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INSTRUCTIONAL CONTROL OF GENERALIZED RELATIONAL MATCHING TO SAMPLE IN CHILDREN

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Three experiments examined the performance of 4-year-old children in matching geometric stimuli. Performance was developed as a simulation in which all components of the behavior were overt and directly measured. A correct match depended on the state of an instructional stimulus: the background color of the display. In the first two experiments, on nonidentity trials (signified by a green background) the next longer length, larger size, or greater distance was correct. With a blue background, a comparison identical to the sample was correct. In Experiment 3, red was added for which shorter, smaller, or nearer was correct. Also here, on nonidentity trials, if a comparison of the correct length was not presented, the children adjusted their search target to the comparison of the next succeeding size (larger or smaller) so as to maintain a constant matching relation. Subsequently, when exposure to the instructional stimulus was reduced to presentation only at the beginning of each trial, performance simulated matching based on instructions about abstract relations. In all experiments, accurate matching generalized across novel stimuli and reduced exposure to the instructional stimuli.

Key words: matching to sample, instructional control, generalization, coding responses, stimulus control, children

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The present research studied a relational matching performance in which children matched line lengths on the basis of three relations: larger, smaller, or identical. The relevant relation depended on the state of an instructional stimulus. Occasionally, a length of the size specified by the sample and instructional stimulus was absent. On these trials the children compensated by selecting the length closest to the specified size that also bore the instructed relation. When presented with novel stimuli, the children demonstrated generalized relational matching by continuing to select on the basis of the relations specified by the instructional stimuli and also to compensate, when necessary, for absent forms.

This research follows prior studies (Lowenkron, 1984, 1988) of generalized delayed identity and nonidentity matching by using a technique of simulation (Epstein, 1984) in which performances are produced as sets of overt, directly measurable behavioral components. Generalized identity matching was a product of only two components (Lowenkron, 1988). One component was a sample-coding response: For relevant features of the sample it produced a unique cue that could be preserved over a delay interval. The second component was a coding response to the comparison that was under *joint* stimulus control both by the cue produced by the sample-coding response and by the appropriate comparison stimulus. As demonstrated in Lowenkron (1984, Experiment 2) a comparison-coding response must be under this form of control for a relational matching performance to generalize to novel stimuli. (See Lowenkron, 1984, 1988, for a distinction between comparison selection under arbitrary control and under joint control.)

Adding a type of transformation behavior to modify the coding of the sample by a constant amount (e.g., changing line length by a fixed amount) turned the performance into generalized nonidentity matching in which comparisons were selected that bore a constant relation to the sample (Lowenkron, 1984). Together, these studies suggest that bringing the occurrence and nonoccurrence of the transformation behavior under the control of a discriminative stimulus would allow that stimulus to determine whether an identity or nonidentity match occurred on a particular

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trial. The stimulus would thus acquire instructional control over the matching relation. This source of control is examined in the first two experiments.

EXPERIMENT 1

METHOD

Subjects

Four boys (GH, SA, PE, and BW) and 1 girl (EN) from the campus day-care center served as subjects. All were between 4 and 5.5 years old with a mean age of 4.8 years.

Apparatus and Setting

Stimuli. The stimuli of the training and transfer sets (Figure 1) appeared in four different lengths: 1.7, 2.7, 4.7, and 6.7 cm. In the training set, these were the line lengths. In Transfer Set 1, these were the widths of the rectangles, all of which were 1.6 cm high. In Transfer Set 2, the lengths of the three rows of shapes (circles, diamonds, and lines) that comprised each stimulus were selected from these values so that no two rows were of the same length. Also, no two rows of the same shape in different stimuli were of the same length. All stimuli in Set 2 were 3.7 cm high. In Transfer Set 3 all the stimuli were 6.7 cm long, and the four lengths were the distances between the solid dots. In addition, a transformation grid, consisting of five vertical lines spaced to correspond to the four lengths (Figure 1), appeared as necessary.

During the early stages of training, stimuli were presented in black ink on white, blue, or green paper. In later stages, they were presented by a Commodore 64® computer as white character graphics with light blue or light green background screen colors on a 19-in. (45-cm) Amdek II® color monitor. When presented as samples, the stimuli were located at the center of the monitor screen. When presented as comparisons, all four members of a set were presented with one in each corner of the screen.

Test sequences. All training-set baselines and transfer tests consisted of sequences of 12 counterbalanced zero-delay matching trials. Six trials in each sequence were identity trials and six were nonidentity trials. Training-set baselines contained only training-set stimuli. Transfer-test sequences contained eight trials with the relevant transfer set interspersed with four trials from the training set.

The stimuli on trials with Transfer Set 2 were selected so that each row of shapes in the correct comparison for a nonidentity match was one size larger than in the sample. Thus, in Figure 1, the sample contains a row of diamonds 1.7 cm long, circles 2.7 cm long, and lines 4.7 cm long. The adjacent stimulus, the correct comparison for a nonidentity match, contains these same shapes in rows one size longer. The row of diamonds is 2.7 cm long, the row of circles is 4.7 cm long, and the row of lines is 6.7 cm long.

An inaccurate match during a baseline or test produced a 3-s screen blackout followed by the next trial. An accurate match produced the Sesame Street® character Big Bird® at the correct comparison with a 2-s tone. The screen then cleared, and a string of 12 cookies appeared from left to right across the screen with a little boy to the right of the rightmost cookie. Touching the boy caused him to move left and pick up one cookie. After each subsequent correct match, the string of *remaining* cookies was shown and the subject touched the boy to pick up one more cookie.

When all the cookies had been picked up, sounds and flashing screen colors signaled access to a selection of stickers. Because 12 *correct* trials were required to pick up all the cookies, the actual number of identity and nonidentity trials with the training and transfer sets depended on the number of errors because the 12-trial stimulus sequence repeated until all 12 cookies had been picked up.

With few or no errors the test sequence was conducted twice in order to acquire at least 24 trials of data. Regardless of the number of trials or errors, subjects were always allowed to finish and collect all the cookies.

Data collection. The selection of comparisons on each trial was measured by a touch-sensitive screen (Personal Touch Corp. IBM® analog model). Its output specified which screen area was being touched.

To represent stimulus lengths and sizes, subjects were trained to use a compass consisting of two notched plastic disks (Figure 1) mounted on a variable resistor and connected by cable to the computer. A button-activated switch was located on the right side of the compass. This reported the size of the compass opening at the moment the button was pressed. Both the touch-screen inputs and compass sizes were recorded by the computer.

Setting. Sessions were conducted in a small, quiet room at the campus day-care center. The

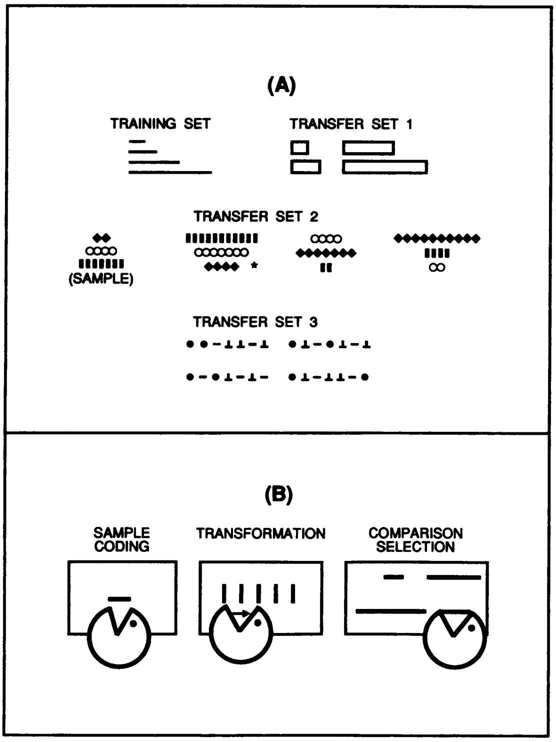

Fig. 1. Stimulus sets and component responses. (A) Sets 1 and 3 are shown complete. A subset of Set 2 illustrates a sample (which is also the identity match) and three other comparisons. Each consists of three rows of shapes of different lengths. The asterisk marks the correct comparison for nonidentity matching (larger), in which each row of shapes is one size larger than in the sample. (B) The component responses. Sample coding—adjustment of compass to a length equal to the sample. Transformation—adjustment of compass to one size larger on the grid (if the background was green). Comparison selection—length of comparison selected must equal compass size.

child sat at a small table facing the monitor. The computer and keyboard were to the right of the subject, in front of the experimenter. Between the child and experimenter lay the sheets of stickers. A second observer sat behind the child.

