Wavelength Matching in the Pigeon

Robert W. Griffin

Western Michigan University

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WAVELENGTH MATCHING IN THE PIGEON

by

Robert W. Griffin

A Thesis
Submitted to the
Faculty of the Graduate College
in partial fulfillment
of the
Degree of Master of Arts

Western Michigan University
August, 1971
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The author would like to express his appreciation to his committee members, Dr. Jack Michael, Dr. David Lyon, and Dr. Richard Malott, for their advice and guidance.

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Robert W. Griffin
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Figure 6 Results from the second battery of wavelength tests for group C are shown with constant color tests arranged vertically and results from each subject arranged horizontally. Percentage of maximum responses is shown as a function of the variable wavelength within each test. The first 12 min of each test is represented by the gradients drawn with circles; the last 16 min is drawn with squares. Absolute number of responses at maximum during the first 12 min is given above the maximum number of responses during the last 16 min of each test.

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A single-response free-operant procedure for studying matching behavior was evaluated by Malott and Malott (1970). The procedure involved the successive presentation of stimuli with response rate as the measure of stimulus control. It was felt that this procedure was optimal for at least two reasons. First, the use of a single operant, as opposed to two or more, simplifies the dependent variable and results in an increased emphasis on the independent variable. For example, in a typical three-key matching-to-sample experiment, Cumming and Berryman (1961) noted a position preference; such a response bias must necessarily complicate data analysis and the determination of the control exerted by the stimulus class under study. Second, response rate can vary over a wide range and is sensitive to the manipulation of independent variables; hence, response rate is a good measure of stimulus control.

In the single-response procedure used by Malott and Malott (1970), stimuli divided into right and left halves by a black vertical line were projected onto a response key. Matching wavelength combinations (the same dominant wavelength presented on both halves of the key) or non-matching combinations (different wavelengths presented on the two halves of the key) were presented. Responses were reinforced in the presence of the matching stimuli (S+s) and not reinforced in the presence of the non-matching stimuli (S-s). Some subjects were given non-differential training with one, two, or four matching wavelength combinations (i.e., no discrimination training); other subjects were given discrimination training with either two or four S+s and two S-s. Following training, novel wavelengths and wavelength combinations were
presented in generalization tests conducted in extinction. The results indicated that discrimination training was required to demonstrate matching behavior. Although there was statistical evidence for matching behavior following training with the four S+s (no discrimination training), response decrements to the non-matching stimuli were small and did not occur to all non-matching stimuli. Generalization of matching behavior to novel wavelengths was obtained following discrimination training.

One objection to these experiments which can be raised is that generalization tests over the entire wavelength continuum were not given; rather, only two wavelengths were presented during the tests. For example, after training with two S+s (matching combinations of violet and red) and two S-s (non-matching combinations of violet and red), subjects were tested with two novel wavelengths, blue and yellow. Matching behavior was demonstrated by observing lower response rates in the non-matching combinations of blue and yellow than in the matching combinations. However, if violet and red had also been presented with blue and yellow during the tests, matching behavior might not have been demonstrated. For example, a non-matching combination composed of the training color, red, combined with the novel color, yellow, might have generated higher response rates than the matching combination composed entirely of the novel color yellow. A different study lends support to the criticism. Using the single-response procedure, Liebold (1969) trained subjects in the presence of four S+s (matching combinations of blue, green, yellow and red) and two S-s (non-matching combinations of

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blue and green). Generalization tests were given over the entire visible wavelength continuum. During each test, one wavelength was held constant on either half of the key and successively paired with each of five dominant wavelengths (a novel wavelength, yellow-green, was added during testing). Matching behavior would have been demonstrated if generalization gradients were peaked at the variable wavelength which matched the constant wavelength. However, matching behavior was obtained only when the constant color was yellow or red. There was only slight evidence for matching when blue was the constant color and no indication of matching when green was the constant color. Leibold offered a peak shift analysis of the gradients that showed no matching behavior; Hanson (1959) reported that the peaks of generalization gradients were displaced from the S+ in the direction away from the S-. Liebold's gradients from the blue-constant tests were high at blue, very low at green, and then high again at yellow and red; the gradients from the green-constant test were low at blue but high at green, yellow and red. Both sets of gradients gave the appearance of having been shifted away from the lower end of the wavelength continuum. Liebold concluded that the peak shifts may have been interfering with matching behavior when the constant color during the test was part of the subject's S-s during training. In any case, pure matching was not demonstrated when the tests were conducted over the entire wavelength continuum.

