gradients when red and blue-green were used as the background color are slight, although the gradient for blue-green is somewhat steeper. When yellow was the background color, the peak was at 60° and the overall gradient was flattened; there are subpeaks at 0° and 90°, the line angles used in training.

The conclusion reached as a result of these data is that, at least early in testing, the introduction of a novel colored background results in response rates being highest at a novel line angle. The line angle to which the most responding occurred when yellow was present was 60° for four out of six subjects.

Figure 6 shows an equal response contour similar to those in Fig. 2. The contour in Fig. 6 was constructed by plotting the peaks of the median gradients for the first four presentations in the test for each of the three colored backgrounds. The relation between line angle and background color was nearly linear, though additional points might emphasize the departure from linearity.

Figure 5. The median generalization gradient (for each background used) obtained from tests where enough data were obtained to construct reliable gradients. These medians are for the first 4 presentations of each stimulus.

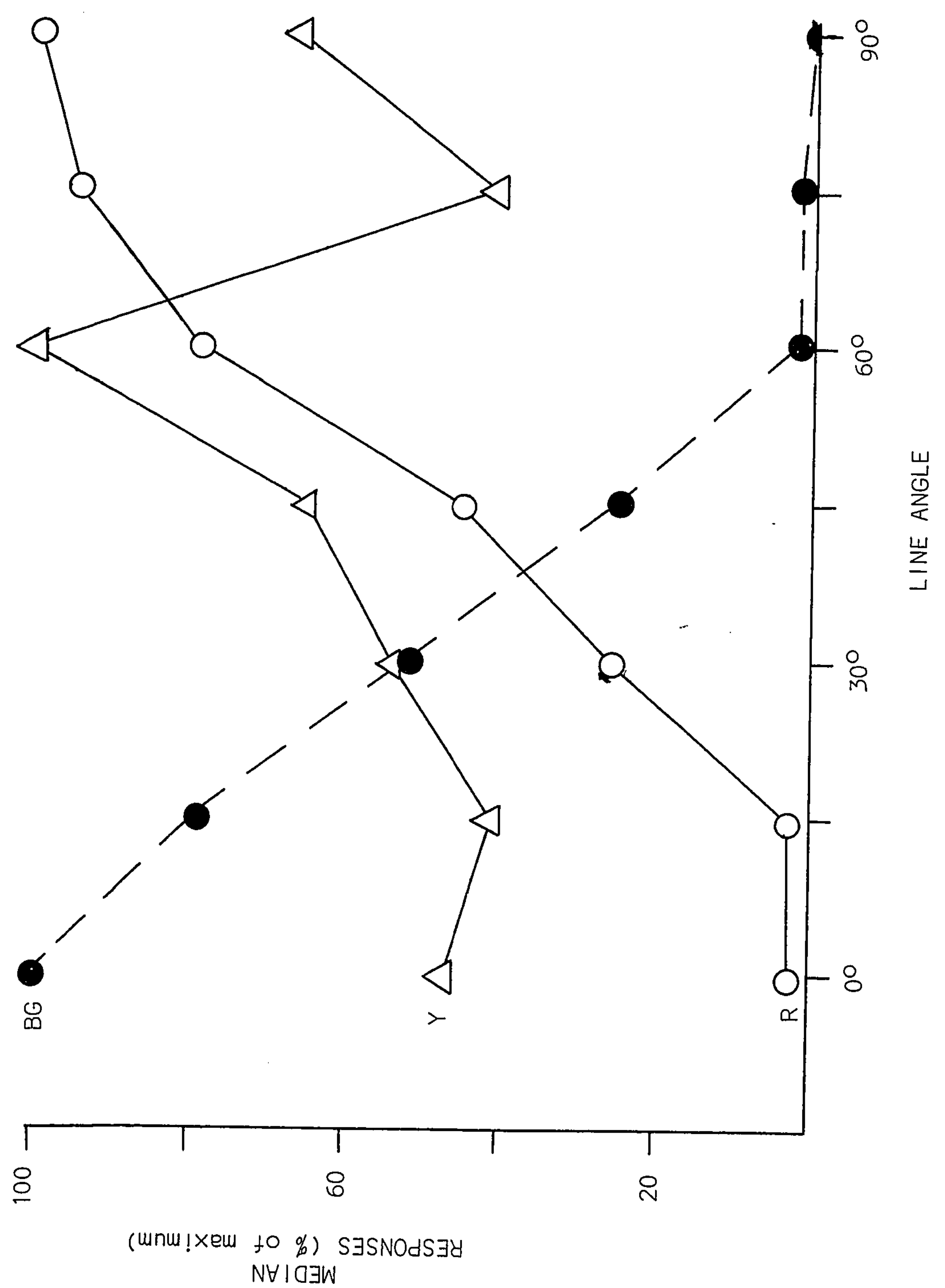
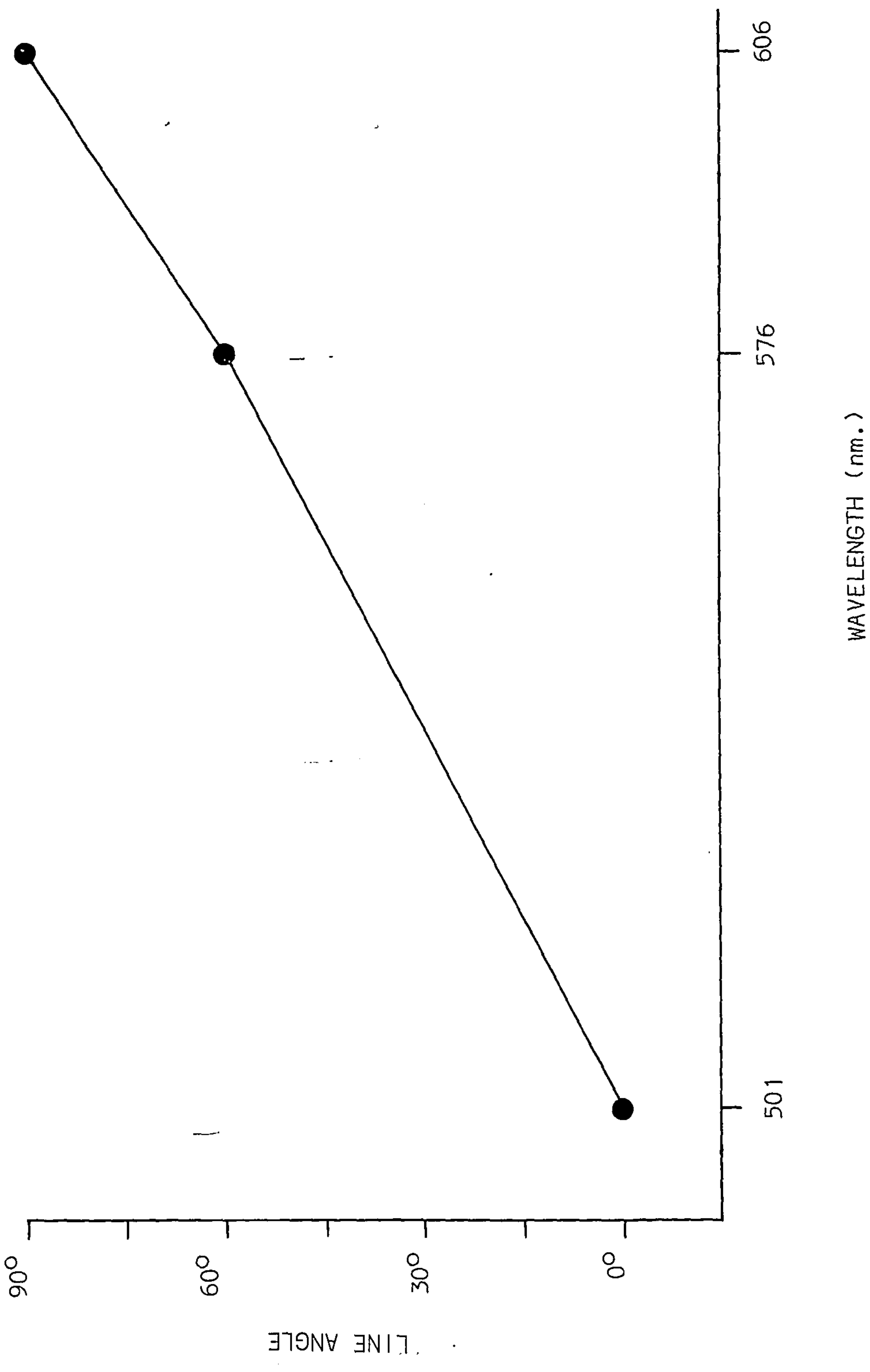