Procedure

General overview. To attain the initial zero-delay matching performance, each component behavior was trained separately and then integrated with the others to produce a performance in which children coded the length of a sample with the compass, incremented the length by one size if the background color was green (transformation for nonidentity matching) or left the length unchanged if the background was blue (identity matching), and then selected a comparison appropriate to the current coding.

The performance was trained as follows. In sample-coding training a line was presented at the center of the screen (Figure 1) as a sample. The children learned to code the shape by adjusting the compass so that its edges coincided with the ends of the line. Next, to train comparison selection under joint control, subjects learned to seek among the comparisons in order to find one whose line ends coincided with the compass edges without changing a preset compass size. Next, training in instructional control taught the children to change the compass size by one increment on the grid if it had a green background and to leave it unchanged when the background was blue.

The components were then integrated in two steps. First, behavior in the latter part of the sequence was integrated by starting with the initial compass size preset by the experimenter, allowing the child to transform the compass—when appropriate for the background to color—and then use the resultant setting to select a comparison whose line ends coincided with the edges of the compass with no further change in the compass setting. In final training, a trial began with a sample that subjects coded themselves to provide the initial compass setting before proceeding through the remainder of the sequence. Generalization of this performance was then tested with Transfer Sets 1 and 2.

Sessions of 30 min were conducted two or three times per week. In each session, previously taught behavior was reviewed and, where necessary, retrained before new training was begun.

Sample-coding response training. Initially, each line length of the training set was drawn on a white card. The experimenter demonstrated how to adjust the compass and place it so that its edges coincided with the ends of each line (see Figure 1). The placement of the compass edges at the line ends was pointed out. Then the child was asked to place the compass in a similar fashion. After each incorrect placement, the child was prompted ("Do it right.") until the compass was properly adjusted. Where necessary, the experimenter demonstrated the adjustment again. Each correct placement by the subject was followed by verbal praise with an opportunity to select a sticker after approximately eight correct trials (variable ratio 8 or VR 8).

After two correct, unprompted trials with each of the four shapes, the stimuli were presented on the computer monitor as samples with the light blue background color. As each line length was displayed, the experimenter gave verbal praise for an accurate setting and instructed the subject to push the button on the compass. This usually produced an adequate contact of the compass with the touch screen. If not, the button-push had no effect, and the subject was instructed to push the compass against the screen and then push the button. Only the compass size at the moment the button was pushed and the screen was touched was recorded. The screen touch guarded against accidental button-pushes.

If the compass size was more than 0.5 cm different from the line length, the screen color changed to grey for 2 s to provide a brief timeout and then returned to light blue to provide an opportunity to correct the compass setting. A correct setting produced a 0.5-s change in the background to a novel color, a musical sound from the computer, verbal praise, an occasional chance to choose a sticker, and a new trial. The training criterion was 12 consecutive correct trials.

Comparison selection training under joint control. This phase trained children to use a preset compass size to select a line length whose ends coincided with the compass edges. Based on numerical information on the monitor, the experimenter set the compass size and then handed the compass to the child. If the child disturbed the setting, the number on the monitor changed, and the experimenter reset the compass and admonished the child to be careful.

When the child pressed the compass button, a line length corresponding to the current compass setting appeared as a comparison in one corner of the screen on the blue background, and the experimenter prompted "Where is it?" If the child disturbed the setting at this point, the background color changed to grey and all selection functions were disabled until the child adjusted the compass back to the correct setting and the screen color returned to blue. The child was then prompted to place the compass so that its edges coincided with the ends of the lines. If the child placed the compass within 1 in. (2.56 cm) of the line and pressed it against the screen, there was a brief reinforcement sound, a change in the screen color to pink, the appearance of Big Bird® at the correct location, verbal praise, and, on a VR 8 schedule, a sticker was provided. Because no adjustment of the compass was required here, a button push was not required.

After six consecutive correct trials, *two* comparisons of different lengths were presented on each trial. This required the subject to actually use the preset compass size to find a line whose ends coincided with the edges of the compass. After six consecutive correct selections, the number of comparisons was increased to four. Training continued until the subject made at least 11 out of 12 correct selections in each of two successive sessions. Incorrect selections produced a 2-s blackout followed by a reappearance of the comparisons.

Training instructional control. To develop instructional control, children were taught to adjust the compass size according to the screen color. The experimenter set the compass size and then presented either a blue or green card with the grid drawn on it. The child was taught by demonstration and prompting to place the edge of the compass without the button (left edge) on the leftmost grid line of the card, and then to place the right edge on whichever grid line it fit without changing the compass setting. If the card was blue, this response was reinforced with praise and a scheduled sticker. If the card was green, the child was next prompted "Now make it bigger," and was shown how to move the right leg of the compass to the next larger grid line. Alternating between blue and green in an irregular order, the prompt was increasingly delayed over trials and omitted after a 5-s delay. Training continued to a criterion of 11 correct in 12 trials.

Next, performance was transferred to the monitor screen and integrated with comparison selection. The experimenter adjusted the compass size according to numerical information on a black screen and then handed the compass to the child, who pressed the button to produce the grid and background color. On trials with the blue background, the child needed only to place the compass properly on the grid and press the button for the trial to continue. On trials with a green background, the verbal prompt for green was given ("Make it bigger.") and the child was required to enlarge the compass by one size before pressing the button. Incorrect adjustments produced a grey screen until the button was released; then the adjustment could be corrected.

When the adjustment was correct at the button-push, the comparisons appeared with the screen color unchanged and the comparison selection prompt "Where is it?" was given. As before, a correct comparison selection produced reinforcement. Over trials, the verbal prompts for instructional control and comparison selection were again faded to a 5-s delay and then omitted. Training continued to a criterion of 11 out of 12 correct in two consecutive training sessions.

Final training. This procedure integrated the complete performance. Trials began with the presentation of a sample. A correct sample coding produced the transformation grid. A correct compass adjustment on the grid produced the comparisons. All prompts were given on the initial trials, faded to a 5-s delay, and then omitted. Training continued until the subject completed 12 consecutive trials with no errors.

Test 1. To provide a baseline of accurate matching with the training set, the training-set baseline was presented until the subject completed three sequences or two consecutive sequences with no more than two errors in each, whichever came later. In this and all subsequent tests, the contingencies requiring accurate performances of the components were eliminated except that an accurate sample coding was required on each trial. Other than that, subjects could select comparisons by simply pressing a comparison with their finger.

Familiarization with Transfer Set 1. To ensure that subjects could discriminate the rectangles, 12 simultaneous matching trials were given. Touching the sample produced a display with the sample at the center and all four shapes arrayed as comparisons. As the experimenter pointed to the sample, the subject was instructed to "Find the one like this" by pointing to one of the comparisons.

Test 2. Before this and all subsequent tests, the training-set baseline was presented until the subject completed 10 out of 12 correct. Then, two test sequences with Transfer Set 1 were presented to provide a minimum of 24 trials. In all tests accurate matches in both the training and transfer trials were reinforced.[1]

Familiarization with Transfer Set 2. The familiarization procedure described for Transfer Set 1 was repeated with Set 2.