One may raise the question of what constitutes a demonstration of the "concept" of matching. Keller and Schoenfeld (1950) defined conceptual behavior as "generalization within classes and discrimination between
classes..." When a generalization test includes novel examples of both matching and non-matching stimuli, and subjects respond maximally to the novel matching stimuli and minimally to the novel non-matching stimuli, there appears to be no problem in concluding that a matching concept has been acquired. However, when only the non-matching stimuli are novel and conceptual behavior is said to be indicated by a response decrement to the novel non-matching stimuli, as in Liebold's study described above, a serious objection can be raised. Guttman and Kalish (1956) reported decreased responding to novel wavelengths after responses had been reinforced in the presence of one specific wavelength. Hence, one might conclude that, while response decrements to the novel non-matching stimuli may indicate a matching discrimination, a matching concept was not necessarily acquired. The study by Malott and Malott (1970) is pertinent to this objection. Following training with four S+s only (no discrimination training), tests revealed only slight evidence for matching. Further, a pilot study more similar to the present study, conducted in this laboratory presented the same four S+s during training, also without discrimination training. After the response rates in all stimuli were equivalent, generalization tests were administered. One color was held constant during each test and successively paired with each of the four dominant wavelengths. If novel stimuli produced a response decrement, the gradients obtained from this study should have shown a peak at the matching wavelength combinations. However, the results revealed gradients that were extremely flat across all stimuli, novel or otherwise. Hence, the notion that stimulus novelty alone would
lead to substantial response decrements does not appear to be substantiated. Using this procedure, then, a response decrement to novel non-matching stimuli would indeed be evidence for the acquisition of a matching concept.

One final, but most serious objection may be leveled at the studies of Malott and Malott (197) and Liebold (1969). No attempt was made to control for brightness in either of these two studies. It may very well have been that the subjects made the discrimination on the basis of matching and non-matching brightness combinations rather than matching and non-matching wavelength combinations. If this were the case, it could not be said that a matching concept had been acquired because the test stimuli may not have differed from the training stimuli in terms of brightness. For example, in the Malott and Malott (1970) study where subjects were trained in the presence of two S+s (matching combinations of violet and red) and two S-s (non-matching combinations of violet and red), red may have been brighter to the pigeons than violet and they may have based their discrimination on the brightness variable during training. Later, in the testing situation, matching and non-matching combinations of blue and yellow were presented to the subjects in extinction. It may have been that blue was the same brightness as violet and that yellow was equal in brightness to red. When the results were obtained that showed a response decrement to the "novel" non-matching stimuli, no conclusions could be made regarding the acquisition of a concept because the stimuli were novel only in terms of wavelength, not brightness. Since wavelength may have been an irrelevant cue for the
subjects (if they, in fact, made the discrimination on the basis of brightness), the stimuli in the testing situation may have been in no way novel.

In the present study, six subjects' responses were reinforced in the presence of matching combinations of four dominant wavelengths (blue, green, yellow, and red) and not reinforced in the presence of two non-matching combinations (composed of either blue and green or blue and yellow). If Liebold's results were affected by a peak shift, then the results of this experiment should also be affected; furthermore, there should be differential effects between groups because of the different S-s values during training. For example, generalization gradients obtained from green-constant tests should be peaked at yellow or red for subjects whose training S-s were composed of non-matching combinations of blue and green; on the other hand, results from green-constant tests of subjects whose training S-s were non-matching combinations of blue and yellow should yield gradients peaked at the matching wavelength combination. In an attempt to control for brightness, neutral density filters were alternately placed over either half, all, or none of the stimulus during training so that the availability of reinforcement was not correlated with matching nor non-matching brightness combinations. Wavelength tests over the entire continuum were conducted in extinction to test for the acquisition of the concept of matching; response decrements to the novel non-matching wavelength combinations were used as evidence for the acquisition of this matching concept.
Furthermore, brightness tests were also administered to determine how much, if any, of the matching behavior could be accounted for in terms of brightness.
METHOD

Subjects

Six experimentally naive White King barren hen pigeons from the Palmetto Pigeon Plant, Sumter, South Carolina, were maintained at 70% of their free-feeding weights with Purina Pigeon Grains (50% Kaffer corn, 40% Hempseed, and 10% vetch) which also served as the reinforcer. The subjects were individually housed with grit and water always available.

