

Same–Different Texture Discrimination and Concept Learning by Pigeons

Robert G. Cook, Kimberley K. Cavoto, and Brian R. Cavoto
Tufts University

The acquisition and transfer of a “same–different” conditional discrimination using multi-dimensional visual texture stimuli was investigated in pigeons. Using a choice task, 4 pigeons were reinforced for discriminating *different* displays, created from aggregated differences in element color or shape, from *uniform* displays, in which all elements were identical. Discrimination of these 2 display types was readily acquired by the pigeons when they were required to locate and peck the contrasting target region of the different displays. The pigeons showed high levels of discrimination transfer to novel texture stimuli both during acquisition and in 2 subsequent transfer tests. The results suggest that pigeons may be able to learn a generalized same–different concept when promoted by the use of large numbers of multi-element stimuli during training.

Concepts are an essential part of human cognition, intelligence, and expression. With the growing interest in the cognitive abilities of nonhuman animals, a natural question is to what extent do animals use concepts in guiding their behavior (Herrnstein, 1990). Over the last 30 years, for instance, researchers have established abundant evidence for the formation and use of visually based object concepts by pigeons (Herrnstein & Loveland, 1964; Herrnstein, Loveland, & Cable, 1976; Wasserman, Kiedinger, & Bhatt, 1988). However, evidence for the use of more abstract concepts by pigeons, such as generalized “matching,” “oddity,” or “same–different” discriminations, has been far more difficult to obtain.

Research on abstract concept learning in pigeons has for the most part focused on whether pigeons learn generalized matching or oddity rules in matching-to-sample and oddity-from-sample discriminations. Although many studies have failed to find evidence of concept-based transfer in such conditional discriminations (Berryman, Cumming, Cohen, & Johnson, 1965; Cumming & Berryman, 1961; Cumming, Berryman, & Cohen, 1965; Farthing & Opuda, 1974; Holmes, 1979; Santi, 1978, 1982), several lines of recent research have suggested that pigeons can form and use such matching and oddity rules (Lombardi, Fachinelli, & Delius, 1984; Wright, Cook, Rivera, Sands, & Delius, 1988; Zentall, Edwards, & Hogan, 1984; Zentall, Edwards, Moore, & Hogan, 1981; Zentall & Hogan, 1975, 1978, 1981).

Evidence of same–different concept formation by pigeons is more limited and not as definitive (Edwards, Jagielo, & Zentall, 1983; Santiago & Wright, 1984). The same–different task requires the subject to respond *same* when two or more stimuli are identical and *different* if one or more of these stimuli are different from the others. In Santiago and Wright (1984) and Edwards et al. (1983), the pigeons chose between right and left choice keys depending on whether a pair of stimuli were identical or not. By testing hue, shape, and flickering stimuli, Edwards et al. found that pigeons had difficulty acquiring this discrimination and showed limited transfer to novel stimuli (58%) in the critical first test session. Using slides of complex scenes and objects, Santiago and Wright also found that pigeons acquired this type of discrimination with difficulty and showed only a limited degree of transfer (60%) in the first test session. These and other results led some to suggest that nonhuman animals may be incapable of forming same–different concepts except under special training conditions (Premack, 1983).

Our interest in same–different discrimination is derived from our recent experiments investigating avian visual cognition through the use of textured visual stimuli (Cook, 1992a, 1992b, 1992c, 1993a, 1993b; Cook, Cavoto, & Cavoto, in press). These stimuli were multidimensional, multi-element, visual patterns in which global target and distractor regions were arranged from the grouping of smaller component elements (Beck, 1982; Julesz, 1981; Marr, 1982). Using a target-localization task, in which pigeons had to locate and peck at the odd color or shape target region randomly placed within a larger texture, we have established a number of parallels between how pigeons and humans perceptually group and process the featural differences of such multi-element displays. These similarities suggest that these different species may share analogous early visual processes for perceiving object boundaries and surfaces.

The target-localization task has several limitations, such as requiring the stimulus to remain visible until the animal responds, which motivated us to explore alternative proce-

Robert G. Cook, Kimberley K. Cavoto, and Brian R. Cavoto,
Department of Psychology, Tufts University.