Test 3. Two test sequences with Transfer Set 2 were presented to provide a minimum of 24 trials.

Sample-coding training. The procedures described for training sample coding were applied with the stimuli of Transfer Set 2. Subjects were trained to ignore circles and diamonds and code only the length of the row of lines.

Test 4. Test 3 was repeated.

Results and Discussion

Figure 2 illustrates the overall accuracy of nonidentity and identity matching and the accuracy of each of the three components on each trial. The three components were measured directly by the computer as follows. A sample coding was scored as correct if the compass button was pushed with the compass adjusted to within 0.5 cm of the size of the sample. A transformation was scored as correct if the compass size at the second button push (in the presence of the grid) was appropriate to the screen color—one size larger than the sample for green, no change for blue. Comparison selection was scored as correct if the length of the comparison selected was within 0.5 cm of the current compass size.

Overall matching accuracy, scored as the selection of a comparison appropriate to the sample given the instructed relation, was partially redundant on the accuracy of the components. Although an accurate performance with all components necessarily produced an accurate match, inaccurate performances on two or more components could cancel and thereby yield an accurate match. To provide a stringent test of generalization, only performance in the first 24 trials of each transfer test is reported.

Baseline Performance

In the baseline (Test 1) all subjects matched accurately with the training set on at least 10 out of the last 12 trials.

[1] Reinforcement of accurate matching during transfer trials was necessary to maintain performance throughout the test. There was no evidence, however, that reinforcement resulted in enhanced matching accuracy during tests. First, matching accuracy remained low throughout all tests administered before stable coding responses were trained for the novel stimuli (Test 3 and in Experiment 2, Test 5). Second, when accuracy was high (in Test 2, and in later experiments: Experiment 2, Tests 2, 4 and 6; Experiment 3, Test 3 with Task 3-0-G) it remained uniformly high throughout the test. The absence of an effect of reinforcement on differential matching accuracy during tests can be attributed to the brevity of the tests, with only four exposures to each novel stimulus.

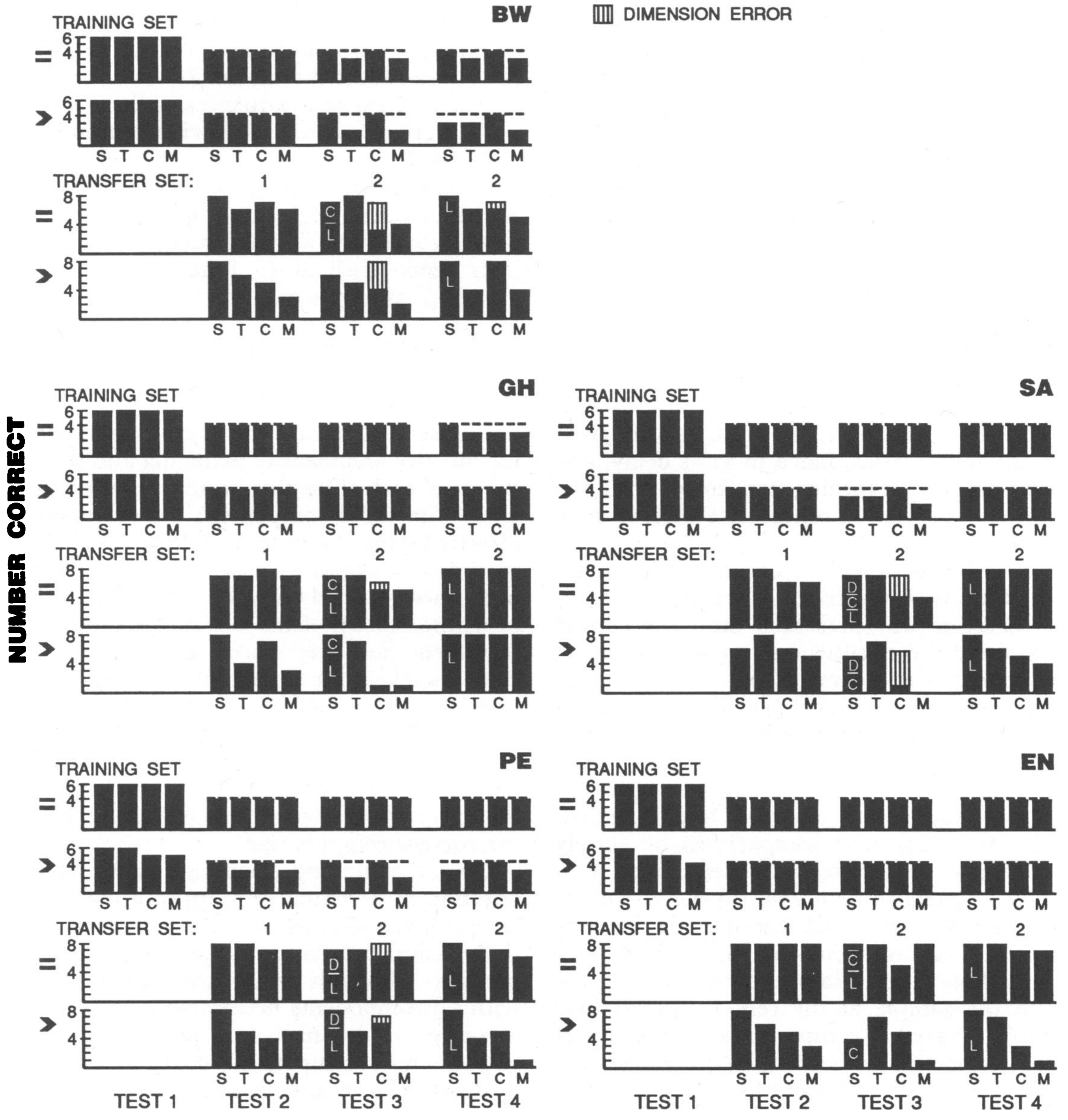

Fig. 2. Performance on each component behavior and overall matching in the training set and Transfer Sets 1 and 2 on Tests 1 to 4. S, sample coding; T, transformation; C, comparison selection; M, overall matching. Dashed lines indicate the actual number of trials of each type of matching relation where they are fewer than the highest value on the ordinate. =, identity matching; >, nonidentity (larger). Dimensions of stimuli in Transfer Set 2 that subjects coded as samples: C, circle; L, line; D, diamond. Dimension errors occurred where the comparison was coded accurately but on a different dimension than the sample.

Transfer Set 1

In Test 2, all components acquired with the training set generalized to Transfer Set 1. This produced generalization of both identity and nonidentity matching and hence generalized instructional control. Accurate matching occurred in 66% of all transfer trials, but not equally among identity (85% correct) and nonidentity matching trials (48% correct).

Among the components, sample coding generalized almost completely—only 13% of all errors with the transfer set were of this sort.

The loss of stimulus control over the transformation provided a much greater source of error. Thus, 32% of all errors arose from transforming more than one size, or not at all, on nonidentity trials, but only 4% arose from transforming the compass size on identity matching trials.

The third, and greatest, source of error was in comparison selection. It accounted for 48% of all errors: 37% in nonidentity matching and the remaining 11% in identity matching.

Transfer Set 2

In Test 3, the presence of stimuli from Transfer Set 2 frequently disrupted performance with the training set even though Transfer Set 2 was the *second* novel set presented. The overall level of matching accuracy (38%) with Transfer Set 2 was a product of two different rates. Identity matching was sustained at a moderate level of generalization (65% correct), whereas accuracy in nonidentity matching was only 11%.