Apparatus

Two Lehigh Valley Electronic pigeon test chambers, #1519c, were connected to BRS Foringer, #100 series, solid state digital switching circuitry and Sodeco electro-mechanical counters for the recording of responses and time. The chambers were sound masked with white noise. The houselights on the intelligence panels within the chambers were made inoperative. A transparent paddle, located behind a 2.5 cm circular opening on the panel, served as the response key. The key was trans-illuminated from the rear via an Industrial Electronics Engineers, Inc. one-plane readout projector, series #10. The stimuli presented on the translucent screen of the projector were divided into right and left halves by a 0.6 cm wide black vertical line. General Electric #47 incandescent bulbs were illuminated behind Kodak Wratten gelatin filters #65, #74, #73, and #72B to obtain the four dominant wavelengths of 501.3 nm (blue), 538.0 nm (green), 576.0 nm (yellow), and 605.0 nm (red),
respectively. These dominant wavelengths could be projected onto either half of the response key. During training, Kodak Wratten #96 neutral density 0.20 filters were placed behind the response key and the projector in order to vary intensity. Two human observers served to select the 0.20 neutral density value. When this filter was placed over the brightest stimulus (green), this stimulus appeared approximately equal in brightness to the dimmest stimulus (red). When intensity was varied during testing, neutral density 0.20 and 0.10 filters were combined inside the projector with the filters for green to produce a "dim" and a "medium" stimulus, respectively. When no neutral density filter was present, the stimulus was called "bright".

Procedure

Each of the six subjects was arbitrarily assigned to one of two groups, A or C, with three subjects per group. Stimulus assignments can be seen from an inspection of Table 1. Each letter represents one of the four dominant wavelengths (B for blue, G for green, Y for yellow, and R for red) on one half of the response key. For example, BB represents a matching combination of wavelengths with blue on the left and blue on the right; BG represents a non-matching combination with blue on the left and green on the right. Both groups received six training stimuli: four S+s (stimuli in the presence of which responses were reinforced) and two S-s (stimuli in the presence of which responses were not reinforced). The S+s were matching stimuli and the S-s were non-matching stimuli. Each available dominant wavelength appeared in an S+.
**TABLE 1**

Stimulus Assignments for Discrimination Training

<table>
<thead>
<tr>
<th>Group</th>
<th>S+1</th>
<th>S+2</th>
<th>S+3</th>
<th>S+4</th>
<th>S-1</th>
<th>S-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>BB</td>
<td>GG</td>
<td>YY</td>
<td>RR</td>
<td>BG</td>
<td>GB</td>
</tr>
<tr>
<td>C</td>
<td>BB</td>
<td>GG</td>
<td>YY</td>
<td>RR</td>
<td>BY</td>
<td>YB</td>
</tr>
</tbody>
</table>
two groups differed only with respect to the S-s present during training, one group receiving blue and green in their S-s and the other group receiving blue and yellow.

Throughout training, the neutral density 0.20 filters were placed in front of one half, all, or none of the stimulus projector generating a repeating sequence as shown in Table 2. For example, Bright-Bright represents no filter over the projector and Bright-Dim represents no filter on the left with a filter on the right. These intensity conditions were constant during any one training session but varied between sessions. They were also independent of the wavelength presentation, hence, not related to reinforcement availability. For example, the intensity condition may have been non-matching (e.g., bright-dim) while the wavelength was matching (e.g., blue-blue) and reinforcement was available, or the filter conditions may have been matching (e.g., dim-dim) while the wavelengths were not (e.g., blue-green) and reinforcement was not available. This was done in an attempt to eliminate discriminations based on intensity rather than wavelength.