MEDIAN
RESPONSES (% of maximum)
100
60
20
BG
Y
R
0°
30°
60°
90°
LINE ANGLE

Figure 6. The obtained equal response contour in which line angle is mapped on background color.


LINE ANGLE
90°
60°
30°
0°
WAVELENGTH (nm.)
501
576
606

DISCUSSION

The increase in responding obtained at intermediate line angles in the presence of an intermediate color (yellow) is in conflict with some available data. Migler (1964) and Cumming and Eckerman (1965), in studies involving a relational discrimination, found that when responses at two stimulus values on a continuum were reinforced and tests with intermediate values on that continuum were subsequently conducted, the generalization gradients had a peak at one of the training values (or, in sòme cases, both the training values). In no case, did they obtain a peak at an intermediate value.

In both of the above mentioned studies, the task involved was a relational one. In Migler's study when the auditory click frequency was 45.8, reinforcement was available for responses with no appreciable interresponse time; and when the click frequency was 2.5, reinforcement was available only for responses that were separated by 6 sec or more. The two dimensions involved in that discrimination were click frquency and interresponse time (or delay). Click frequency was obviously experimenter controlled. However, interresponse time was subject controlled. The dimensions used by Cumming and Eckerman were light intensity and position of the key responded on. Here again, one dimension (light intensity) was experimenter controlled and the other (key position) was under the control of the subject.

In the present study, the dimensions involved (background color and line angle) were experimenter controlled. This allowed the prevention of intermediate responses during training. In the studies by

Migler and Cumming and Eckerman, the subjects could respond to intermediate keys on the key panel or with delays too short to be followed by reinforcement. Both of these situations were essentially S-s. In Cumming and Eckerman's study, the responses were reinforced only if they were on the appropriate end keys. Responses on the intermediate keys did not produce reinforcement except early in training. Essentially what they did in the final phase of their training procedure was to extinguish responding to the intermediate keys. In view of this, it does not seem surprising that, during testing over intermediate light intensities, response rates on intermediate keys were very low.

In the present study, since both dimensions were experimenter controlled, it was possible to arrange the situation such that intermediate line angles did not appear until the generalization test. Thus, when the first test was conducted, the subjects had never responded to the intermediate stimuli. This may be very important in that it was demonstrated that the peak at the intermediate line angles disappeared with continued testing in extinction. In Cumming and Eckerman's case, there had been opportunity for extinction to take place prior to the test situation and perhaps mask or eliminate any tendency to respond at intermediate values. The training situation used by Cumming and Eckerman would be comparable to training with a red background and a 90° line as S+ and all other line angles with a red background as S-s and with a blue-green background and a 0° line as S+ and all other line angles with a blue-green background as S-s. Given that training, it might be surprising if a peak at an intermediate line angle were obtained with a yellow background since the amount of extinction at the intermediate line angles prior to the test would probably be sufficient to eliminate any peak at the intermediate stimuli.

Herrnstein and van Sommers (1962) used five training stimuli and four intermediate test stimuli. They found that intermediate test stimuli produced intermediate response rates. Their results were essentially the same as those in the present study, although one of the dimensions was subject controlled. Malott and Cumming (1965) obtained similar results when they tested with two S+s (each associated with the reinforcement of different interresponse times) and an intermediate test stimulus. Response rates were sometimes, although not always, intermediate for the intermediate stimulus, depending upon the values of the reinforced interresponse time. Herrnstein and van Sommers' and Malott and Cumming's results might have been due to the effects of averaging data during stimulus generalization. Migler (1964) found that, when working with response rates, the IRTs were either long or short if the data were analyzed in small sections. However, if these data were averaged over an entire stimulus presentation, the IRT was intermediate to the IRTs that were reinforced in training. Therefore, any peak at intermediate IRTs was an artifact of averaging data. Such a criticism cannot be made of the data obtained in the present study but may explain the discrepancies obtained among the previous studies.