Because sample-coding responses had not yet been taught for these stimuli, coding the length of any row of a sample (lines, circles, or diamonds) was scored as correct if the compass was placed adjacent to the row and adjusted to within approximately 0.5 cm of the length of the row. As the data indicate, there was variability in the dimension coded, but few errors: Sample coding generalized across dimensions.

A comparison selection was scored as correct if it was placed on any row meeting the 0.5-cm tolerance. However, the stimulus set was designed so that accurate sample coding, comparison selection, and transformation produced a correct match only if the subject did not switch dimensions; that is, if the same dimension was coded on both the sample and the comparison. It was just such dimension switching, noted in Figure 2 as dimension errors, that suppressed the matching accuracy of BW and SA.

In Test 4, after appropriate sample-coding responses were trained to the row of lines, the dimension errors ceased, but high error rates in the other components prevented accurate matching.

Combining data for all tests (except the unstable performance with the transfer set in Test 2) confirmed that accurate matching *depended* on accurate mediating behavior. Thus, errors in matching occurred on 94% of all trials with incorrect transformations but on only 13% of the trials with correct transformations. The fact that transformations were performed before the comparisons appeared eliminates the possibility that they, and hence the other types of mediating behavior, were functionless byproducts of the matching performance. Rather, the data demonstrate that control by the instructional stimulus over the matching relation resulted from its control over the transformation behavior.

EXPERIMENT 2

Although Experiment 1 demonstrated generalized matching with the rectangles of Transfer Set 1, matching accuracy was appreciably poorer with the multidimensional shapes of Transfer Set 2, even after coding responses had been trained. Performance with this set may have been impaired by the opportunity to practice errors (Schilmoeller, Schilmoeller, Etzel, & LeBlanc, 1979) afforded by the test for generalization (Test 3) before stable coding responses were trained. To investigate this, additional subjects were studied with Test 3 deleted so that sample-coding responses were trained for Transfer Set 2 before any test for generalization was given. Also, to replicate the effect of practicing errors on generalization, tests for generalization were made with Transfer Set 3 (Figure 1) before and after sample-coding training.

METHOD

Subjects

Three children from the day-care center, 1 boy (DL) and 2 girls (RC and BR) between the ages of 4.7 and 4.8 years, participated.

Procedure

All of the procedures described in Experiment 1 were repeated except for the deletion of Test 3 and the addition of Tests 5 and 6.

Familiarization with Transfer Set 3. The simultaneous matching procedure described in Experiment 1 was presented with the stimuli of Transfer Set 3.

Test 5. Two test sequences with Transfer Set 3 were presented to make a 24-trial test for generalization.

Sample-coding training. The procedures described in Experiment 1 for training sample coding were applied to Transfer Set 3. Subjects learned to code the distance between solid dots.

Test 6. The procedures described for Test 5 were repeated.

Results and Discussion

Baseline Performance

In Test 1, all subjects matched on at least 11 out of the last 12 trials with the training set (Figure 3).

Transfer Set 1

The results of Test 2 replicated those of Experiment 1. Performance on each of the components, and instructional control by background color, generalized with few errors. Again, sample coding proved to be less difficult than comparison selection. All subjects made at least one comparison-selection error, but only DL made sample-coding errors. The data confirm the tendency to make more transformation and comparison-selection errors on nonidentity trials than on identity trials.

Transfer Set 2

The acquisition of stable sample-coding responses to the lines eliminated dimension switching between the sample and comparison codings in Test 4; generalization, especially in nonidentity matching, was much improved in Test 4 here compared to Experiment 1. Only RC showed a consistent pattern of errors where stimulus control over the transformation was lost in both the training and transfer sets.

Transfer Set 3

In Test 5, as a result of an experimental error, BR saw the experimenter correctly code a sample stimulus from Transfer Set 3 using the distance between dots, and she attained 100% accuracy in sample-coding performance. For DL and RC, placements of the compass edges at the extreme ends of the row of shapes were scored as correct sample codings, because this was the general form of sample coding in all prior sets and specific coding responses for Transfer Set 3 had not yet been trained.

Accuracy on the transformation was mixed. Because by coding overall lengths of the samples they consistently opened the compass at its largest setting, DL and RC could make no transformations. This caused an error on nonidentity trials, but was appropriate for identity matching.

Because a comparison-coding response to a stimulus is correct if it is a repetition of the coding response to that stimulus when it occurs as a sample, comparison-coding responses based on the overall lengths of the Transfer Set 3 stimuli were classified as correct in Test 5. But matching accuracy for DL and RC was still poor of course, because responding was not controlled by the relevant dimension: distance between dots.

Subject BR, perhaps as a result of the stable sample coding, maintained accurate instructional control over the transformations but selected comparisons on some nonobvious basis and adjusted the compass size to fit the distance between dots. Hence, matching accuracy was poor.

As a result of sample-coding training, the acquisition of differential responding to the distance between dots in Transfer Set 3 caused compass size to become discriminative in the control of comparison selection in Test 6. This led to high levels of matching accuracy in Test 6 by DL and RC. But on nonidentity-matching trials BR continued as before to adjust the compass size to fit selected comparisons; therefore, overall matching accuracy on those trials was depressed.

As in Experiment 1, accurate relational matching depended on accurate stimulus control over the transformations. Combining all subjects and tests (except Test 3), 90% of all incorrect transformations led to incorrect matches, whereas only 5% of the trials with a correct transformation resulted in an incorrect match.

EXPERIMENT 3

To study more abstract forms of matching, three additions were made. First, a new nonidentity relation was added: *Smaller* was brought under control of a red background. Second, *constant-relation* matching trials were added in which the normally correct comparison for nonidentity matching was not present. On these trials, which could only be detected by a failure to find the normally correct comparison, subjects had to make a second transformation in accord with the current instructional stimulus (red or green), and so locate a comparison bearing a constant relation to the sample. As illustrated in Figure 4, after the compass was enlarged by one increment on a green background, the appropriate compari-