Using standard operant conditioning techniques, all subjects were trained to eat from the food magazine and peck the key. Responses were reinforced by three sec access to grain, with the magazine light on, according to a continuous reinforcement (CRF) schedule. The S+s, BB, GG, YY, and RR were repeatedly presented in that order. The stimulus was changed after each reinforcement. Sessions lasted for five min or until 50 reinforcements had been delivered, whichever came first.
<table>
<thead>
<tr>
<th>Ordinal Position</th>
<th>Brightness Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bright-Bright</td>
</tr>
<tr>
<td>2</td>
<td>Bright-Dim</td>
</tr>
<tr>
<td>3</td>
<td>Dim-Dim</td>
</tr>
<tr>
<td>4</td>
<td>Dim-Bright</td>
</tr>
</tbody>
</table>

TABLE 2

Alternating Sequence of Brightness Combinations
When a rate of 20 responses per min was obtained during a session with CRF, the schedule of reinforcement was changed. Reinforcement was made progressively less dense across sessions by initiating successively larger values of a random interval (RI) schedule (Farmer, 1963). During each successive four sec interval, the probability of the first response being reinforced was 1/2, 1/4 or 1/8. Responses in the four sec interval which occurred thereafter were never reinforced. The expected values of inter-reinforcement availability intervals are defined by:

\[ \frac{4}{p} = \sum_{n=1}^{\infty} (4n)(p)(1-p)^{n-1} \]

where \( n \) equals the number of seconds since the last reinforcement and \( p \) equals the probability value. The schedule values for these probabilities were, thus, RI 8 for a probability of 1/2, RI 16 for 1/4, and RI 32 for 1/8. The criterion for a schedule change was a rate of 25 responses per min. Session lengths were 10 min for RI 8, 20 min for RI 16, and 26 min for RI 32. Only the four S+s were present during this training phase. The stimulus present was randomly determined every two min.

When the rate averaged at least 25 responses per min during a session with RI 32, the S-s were introduced during the next session; this was called session #1. These discrimination training sessions were 50 min in duration. The first 12 min of the discrimination training sessions was followed by a two min time-out (TO) during which the response key was dark and non-functional but the white noise remained on. This procedure was put into effect to make training days more
similar to testing days which also had 12 min of training followed by a TO for program changes. The stimuli present during the discrimination training sessions were randomly selected every two min with no TO occurring between presentations. For any two min interval, the probability that an S+ or S- would be presented was 1/2. Individual stimuli within each category occurred with equal probability. The reinforcement schedule in the S-s remained at RI 32 throughout discrimination training; the extinction schedule was in effect when the S-s were present.

With the exception of the first 12 min, total time and number of responses in each stimulus were recorded at the end of each session. Data from the first 12 min of the sessions were excluded. Response rates were calculated for each individual S+, all S+s combined (responses in all S+s/time in all S+s), and both S-s combined. A discrimination ratio (combined S- rate/combined S+ rate), and an "equivalence" ratio (individual S+ rate/combined S+ rate) for each S+, were also calculated for each session. If a stimulus equivalence ratio fell below 0.800 for the last two sessions or any three of the last six sessions, the reinforcement schedule was lowered to RI 16 for that S+ but kept at RI 32 for the other three S+s during the next session. If ever two stimuli fell below 0.800 for the same number of sessions, that stimulus having the lowest ratio was run on the lower schedule during the next session. The schedule was returned to RI 32 when these conditions no longer held.
After a minimum of ten discrimination training sessions, the first generalization test was administered if the following criteria were met during each of the three immediately preceding sessions: (1) the total rate in S+ was greater than or equal to 25 responses per min, (2) the discrimination ratio was less than or equal to 0.300, and (3) no S+ was run on a lower schedule. Succeeding tests were conducted after the criteria were again met with a minimum of three training sessions since the last test. Training sessions occurred seven days per week prior to the first test. Earlier pilot work revealed that consistent daily training was important in the acquisition of such a complex discrimination. After the first tests, sessions were conducted at least five days per week. A training session always occurred on the day immediately preceding a test.

Generalization tests were preceded by a 12 min warm-up, exactly like training, followed by a two min TO. Reinforcers were delivered in warm-up but not during the tests. All neutral density filters were removed from the front of the projector. Within wavelength matching tests, one constant color always appeared on one or the other half of the key; each of the four dominant wavelengths appeared successively on the other half according to a pre-determined random sequence. The sequence was the same across all color tests and was as follows:

\[\text{CG, RC, CB, YC, CR, GC, CY, BC}\]

where C represents the constant color in the test. Hence, during a "Yellow-Constant" test, the stimulus sequence was:

\[\text{YG, RY, YB, YY, YR, GY, YY, BY}.\]
The above sequence was presented seven times, each stimulus presentation lasting for 30 sec. No TO occurred between presentations. The number of responses in each stimulus was recorded for the first 12 min, last 16 min, and total at the end of each 28 min test.