Thus, the finding of the present study that, at least early in testing, the introduction of a novel background results in a peak in the generalization gradient at a line angle intermediate to the training angles is not necessarily inconsistent with the available data. Discrepancies that arise can be dealt with in terms of the procedural differences among the various studies. Failure to obtain the intermediate peaks could be due, in all cases, to extinction of responding during training to the stimulus values used in testing. In studies where this process occurred and the intermediate peak was obtained, averaging of the data could have produced an artifact.

Carter, Cumming, and Eckerman (1968) have compared a matching-to-sample procedure with a relational discrimination procedure similar to the one used in the present experiment. They found that the relational discrimination was not more difficult to learn than matching-to-sample. This would seem to indicate that the similarities between the two procedures are not merely surface similarities. One is learned as readily as the other. It has also been demonstrated here that knowledge of the results of stimulus matching can allow one to predict the results of a more general form of a relational discrimination.

When doing psychophysical scaling with humans, Graham & Ratoosh (1962) have pointed out that typically, the results are discussed in an undesirable manner. The numerical assignment to a stimulus value is often treated as though it were the quantitative outcome of a measuring operation. In reality, it is the qualitative outcome of such an operation. If the outcome were quantitative, averaging the numbers assigned to a given stimulus would be permissable. However, since the outcome is qualitative, averaging cannot validly be done;

rather, the most frequent number assigned must be taken as the value attached to that particular stimulus. The present procedure may be used to avoid these objections that have been leveled against scaling procedures used with humans since the qualitative response dimension has been replaced by a quantitative stimulus dimension.

Several experiments remain to be conducted to clarify the present results. The procedure for training the subjects to peck the key involved a yellow stimulus. It is possible that the use of yellow in the initial phase of training was responsible for the position of the peak of the line angle gradients when the test background was yellow. However, one might expect relatively high response rates if the training on yellow produced any large effects. The response rates in the presence of a yellow background were very low compared to those in the presence of red and blue-green. Still, this experiment should be replicated with initial training on the two S+s instead of yellow; this is currently being done.

Since the phenomenon of interest here disappeared relatively early in testing, another group of subjects should be tested with the red and blue-green backgrounds first. Perhaps the peak occurs at the intermediate line angles occurs in the first test regardless of the background color. This experiment is also being conducted. The same training procedure should be used for another group which should be tested first with a yellow-green backgound so that, (1) the response rates in testing will not be so low as to prohibit obtaining a gradient and (2) any effects that disappear with continued testing may be observed.

An experiment should be conducted in which subjects are trained with a simple discrimination (such as a 90° line as S+ and a 0° line as S-, both on black backgrounds) and then tested with a yellow background and various line angles. It is possible that the introduction of a novel color shifts the peak of the gradients to a novel line angle even when there is no relational discrimination training. One such experiment has been conducted. Prior to the test the subjects received reinforcement in the presence of a yellow key with no line in addition to the 90° vs 0° discrimination. The results indicate that, with a yellow background, the relative rate increases in the presence of the 75° line but rates in the presence of all smaller line angles are quite low. A second related experiment is in progress. This experiment did not use yellow as a training stimulus and the subjects will be tested over line angle with a yellow background. No data have been obtained to date.

CONCLUSION

The conclusion reached is that, in a relational discrimination, the stimulus aspects interact in complex ways. An analysis in which one stimulus aspect is mapped on another stimulus aspect leads to a prediction of a peak at one intermediate stimulus when another intermediate stimulus is present. The present data support such an analysis. This conclusion was based on data obtained using line angles and colored backgrounds in a specific relational discrimination. Apparently, neither summation of positive gradient nor simple stimulus generalization is sufficient to account for the interaction effects observed.

In summary, the general procedure used in the present experiment permits the investigation of equal response contours and sensory scaling. The procedure involves control of both stimulus aspects which prevents undesirable extinction from occurring. This procedure can be used with humans for comparative purposes and is, potentially, an aid to developing an understanding of complex relationships which sometimes need to be investigated in humans.

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