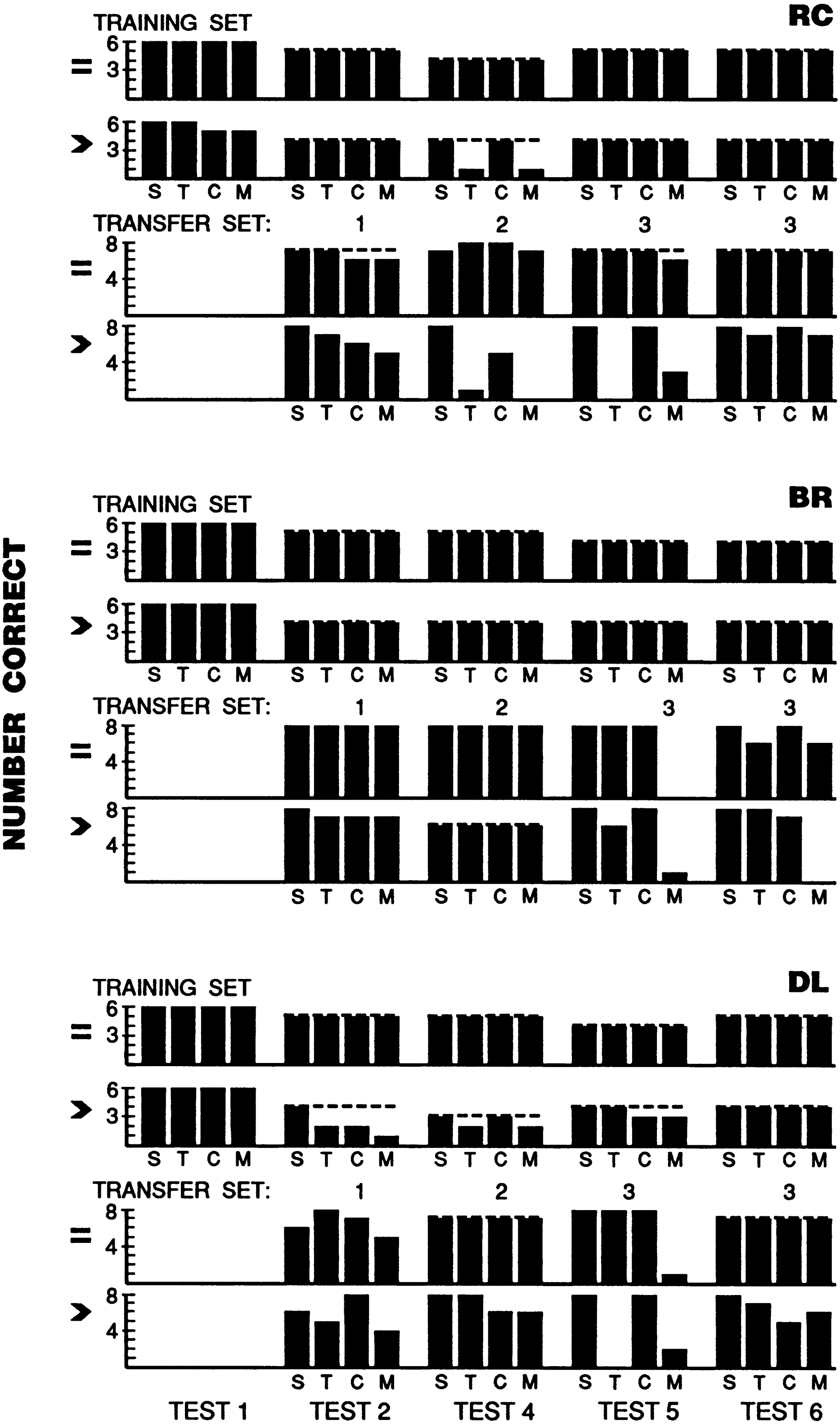

Fig. 3. Accuracy in performing each component behavior and overall matching in Experiment 2. (Test 3 was not conducted.) See legend of Figure 2 for details.

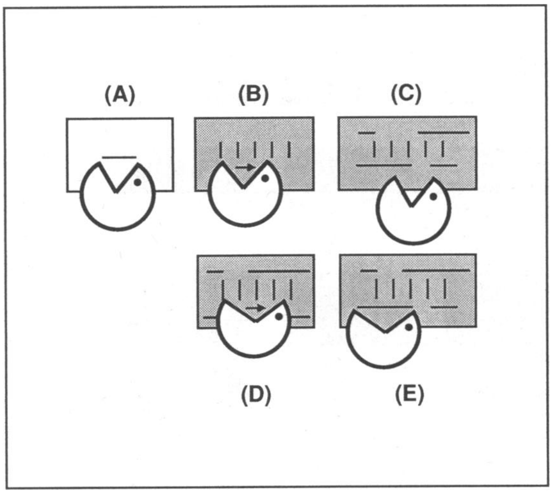

Fig. 4. Components of behavior for constant-relation matching in Task 0-3-(G+3). Cross hatching indicates green background. (A) Sample coding. (B) First size transformation (larger). (C) Attempting to select a comparison where none is appropriate to the current compass size. (D) Second transformation—one size larger still. (E) Successful comparison selection.

son was not found; therefore, the compass size was increased by one more increment and the comparison appropriate to this new setting was selected. Having two nonidentity relations ensured that transformations remained under the control of the instructional stimuli rather than the absence of a suitable comparison.

The third change was the addition of memory requirements. Across tasks, background color was removed from the transformation grid, and in the final task it was presented only with the samples. On normal trials this displaced instructional control by only a few seconds, because the transformation grid immediately followed the sample. But on constant-relation trials, this greatly extended the required duration of control by background color, because the need for a second transformation could not be ascertained until after a comparison appropriate to the first transformation had not been found.

Behavior in this final task was intended to simulate a matching performance in which the instructions appear to specify the matching relation itself rather than the appropriate transformation (i.e., "Find one larger than this."). Here larger might mean either one or two sizes larger and thus require either one or two transformations, depending on the comparisons available.

Method

Subjects

Three girls and 2 boys from the day-care center served as subjects. Their ages ranged from 4.7 to 5.2 years with a mean of 4.9. The girls, RC and BR, and the boy, DL, continued from the prior experiment. A boy, AA, and girl, SL, were added.

Apparatus

Stimuli. All features remained as described previously except stimuli one size larger (8.2 cm) were added so that the training set and Transfer Sets 1 and 3 contained five stimuli. Also, a red card with the grid on it was added to the blue and green cards.

Test sequences. For simple-relation matching tasks, the 12-trial sequences were constructed and reinforced as described in Experiment 1 except they contained four identity and eight nonidentity trials, and equal numbers of nonidentity trials contained the *larger* and *smaller* relations. In all the constant-relation tasks, simple- and constant-relation matching occurred on equal numbers of nonidentity trials.

Constant-relation matching and memory tasks. As indicated in Table 1, each task can be described by a three-unit name. Each unit describes one component of the task. Thus, Task 0-3-0 was a simple-relation matching task involving three relations: larger, smaller, and identity. The sample was presented against a black background, then an instructional background color appeared with the grid, followed by the comparisons with a black background. In Task 0-3-3, the three background colors also appeared with the comparisons. In Task 0-3-(G+3), the grid also appeared with the background colors and comparisons (Figure 4). This task allowed constant-relation matching, but with the instructional stimuli present continuously, instructional control required no memory.

In the succeeding tasks, memory requirements were introduced. In Task 0-3-G, the grid, but not the background color, appeared with the comparisons. This allowed subjects to use the background color on simple-relation matching trials, but required that they recall

Table 1

Description of tasks in Experiment 3. Each task name describes the presence or absence of the instructional stimuli in each of the components that comprise each task.

Task	Matching relation	Task component: Sample coding	Transformation grid	Comparison selection
0-3-0	Simple	0	3	0
0-3-3	Simple	0	3	3
0-3-(G+3)	Constant	0	3	Grid + 3
0-3-G	Constant	0	3	Grid + 0
3-0-0	Simple	3	0	0
3-0-G	Constant	3	0	Grid + 0

Note. 0, Black background, no instructional stimuli; 3, colored backgrounds as instructional stimuli; G, transformation grid.

Table 2

Sequence of baselines and tests in Experiment 3.

Task	Stimulus set	Function
0-3-3	Training Set	Baseline
0-3-(G+3)	Training Set	Pretest
Constant relation	Training Set	Training
0-3-(G+3)	Training Set	Posttest 1
0-3-(G+3)	Transfer Set 1	Posttest 2
0-3-(G+3)	Training Set	Baseline
0-3-G	Training Set	Pretest 1
0-3-G	Transfer Set 1	Pretest 2
0-3-0	Training Set	Baseline
3-0-0	Training Set	Pretest 1
3-0-0	Transfer Set 1	Pretest 2
0-3-(G+3)	Training Set	Baseline
3-0-G	Training Set	Test 1
3-0-G	Transfer Set 1	Test 2
3-0-G	Training Set	Baseline
Sample coding	Transfer Set 3	Training
3-0-G	Transfer Set 3	Test 3

the color on constant-relation matching trials. In Task 3-0-0, no grid appeared with the comparisons; thus constant-relation matching was omitted, but the memory interval for simple-relation matching was maximized. Finally, Task 3-0-G maximized the memory requirement *and* required constant-relation matching. Here, the instructional stimulus, shown only with the sample, had to be recalled once in the presence of the grid for the initial transformation and again with the comparisons if the trial happened to require a constant-relation match.

Order of tasks and tests. Table 2 illustrates the order in which the baselines, training procedures, and tests were given. No session with tests contained more than four 12-trial sequences. Each test session began with a baseline. If 11 correct out of 12 was achieved on the first or second presentation of the baseline, that presentation was followed immediately, in the same session, by two 12-trial sequences with the corresponding pretest or test. Otherwise, the baseline was presented twice more for practice and the session ended.