Intensity matching tests were carried out in a similar fashion, the difference being that green was held constant on both halves of the key while intensities were systematically varied. The sequence of intensities presented in a test was:

CM, DC, CB, MC, CD, BC

where C represents the constant intensity during the test, B stands for bright, M for medium, and D represents dim. Therefore, during a "Bright-Constant" intensity test, the stimulus sequence was as follows:

BM, DB, BB, MB, BD, BB.

This sequence was presented four times, each stimulus presentation lasting for 30 sec. The test was 12 min long. The number of responses in each stimulus was recorded at the end of each test.

The sequence of tests is shown in Table 3. The first four tests were wavelength tests; the four dominant wavelengths were successively held constant over these tests. Three intensity tests were then given with the three different intensities successively held constant over tests. The four wavelength tests were then repeated.

That stimulus to which the maximum number of responses occurred during a test was treated as 100% and responses to other stimuli were calculated and plotted as a percentage of that maximum. No test yielding
TABLE 3

Sequence of Wavelength and Intensity Generalization Tests

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Type of Test</th>
<th>Aspect Held Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wavelength</td>
<td>Yellow</td>
</tr>
<tr>
<td>2</td>
<td>Wavelength</td>
<td>Blue</td>
</tr>
<tr>
<td>3</td>
<td>Wavelength</td>
<td>Green</td>
</tr>
<tr>
<td>4</td>
<td>Wavelength</td>
<td>Red</td>
</tr>
<tr>
<td>5</td>
<td>Intensity</td>
<td>Medium</td>
</tr>
<tr>
<td>6</td>
<td>Intensity</td>
<td>Bright</td>
</tr>
<tr>
<td>7</td>
<td>Intensity</td>
<td>Dim</td>
</tr>
<tr>
<td>8</td>
<td>Wavelength</td>
<td>Yellow</td>
</tr>
<tr>
<td>9</td>
<td>Wavelength</td>
<td>Blue</td>
</tr>
<tr>
<td>10</td>
<td>Wavelength</td>
<td>Green</td>
</tr>
<tr>
<td>11</td>
<td>Wavelength</td>
<td>Red</td>
</tr>
</tbody>
</table>
less than 50 responses at maximum was included in the results. If this occurred, the test was disregarded, the subject trained back to criteria, and the same test re-administered. Two gradients are missing from one subject, C-25-9, due to failures to obtain reliable results during the last two tests.
RESULTS AND DISCUSSION

Acquisition of the discrimination for each subject is shown in Figures 1 and 2. A discrimination ratio of 1.0 indicates no discrimination, and a ratio of 0.0 indicates a perfect discrimination. The horizontal dotted line represents the upper limit of the discrimination ratio criterion; the vertical dotted line represents the minimum number of training sessions required before Test 1 could be administered. Each curve stops at the session just prior to the first test. A large difference between groups was observed during early acquisition of the discrimination; all subjects from group A (S-s composed of blue and green) were at or just below chance during session 1 while subjects from group C (S=s composed of blue and yellow) began at well below chance performance. This between-group difference might well have been expected since the S-s of group C were farther apart on the wavelength continuum (and presumably more discriminable) than were the S-s of group A. There was also a marked degree of within-subject variability during early acquisition for all subjects except A-25-8. This variability appears to be a function of the neutral density filter condition present during a session; however, all subjects' discrimination ratios were not affected in the same direction on a given session (e.g., excluding the ratios of A-25-8, four of the ratios decreased during session 2 whereas one of the ratios increased). Very little, if any, of this variability remained after the first test. Most tests thereafter were
Figure 1

Acquisition curves for each subject in Group A are shown on separate sets of axes. The discrimination ratio (combined S- rate/combined S+ rate) is shown as a function of discrimination training sessions. Horizontal dotted lines represent the upper limit of the discrimination ratio criterion; vertical dotted lines represent the minimum number of sessions required before the first generalization test could be administered. Each curve stops at the session just prior to the first test.
Figure 1