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Correspondence concerning this article should be addressed to Robert G. Cook, Department of Psychology, Paige Hall, Tufts University, Medford, Massachusetts 02155. Electronic mail may be sent via Internet to rcook@pearl.tufts.edu.

dures for investigating the processing of these stimuli by pigeons. Towards this goal, we developed an innovative choice procedure in which the pigeons report whether a contrasting color or shape difference is present or absent in a texture stimulus by choosing among two subsequently presented choice alternatives. These choice alternatives consisted of two "choice hoppers" located on the right and left side of the chamber that replaced the choice side keys traditionally used in conditional discriminations. After the presentation of the texture stimulus on each trial, these choice hoppers were illuminated but not raised. The pigeon then indicated its reaction to the stimulus by entering its head into one of the two hoppers. Light-emitting diodes (LEDs) located in front of each hopper detected this choice behavior. If the entered hopper was correct, the hopper was raised, allowing access to its contents; if it was the incorrect hopper, the bird experienced a brief dark timeout. This hopper-choice procedure permitted the birds to express more directly their judgment concerning any discriminative stimulus, without learning the intervening associations required of the ubiquitous side-key procedure, and receive almost instantaneous feedback about the consequence of this choice. More important, for this article, the task provided an excellent opportunity to investigate the inadequately explored issue of pigeon same-different learning and concept formation, as the stimuli involved required the animals to discriminate *different* displays composed of contrasting color or shape regions from *same* displays composed of uniform arrays of identical elements.

The training of the pigeons in this choice discrimination was conducted with large numbers of texture stimuli. As created from a set of 81 small colored shapes, 1,296 different displays containing contrasting target and distractor regions that differed in color or shape and 81 uniform displays, which had no such dimensional differences were used during training. The correct response following presentation of any different display was selection of the nominal *different* choice hopper and following any of the uniform displays the selection of the nominal *same* choice hopper. Following acquisition of the discrimination, transfer tests with novel texture stimuli were conducted to examine how the pigeons had learned to distinguish these two stimulus classes. If the pigeons had learned the discrimination on a conceptual basis, their performance should have transferred to these new stimuli composed from novel colors and shapes. If, however, memories for the specific training stimuli were the primary discriminative cue guiding choice behavior, they should have failed to discriminate among these novel displays.

This article describes new evidence about the acquisition and transfer of same-different discriminations by pigeons. We report that, when trained and tested in our choice task using large numbers of different and uniform multi-element texture stimuli, pigeons readily acquired this discrimination and transferred it to novel examples of these stimuli. These outcomes suggest that a form of generalized same-different concept may have been involved in the learning and performance of this task.

Method

Subjects

Four male naive White Carneaux pigeons were tested. They were maintained at 80% of their free-feeding weights during testing.

Apparatus

Testing was conducted in a flat black Plexiglas chamber (39 cm wide \times 33 cm deep \times 41 cm high). All stimuli were presented by a computer on a color monitor (NEC Multisync 2A, Wooddale, IL), which was visible through a 26- \times 18-cm viewing window in the middle of the front panel. The viewing window's bottom edge was 20 cm above the chamber floor. A thin piece of glass mounted in this window protected the monitor. Pecks to the monitor screen were detected by an infrared LED touchscreen (resolution of 96 \times 48 locations; EMS Systems, Champaign, IL) mounted behind a 40-mm wide Plexiglas ledge that went around the inside edge of the viewing window. A 28-V houselight was located in the ceiling and illuminated at all times, except when an incorrect choice was made. Identical food hoppers (Coulbourn #E14-10, Lehigh Valley, PA) were located in the right and left walls of the chamber, each 3 cm from the front panel and flush with the floor. Infrared LEDs mounted 2.5 cm in front of each hopper detected the approach of a bird's head towards its opening.

All experimental events were controlled and recorded with a 386-class computer. A video card (VGA Wonder; ATI Technologies, Scarborough, Ontario, Canada) controlled the monitor in the VGA graphics mode (640 \times 480 pixels). Computer-controlled relays (Metrabyte, Taunton, MA) operated the hoppers and houselight. Stimulus and event programming were done with Quick-Basic (Microsoft, Redmond, WA) with an attached graphics library (Xgraf, Pittsburgh, PA).