Pretests in which matching accuracy fell below 20 out of 24 correct were followed by training in the specific task and then a posttest. No such criterion or training contingency was in effect for tests or posttests.

Procedure

The 2 new subjects were trained and tested through Test 2 with the procedures described in Experiments 1 and 2. Then, the procedures described for training the relation *larger* with a green background were applied to train all subjects in the nonidentity relation: match *smaller* on a red background. Subjects then practiced Task 0-3-0 to a criterion of 11 out of 12 correct in two successive sequences.

Constant-relation matching. After completing Task 0-3-0, subjects practiced Task 0-3-3 until the baseline criterion was reached. This was followed by the pretest with Task 0-3-(G+3) to provide a baseline of untrained constant-relation matching performance.

Constant-relation matching was then trained. A black screen with digital information allowed the experimenter to preset the compass size. The subject was then handed the compass. When the subject pressed the button, the grid with the background color appeared. If the subject then transformed the compass appropriately and pressed the button again, the comparisons with the grid and the current background appeared.

If the trial required only simple-relation matching, one of the comparisons was of the size specified by the compass and a correct comparison selection was reinforced with a colored screen, tones, and Big Bird.® Any change in the compass size produced a grey screen until the subject corrected the compass.

On constant-relation matching trials, after subjects had found no comparison that fit the current compass size, they were trained by demonstration and prompt ("How do you do this?" while the experimenter pointed to the grid) to transform the compass size by one increment (in accord with the background color) and again attempt to locate a suitable comparison. On these trials compass movement did not produce a grey screen. Training continued to a criterion of 10 consecutive correct trials in two consecutive sessions. This was followed by the posttests with Task 0-3-(G+3).

Constant-relation matching with memory. Task 0-3-(G+3) was then used as a baseline and followed by Task 0-3-G. Then accurate matching was regained on simple matching with the training set in Task 0-3-0, and the effect of moving the instructional stimuli to the sample was studied in Task 3-0-0 with the training set and Transfer Set 1 (except for Subject SL).

Because this was the only pretest in which a subject (RC) scored below the pretest criterion, only this training is described. Essentially it is the procedure described in Experiment 1 to train instructional control except that the instructional stimuli appeared only with the numerical display at the beginning of each trial. When the subject was handed the compass, she was asked to name the color aloud before pressing the button to produce the grid. Criterion was 10 successive correct in each of two sessions, followed by posttests in Task 3-0-0. Subsequently, Task 0-3-(G+3) was used to regain constant-relation matching, followed by Task 3-0-G.

Follow-up. Four months later, matching performance was regained in Task 3-0-G and in sample coding the stimuli of Transfer Set 3. Then, generalization of matching to Transfer Set 3 in Task 3-0-G was measured in Test 3.

Results

After finishing an errorless performance in Task 0-3-3, subjects continued to match accurately (Figure 5) on the simple-relation matching trials in the pretest with Task 0-3-(G+3). They did not, however, perform well on the constant-relation matching trials. The most consistent source of error, naturally enough, was a failure to readjust the compass appropriately (Transformation 2) after finding no comparison that fit the first transformation. As a result, these subjects maintained the compass size produced by the first transformation and selected a comparison that was incorrect for that size. But these comparison selection errors were not random. Rather, they appeared to result from stimulus generalization of the comparisons over the coding responses. Thus, in the absence of an exact fit, subjects almost invariably selected the comparison nearest in size to the current compass setting (i.e., one size larger or smaller). For example, RC always selected comparisons one size larger than the compass. This error, incidentally, compensated for her failure to make the second transformation, and so yielded correct matches on all trials where the relevant relation was *greater than*.

On trials scored as accurate comparison selections but inaccurate matches, Subjects RC and DL were observed to skip the grid and adjust the compass to fit a particular comparison. This improper adjustment functioned as a correct transformation and yielded a correct match if it happened to coincide with the transformation specified by the instructional stimulus for that trial.

After training, accuracy in performing the second transformation reached high levels (in Posttest 1), producing a comparable rise in the overall accuracy of constant-relation matching. In Posttest 2, instructional control of relational matching generalized to Transfer Set 1. Only AA failed to show generalized instructional control. Although he performed almost flawlessly with stimuli of the training set, he repeatedly failed to make the second transformation with Transfer Set 1.

When the instructional stimuli were removed from the comparison selection phase of Task 0-3-(G+3) to produce Task 0-3-G (Figure 6), 3 of the subjects maintained accurate matching with both the training set (Pretest 1) and Transfer Set 1 (Pretest 2). Although control over the second transformation was lost in the behavior of Subject SL, it was rapidly regained in Posttest 1 after the subject was prompted on a few trials to verbalize the instructional stimulus color as it was presented during the first transformation. She was then heard to verbalize these color names on every trial thereafter. Neither BR nor AA named aloud any colors through the remainder of the experiment.

In Task 3-0-0 (Figure 7), the instructional stimulus could exert only delayed control over

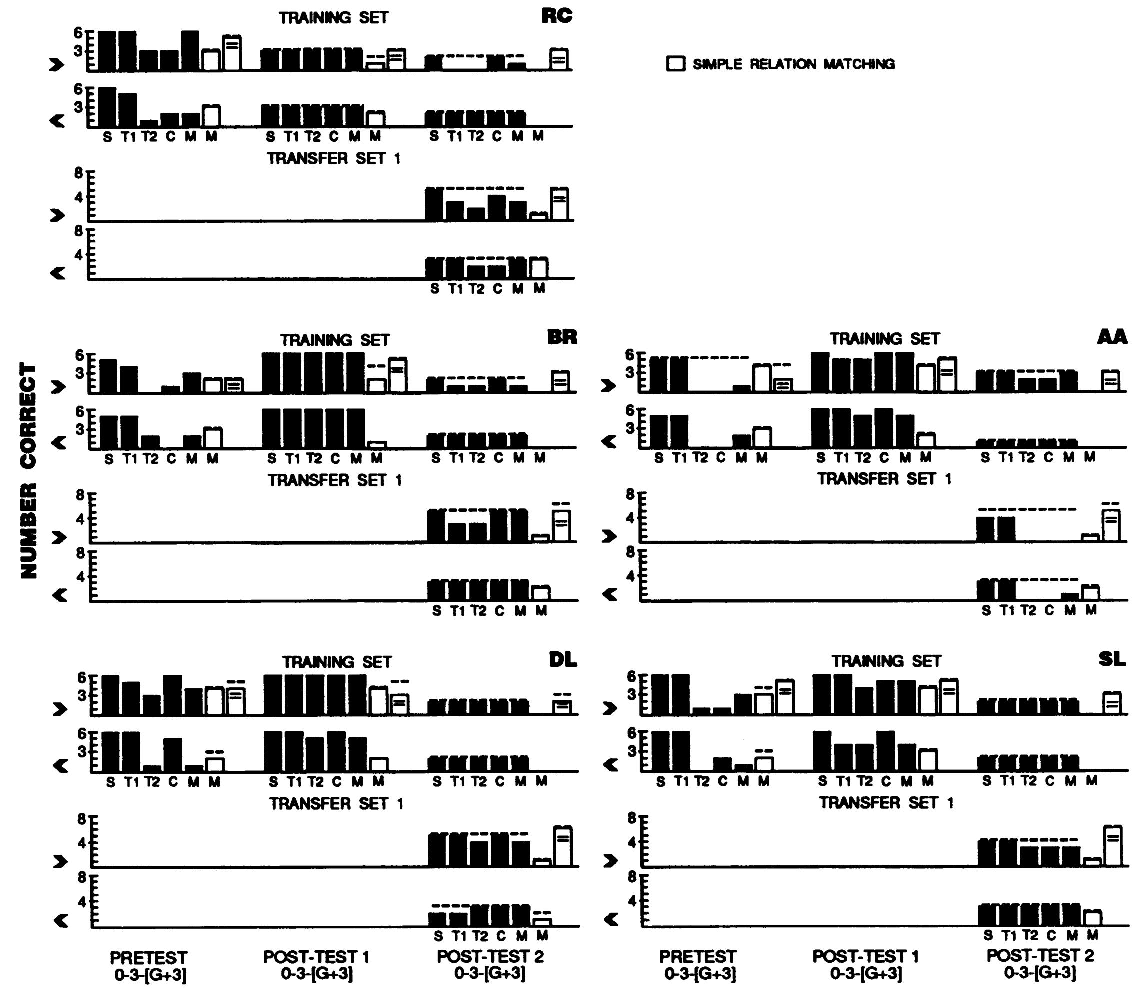

Fig. 5. Performance with the training set in Task 0-3-(G+3) before training (Pretest) and performance on both the training set (Posttest 1) and Transfer Set 1 (Posttest 2) after training. Solid bars illustrate component and overall matching performance on constant-relation matching trials.