A.25.7

A.25.8

A.25.9

RATIO

DISCRIMINATION

SESSIONS

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Acquisition curves for each subject in Group C are shown on separate sets of axes. The discrimination ratio (combined S− rate/combined S+ rate) is shown as a function of discrimination training sessions. Horizontal dotted lines represent the upper limit of the discrimination ratio criterion; vertical dotted lines represent the minimum number of sessions required before the first generalization test could be administered. Each curve stops at the session just prior to the first test.
Figure 2

DISCRIMINATION RATIO

C-25-7

C-25-8

C-25-9

SESSIONS

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given with the minimum number of training sessions between each test; exceptions to this observation were due to failures to meet the equivalence ratio criterion for S+ performance.

Figures 3 through 6 show the results of the wavelength generalization tests. Each set of axes represents a single test for an individual subject. In each test, one wavelength was held constant on either half of the key and successively paired with each of the four dominant wavelengths. Each subject is represented by a single column of axes; each constant color is represented by a single row. Percentage of maximum responses is shown as a function of the variable wavelength within each test. The generalization gradients shown with circles represent the first 12 min of the tests; gradients with squares represent the last 16 min of the tests. Within each set of axes, the absolute number of responses at maximum during the first 12 min is given above the number of responses at maximum during the last 16 min. Gradients drawn with dashed lines may be considered unreliable in that there were less than 50 responses at maximum. Figures 3 and 5 show the gradients from the first battery of wavelength tests for groups A and C, respectively; Figures 4 and 6 represent the second battery of wavelength tests.

For the most part, the wavelength generalization gradients from the earlier tests (Figures 3 and 5) become steeper as a function of time within the tests. Six of the 12 gradients from group C show within-test sharpening and 10 of 12 gradients from Group A become sharper within the tests. Because of this sharpening, gradients from the last 16 min of
Figure 3

Results from the first battery of wavelength tests for group A are shown with constant color tests arranged vertically and results from each subject arranged horizontally. Percentage of maximum responses is shown as a function of the variable wavelength within each test. The first 12 min of each test is represented by the gradients drawn with circles; the last 16 min is drawn with squares. Absolute number of responses at maximum during the first 12 min is given above the maximum number of responses during the last 16 min of each test.
Figure 3

A-25-7

A-25-8

A-25-9

Responses

Wavelength (nm)

Maximum

Percentage

VARIABLE Wavelength

CONSTANT Wavelength (nm)

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Figure 4

Results from the second battery of wavelength tests for group A are shown with constant color tests arranged vertically and results from each subject arranged horizontally. Percentage of maximum responses is shown as a function of the variable wavelength within each test. The first 12 min of each test is represented by the gradients drawn with circles; the last 16 min is drawn with squares. Absolute number of responses at maximum during the first 12 min is given above the maximum number of responses during the last 16 min of each test.
Figure 4

A-25-7

A-25-8

A-25-9

VARIABLE WAVELENGTH (nm)

CONSTANT WAVELENGTH (nm)

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Figure 5

Results from the first battery of wavelength tests for group C are shown with constant color tests arranged vertically and results from each subject arranged horizontally. Percentage of maximum responses is shown as a function of the variable wavelength within each test. The first 12 min of each test is represented by the gradients drawn with circles; the last 16 min is drawn with squares. Absolute number of responses at maximum during the first 12 min is given above the maximum number of responses during the last 16 min of each test.
Figure 5

C-25-7

C-25-8

C-25-9

VARIABLE WAVELENGTH (nm)

CONSTANT WAVELENGTH (nm)

PERCENTAGE OF MAXIMUM RESPONSES

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Figure 6

Results from the second battery of wavelength tests for group C are shown with constant color tests arranged vertically and results from each subject arranged horizontally. Percentage of maximum responses is shown as a function of the variable wavelength within each test. The first 12 min of each test is represented by the gradients drawn with circles; the last 16 min is drawn with squares. Absolute number of responses at maximum during the first 12 min is given above the maximum number of responses during the last 16 min of each test.
Figure 6

VARIABLE WAVELENGTH (nm)

PERCENTAGE OF MAXIMUM RESPONSES

C-25-7

C-25-8

C-25-9

100
80
60
40
20
0

100
80
60
40
20
0

100
80
60
40
20
0

501
538
576
605

501
538
576
605

501
538
576
605

CONSTANT WAVELENGTH (nm)

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testing may frequently be considered to give more reliable estimates of peak location.