Procedure

Stimulus material. All texture stimuli were 18 \times 12 cm in size and consisted of 384 elements arranged in a 24 \times 16 matrix at 0.75-cm intervals. These individual elements were 3 mm to 6 mm in size, depending on their shape. Eighty-one basic elements, made from combining nine colors (blue VGA #1, green #2, cyan #3, red #4, purple #5, brown #20, gray #7, orange #52, and rose #37) and nine shapes (*U*, *T*, triangle, square, chevron, dots, circle, vertical line, and a horizontal line), were used to create 1,296 different displays and 81 uniform displays. The different displays contained an 8 \times 8 target region of contrasting elements that was randomly located at one of 128 locations within the 24 \times 16 matrix of surrounding distractor elements. For the 648 color different displays, the target region's elements were different in color from those of the distractor region but were the same shape (nine target colors \times nine distractor colors \times nine irrelevant shapes = uniform displays = 648 displays). For the 648 shape different displays, the target region's elements were a different shape from those of the distractor region but were the same color. Each of the 81 basic elements was also used once to create a uniform display composed entirely of that element. For each daily session, 60 uniform stimuli and 60 different stimuli were drawn at random from these larger pools of each display type.

For reasons related to earlier research, 2 birds were tested with displays that were 16 \times 8 elements in overall size during the first three phases of discrimination training. In all other respects, these

slightly smaller texture stimuli were constructed as described in the *Stimulus material* section. Both birds were switched to the larger 24×16 displays at the start of the target-directed fixed-ratio (FR) training procedure (Phase 4) described below.

Initial training. The pigeons were trained to eat from the hoppers and then were autoshaped to peck a white 2.5-cm circular ready signal that was centrally presented, using both hoppers. Once consistent responding to this signal was established, texture stimuli were added to the sequence. These texture autoshaping trials started with a peck to the ready signal, after which a randomly selected uniform or different texture stimulus was presented for 20 s or until pecked once. Either event caused only the correct food hopper to be illuminated, and when it was entered by the pigeon, the hopper raised for 2 s. For 2 birds, the right hopper was correct for different stimuli and the left hopper was correct for uniform stimuli. This assignment was reversed for the other 2 birds. Only one or two sessions, consisting of 120 texture autoshaping trials each (60 uniform and 60 different [30 color and 30 shape]), were needed before all birds consistently responded to the texture stimuli. Discrimination training was then started.

Discrimination training. Discrimination training was instituted by simultaneously illuminating both the incorrect and correct hoppers at the time of choice. Each trial began with a peck to the ready signal, followed by a 4-s presentation of a randomly selected different or uniform display, at which point the two choice hoppers were illuminated, allowing a choice to be made. The texture stimulus remained visible until the animal made its choice by entering one of the two hoppers. If the correct hopper was selected, it was raised for 2 s. If the incorrect hopper was selected, the hopper lights were turned off and the overhead houselight extinguished for 15 s. A 5-s intertrial interval (ITI) followed either outcome. Daily sessions consisted of 120 discrimination trials (60 uniform and 60 different [30 color and 30 shape]). After sessions in which a bird showed a clear position bias (90% or more of choices to one hopper), a session using a correction procedure was conducted, and all trials were repeated until correct.

Because the birds appeared not to learn with this initial procedure (designated Phase 1), three procedural changes were successively made to promote learning. Starting at Session 31, differential food outcomes were introduced (Phase 2), with peanut hearts (left hopper) and safflower (right hopper) replacing the mixed grain that had been used to that point. Starting at Session 41, the 4-s stimulus duration was replaced by a FR peck requirement of 10 responses (FR-10) to the display prior to the choice phase (Phase 3). For 10 sessions in the middle of this phase, a correction procedure was used every other session. Discounting those sessions, the third phase lasted 32 sessions.

The final change (Phase 4) involved the nature of the FR requirement. In this target-directed FR (TD-FR) procedure, the pigeons were required to peck five times at the target region of the different displays to enter a trial's choice phase. Pecks to the distractor region of the different displays were recorded but not counted towards completion of this requirement. Because the uniform displays had no target to peck, the number of pecks required to enter the choice phase of these trials were yoked to the different trials to ensure that an equivalent number of pecks were made to each display type. The number of pecks made on individual different trials were chronicled in a pushdown stack and reused with subsequent uniform trials. If the stack was temporarily empty because of the chance randomization of trials within a session, the average number of responses to all previous different trials of that session was used for that uniform display. When a uniform trial was the first of a session, five pecks were required. A single peck at the target was required in the first TD-FR session

and was increased to five pecks over the next four sessions. As noted previously, only larger texture displays were used from this point on. Discrimination training was continued until each bird had recorded five sessions with an overall accuracy score of 73% or greater.