Open bars illustrate overall simple-relation matching performance in each nonidentity relation. Open bars with equal signs illustrate identity matching. T1, first transformation; T2, second transformation. >, nonidentity (larger); <, nonidentity (smaller); =, identity-matching trials.

the transformation, but only RC showed any marked loss of matching accuracy (Pretest 1). On trials where the subject was heard to repeat the color in a low tone, she made no transformation errors and hence no matching errors. But when she did not verbalize, she failed to transform accurately. After RC was trained to name the color at the beginning of every trial, performance improved immediately (Posttests 1 and 2). Subject SL was asked why she didn't say the color names as she had been prompted earlier. She indicated that she did so "to herself." With all subjects, matching generalized to the transfer set with few errors.

In Task 3-0-G, constant-relation matching was reinstated (Figure 8). Again, performance was almost errorless with the training set (Test 1) and Transfer Set 1 (Test 2), even though the instructional stimulus presented with the samples frequently had to maintain control of the second transformation. Finally, as the data for Test 3 illustrate, accurate matching generalized at a high level to Transfer Set 3 after a 4-month interval.

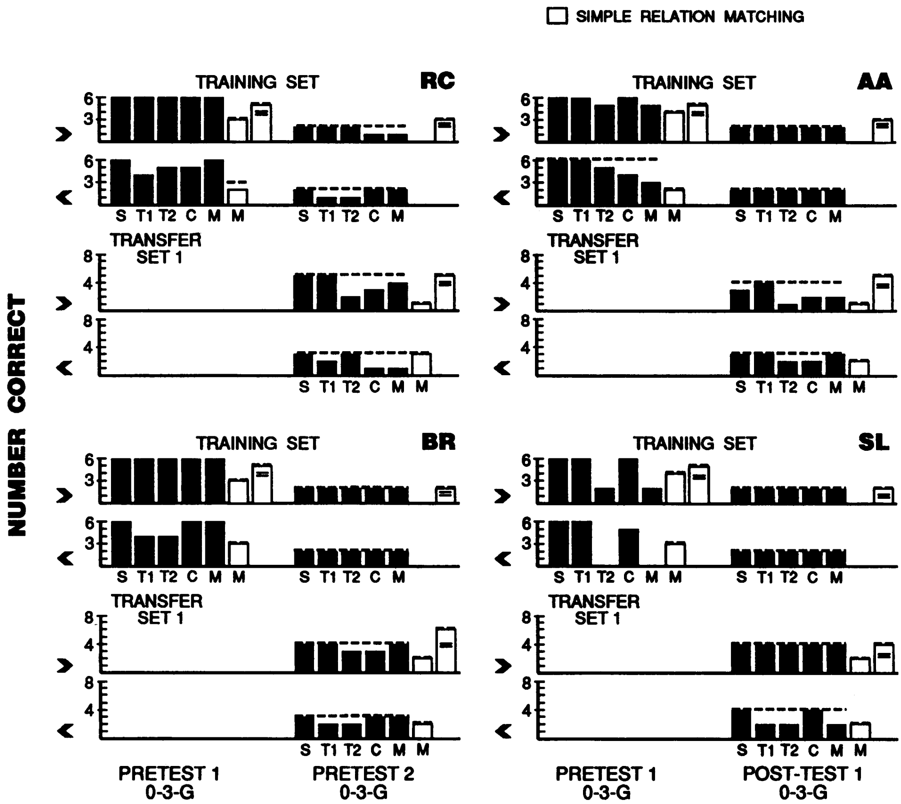

Fig. 6. Generalization of constant-relation matching performance to Task 0-3-G with the training set and Transfer Set 1. See legend of Figure 5 for details.

Discussion

With the development of constant-relation matching, behavior took on a property (goal orientation) typically attributed to cognitive mechanisms such as plans (Miller, Galanter, & Pribram, 1960) and schema (Inhelder & Piaget, 1964). Goal orientation is inferred where the failure of hitherto successful goal-producing behavior, rather than evoking the repetitive responding characteristic of extinction, evokes behavior that modifies features of the environment that control the goal-producing behavior. The newly evoked behavior may modify the location or method of search or, as in the present case, the target of the search. These environment-modifying responses are themselves not particularly obscure. But what is not obvious is their source of control, and it is probably this obscurity that favors appeals to cognitive mechanisms (Epstein, Kirshnit, Lanza, & Rubin, 1984; Skinner, 1969, chap. 6).

In the current study, an apparently goal-oriented type of behavior, constant-relation matching, was in fact the result of explicit training that brought the second transformation under the control of the effects of a failure to find the initially specified comparison. Presumably these effects included an increased trial interval and extended searching among the comparisons.

In progressing from Tasks 0-3-0 to 3-0-G, the instructional stimuli became increasingly remote from the transformations they controlled; thus, behavior appeared to take on a second property typically attributed to cognitive mediators, namely, control by instructions specifying the matching relation. But as the data indicate, constant-relation matching generalized across tasks with little additional training, and so, despite the appearance of a qualitative difference in the performance in Task 3-0-G, an examination of the origin of the behavior suggests that it resulted from a