During the earlier tests, when red or blue was held constant, the gradients of both groups peaked at the variable color which matched the constant color; i.e., red-constant gradients have peaks at red (row 4 of Figures 3 and 5) and blue-constant gradients have peaks at blue (row 2 of Figures 3 and 5).

When the yellow-constant gradients from earlier tests are considered, an obvious difference between groups emerges. All subjects from group A (row 1, Figure 3) began the test with relatively flat gradients and peaks at green; however, during the last 16 min of testing, the gradients tend to have peaks at the matching variable wavelength, yellow. On the other hand, two of the subjects in group C (row 1 of Figure 5) consistently produced peaks at red during yellow constant tests while one subject started the test with a rather steep gradient peaked at red and ended the test with a peak at yellow. The tendency, then, is for group A yellow-constant gradients to have peaks at yellow and group C yellow-constant gradients to have peaks at red.

When green was held constant during the first battery of wavelength tests (row 3 in Figures 3 and 5), two subjects in group A produced peaks at the matching color, green; however, A-25-9 (Figure 3) produced a definite peak at yellow. All subjects from group C (Figure 5) produced gradients that were peaked at green although C-25-7's gradient was quite flat across green, yellow and red.
The wavelength gradients from the later tests for both groups (Figures 4 and 6) are steeper than those from the earlier tests and all of these later tests have peaks at the variable wavelength that matches the constant wavelength.

At least two possible interpretations may be offered for the gradients which have peaks at non-matching variable wavelengths. First, subjects which show such a lack of matching behavior may not have acquired the discrimination as well as others; this may result in flatter generalization gradients and less reliable estimates of the peak location. Support for the interpretation that the "degree of discrimination" attained during discrimination training will determine whether matching behavior will be demonstrated is given below.

A second interpretation is that it may be that some of the data may represent a peak shift phenomenon similar to that reported by Hanson (1959) where the peaks of generalization gradients were displaced from the S+ in a direction away from the S-. In the present experiment, when a subject's S-s were composed of blue and yellow (group C), one might expect to see yellow-constant gradients with peaks at red since, in the presence of yellow, blue was S-; this was the effect observed during the first battery of wavelength tests and accounted for most of the deviations from matching behavior in the experiment. If, during testing, shorter wavelength values than those for blue had been used, peaks to the left of blue would have been expected during the blue-constant tests; in the absence of such short wavelengths, the peak would be expected to occur at blue and this is what happened. Group C's gradients obtained
when green and red (non-training colors) were held constant peaked at the appropriate matching values.

When a subject's S-s were composed of blue and green (group A), on the other hand, the gradient obtained during the green-constant test is the one which should show a peak shift to yellow. This occurred for one subject but the other two produced peaks at the matching color, green. That the other two subjects did not display peak shifts could be due to the fact that peak shifts disappear with continued training (Terrace, 1966); the green-constant test was the third test administered in this experiment and training occurred between tests. (That all subjects in group C did display peak shifts during the yellow-constant tests, as described above, could be due to the fact that the yellow-constant tests were the first ones administered.) The blue-constant tests for group A would not be expected to show peak shifts for the same reasons that were given for group C. Since group A's green-constant gradients shift to yellow, one might expect the yellow-constant gradients for group A to peak at red. The data in fact show, however, that the last 16 min of group A's yellow-constant gradients peak at yellow and the red-constant gradients peak at red. Regarding the first 12 min of group A's yellow constant test, casual observation revealed a burst of responding to the first stimulus presented after TO, whether matching or non-matching. This burst of responding occurred in training as well as in testing and added approximately 30 to 50 responses to the first stimulus and possibly distorted the actual shape of the generalization gradient. Green was the first variable wavelength presented during testing.
and if only 30 responses were subtracted from the non-matching combination of yellow and green of the first 12 min of group A's yellow constant test, the gradients would be flat across yellow and green. Such flatness may possibly result in inaccurate estimates of peak location.

It would seem, then, that the most appropriate interpretation is that, early in training, when tests occur with S-colors held constant, peak shifts may be observed; when other colors are held constant, matching behavior will be displayed. Later, as training progresses, peak shifts may disappear, allowing matching behavior to be observed. Had the discrimination criterion for testing been more stringent in the current experiment (e.g., had lower or more consistent discrimination ratios been required in training prior to test 1), it may have been that no peak shifts would have occurred because they might have disappeared by that time. Further, had the first sequence of stimulus presentations been removed from the present data analysis, peaks only at matching wavelength combinations would have been obtained. Other reasons for the improvement in matching behavior as the number of tests increased are possible, however, and these are discussed below.

The "degree of discrimination" prior to test 1 could be measured in several ways. For example, with a lower discrimination ratio and a greater number of consecutive discrimination training sessions with the ratio at or below 0.300, one might expect a sharper generalization gradient with a peak at a matching wavelength combination. The effect which the absolute amount of discrimination training prior to testing should have is not so clear. More training may eventually lead to a
greater degree of discrimination; on the other hand, fewer sessions required to meet the criteria may indicate an "easier" acquisition of the discrimination, hence, a greater degree of discrimination. A comparison was made between those subjects that yielded at least one generalization gradient with a peak at a non-matching wavelength during the last 16 min of testing in the first battery of wavelength tests (A-25-7, A-25-9, C-25-7, and C-25-8) and those subjects that showed peaks of the gradients only at matching wavelengths during the last 16 min of testing (A-25-8 and C-25-9). There was no significant difference in absolute discrimination ratios nor in the amount of discrimination training prior to testing. The only large difference was in the number of consecutive sessions in which the discrimination ratio was at or below 0.300 just prior to testing; subjects A-25-8 and C-25-9 had 10 and 11 such sessions, respectively, whereas subjects A-25-7, C-25-7, and C-25-8 had three sessions and A-25-9 had four sessions.

Additional evidence that the degree of discrimination determines whether matching behavior will be displayed is that no gradient had a peak at a non-matching wavelength during the second battery of wavelength tests. It was also the case that no discrimination ratio ever exceeded 0.300 after the first battery of tests and there was also a marked reduction in the variability of these ratios. However, it may be argued that the first battery of wavelength tests served as a crude form of discrimination training in that all possible non-matching wavelength combinations were presented to the subjects during extinction. Hence, later tests may not truly measure generalization of matching behavior.
but simply the effects of increased discrimination training. Although this does not appear too likely (only four wavelength tests were given in the first battery and three intensity tests were given in which a matching stimulus was presented in extinction prior to the second battery of wavelength tests), more research is required to bear this possibility out.

The intensity tests were conducted by holding green constant on both halves of the response key and systematically varying brightness combinations. The results from these tests yielded six of 18 gradients that were peaked at a matching intensity; one subject yielded no such results, four subjects had only one such test, and only one subject showed two tests that produced peaks at matching intensities. It may be concluded that no intensity matching was acquired for two reasons. First, five of the six gradients that were peaked at a matching intensity were extremely flat (e.g., the percentage differences between the peak and the lowest point of the gradients was between 5 and 10). The only gradient that was sharp (e.g., the percentage difference was between 55 and 60) bordered on unreliability with only 55 responses at maximum. Although the intensity tests were of only 12 min duration, they were much flatter than the comparable first 12 min of the wavelength tests. The second reason it was concluded that no intensity matching was acquired was that the location of the peaks of the other 12 tests was essentially random with no apparent relation between the constant intensity and the location of the peak of the gradient.
CONCLUSION

A greater degree of discrimination prior to testing may increase the likelihood of obtaining generalization of matching behavior by sharpening the generalization gradients and thus increasing the reliability of peak location, or by decreasing the likelihood of peak shift behavior generally observed early in discrimination training, or both. It is also possible that a greater degree of discrimination simply indicates a better acquisition of the matching concept. Most of the gradients did peak at matching variable wavelengths early in the testing sequence, however, and seem to indicate that a matching concept was acquired, but that in some cases other factors (gradient sharpness and peak shift) also influenced the results. The notion that a wavelength matching concept was acquired is further substantiated by the results from the intensity tests which indicated no intensity matching. It would appear, then, that Liebold's interpretation (1969) of peak shift was replicated in the present study. Further, the intensity variable was successfully controlled for. The study by Malott and Malott (1970) would probably have yielded similar results had intensity been controlled and tests given over the entire wavelength continuum.
REFERENCES