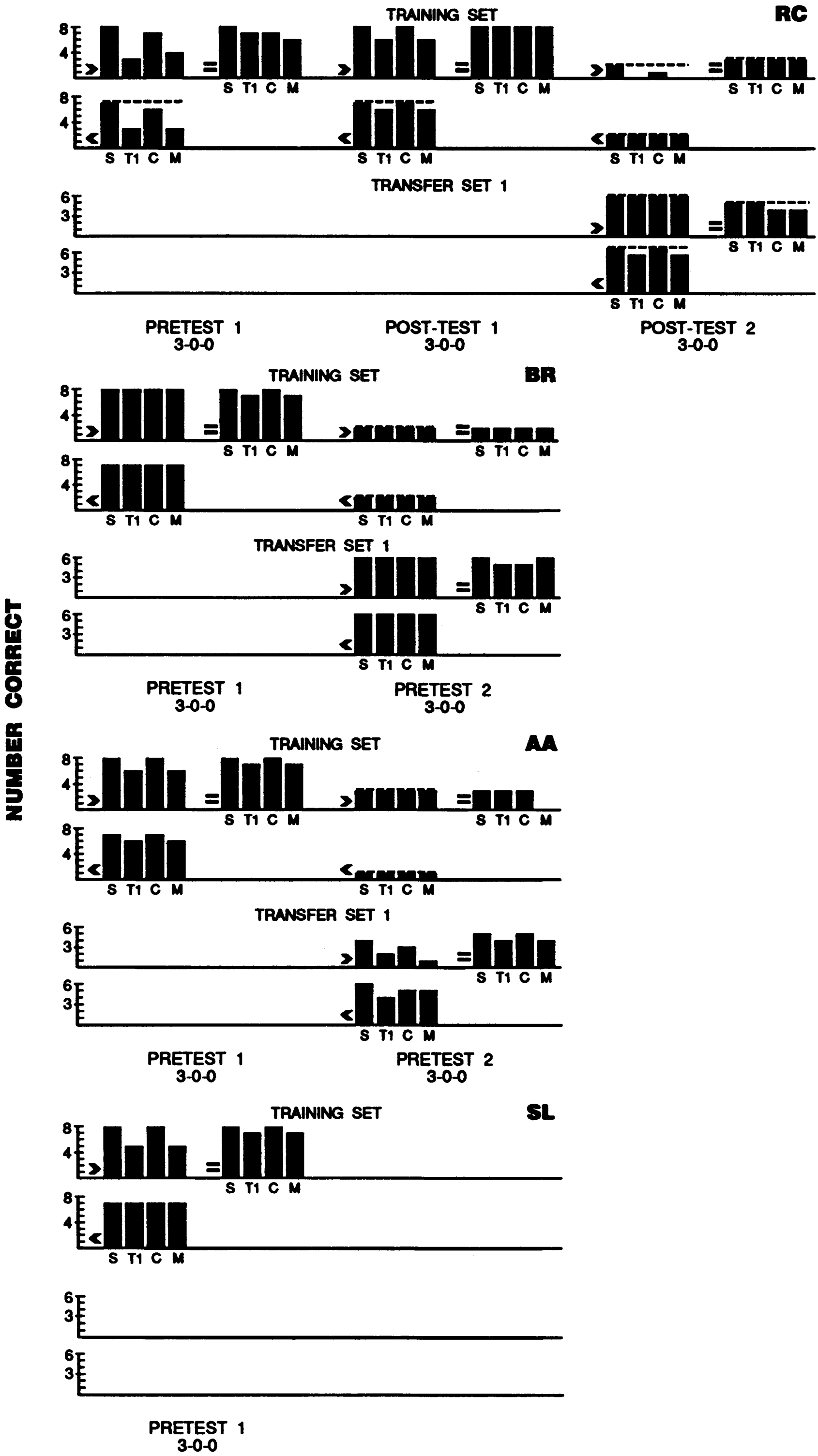

Fig. 7. Generalization of simple-relation matching to Task 3-0-0 with the training set and Transfer Set 1. See legend of Figure 5 for details.

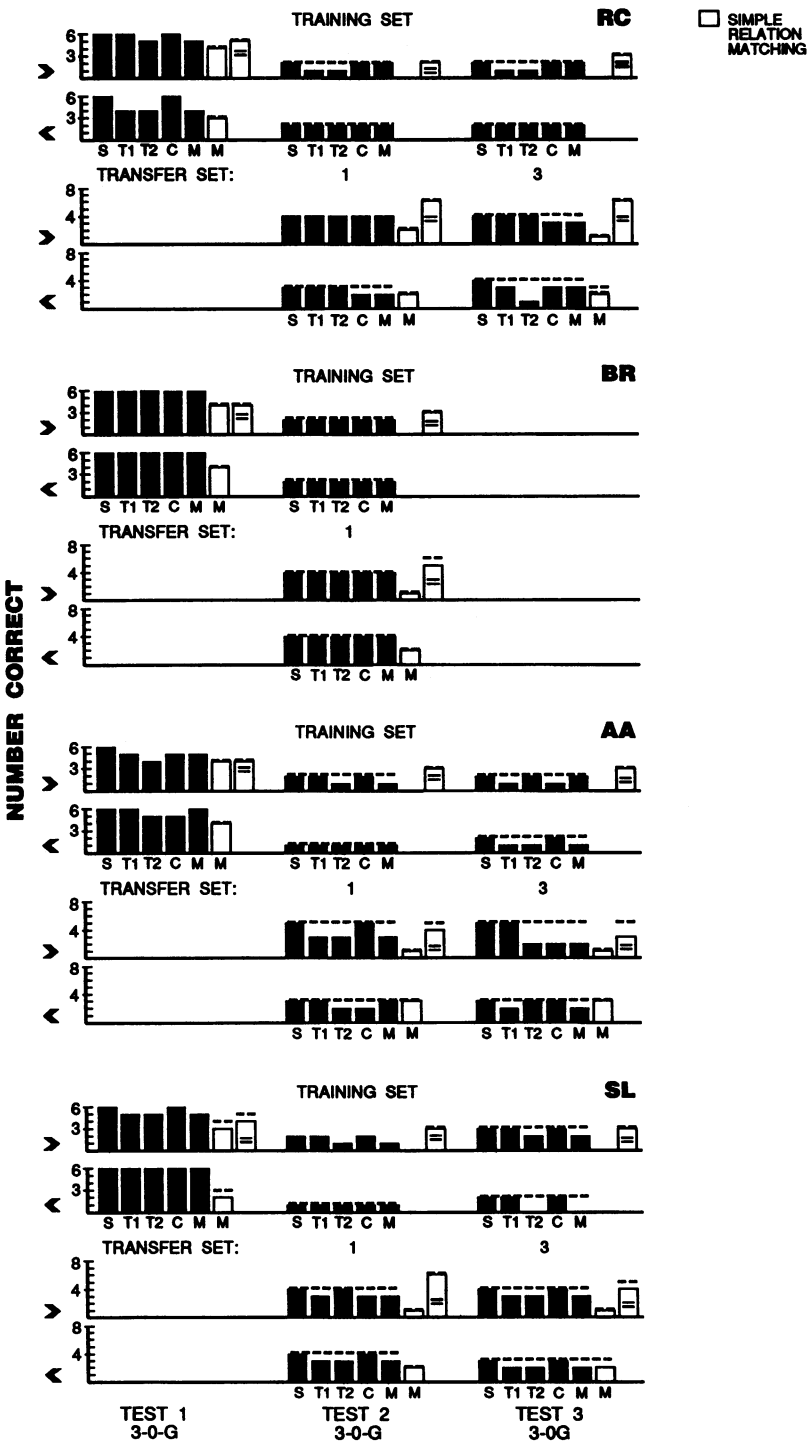

Fig. 8. Generalization of constant-relation matching performance to Task 3-0-G with the training set and Transfer Sets 1 and 3. Test 3 was given after a 4-month interval. See legend of Figure 5 for details.

continuous extension of the duration of instructional control. It seems that once a stable performance is acquired (i.e., performance in Task 0-3-(G+3)), subjects will, if possible, replace the controlling features of a task if they are delayed or deleted (Touchette, 1971), making the sources of control less apparent.

The addition of joint control over comparison coding provides parallels to the typology of conditional discriminations described by Sidman (1986). Thus, the four-term contingency, consisting of the sample, comparison, selection response, and consequence, describes any matching-to-sample performance. With joint control over the comparison-selection response, the four-term contingency describes generalized relational matching (Lowenkron, 1984, 1988).

The five-term contingency describes the second-order conditional discrimination (Sidman, 1986). For example, selecting a square in the presence of a green discriminative stimulus and a circle in the presence of red is correct in the context of the conditional stimulus, Tone 1, whereas with Tone 2 the correct color–shape assignments are reversed. Thomas, Stengel, Sherman, and Woodford (1987) argue that the conditional and discriminative stimuli cannot be distinguished functionally. Changing the labels for tone and color implies no change in behavior. But when joint control over comparison selection is added to the five-term contingency, it describes the form of instructional control explored in the present research where the roles of the instructional and sample stimuli *are* distinguishable. The sample stimuli control sample coding, and the instructional stimuli control transformations.

The simple progression of these tasks suggests that types of behavior of additional complexity may be constructed by the systematic addition and modification of components.

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