Novel transfer: Test 1. The first transfer test examined performance with novel texture stimuli composed of novel color and shape elements. It began 10 days after the last bird reached criterion and consisted of four test sessions that were conducted every other day between training sessions. Each transfer session tested eight uniform and eight different novel transfer trials randomly intermixed among 144 baseline trials (72 uniform and 72 different [36 color and 36 shape]). The spatial and dimensional organization of the transfer stimuli were the same as for the baseline displays. The same TD-FR response requirement was used for the baseline and transfer trials. Correct responses on transfer trials were reinforced.

The 16 novel transfer displays were made from combinations of two novel colors (yellow #11 and lavender #20) and two novel shapes (star and plus sign). The eight different displays (four color and four shape) were made by testing each pair of values from a dimension as both the target and distractor regions in separate displays. Each of these displays was then combined with the novel values of the other dimension. For example, the four transfer shape displays consisted of yellow stars embedded in yellow pluses, lavender stars in lavender pluses, yellow pluses in yellow stars, and lavender pluses in lavender stars. The uniform displays were made from the four combinations of the novel values (yellow stars, yellow pluses, lavender stars, and lavender pluses). Because only four novel uniform displays could be made from these elements, they were presented twice in each session to equate the number of right and left hopper responses for transfer trials.

Novel transfer: Test 2. The second transfer test examined performance with novel stimuli generated from combinations of the four novel values of Test 1 and the familiar color and shape values used in training. Four test sessions were conducted, each separated by a baseline session. Each transfer session consisted of 16 novel transfer trials randomly intermixed among 144 baseline trials. Unlike Test 1, each transfer session tested an entirely different set of novel stimuli. This was accomplished by uniquely combining the four novel values (yellow, lavender, star, and plus) with different groupings of the nine color- and nine shape-training values over the four sessions. To illustrate how this was done, we describe the novel test stimuli for the first transfer session in detail: First, the novel values were combined with a familiar value from the same dimension (star and U, plus and U, lavender and red, or yellow and red) and then were uniquely combined with a familiar value from the other dimension to form pairs of complete elements (cyan stars and cyan Us, brown pluses and brown Us, lavender dots and red dots, or yellow lines and red lines). These four element pairs were then tested as both the target and distractor regions in separate displays. Uniform displays using these elements were also generated (cyan stars, cyan Us, brown pluses, brown Us, lavender dots, red dots, yellow lines, and red lines). Repeating this procedure with different color and shape values for each session, sets of trial-unique novel displays were created for each test session. Note that this procedure results in half of these uniform displays being composed from familiar elements (cyan Us, brown Us, red lines, and red dots in the above example), which were included for the purposes of counterbalancing but excluded from all analyses of transfer performance.

Differential-outcomes reversal and replacement tests. A third transfer test examined what role, if any, the differential outcomes may have had in controlling the birds' choice behavior. To find

out, we reversed the locations of the hoppers containing each grain type for two sessions, so that the grain type formerly associated with the different stimuli was placed in the uniform hopper and vice versa. Following this reversal test, we eliminated the safflower and peanut hearts, refilling both hoppers with mixed grain to see how it affected the birds' discrimination performance.

Results

Figure 1 displays the mean percentage of correct choices for all birds across the four phases of training. No strong evidence of learning occurred in the first three phases. Mean choice accuracy was 50% for Phase 1 (stimuli presented for 4 s before choice test). Mean accuracy was 52% for Phase 2 (introduction of differential outcomes) and was 53% for

Phase 3 (excluding correction procedure sessions). The slight elevation in accuracy during Phase 3 was due entirely to 1 bird that started to discriminate color and uniform displays at a mean accuracy of 59%. In sharp contrast, implementation of the TD-FR procedure (Phase 4) resulted in the immediate learning of the task. As marked from this change, criterion performance (5 sessions \geq 73%) was achieved in a mean of 22.25 sessions, with a range of 18 to 31 sessions.

Because of the large number of different stimuli used during training, a minimum of at least 21.60 sessions was needed to test the entire set of 648 color and 648 shape displays at the rate of 60 per session. This provided an opportunity to track the birds' reaction to "novel" different

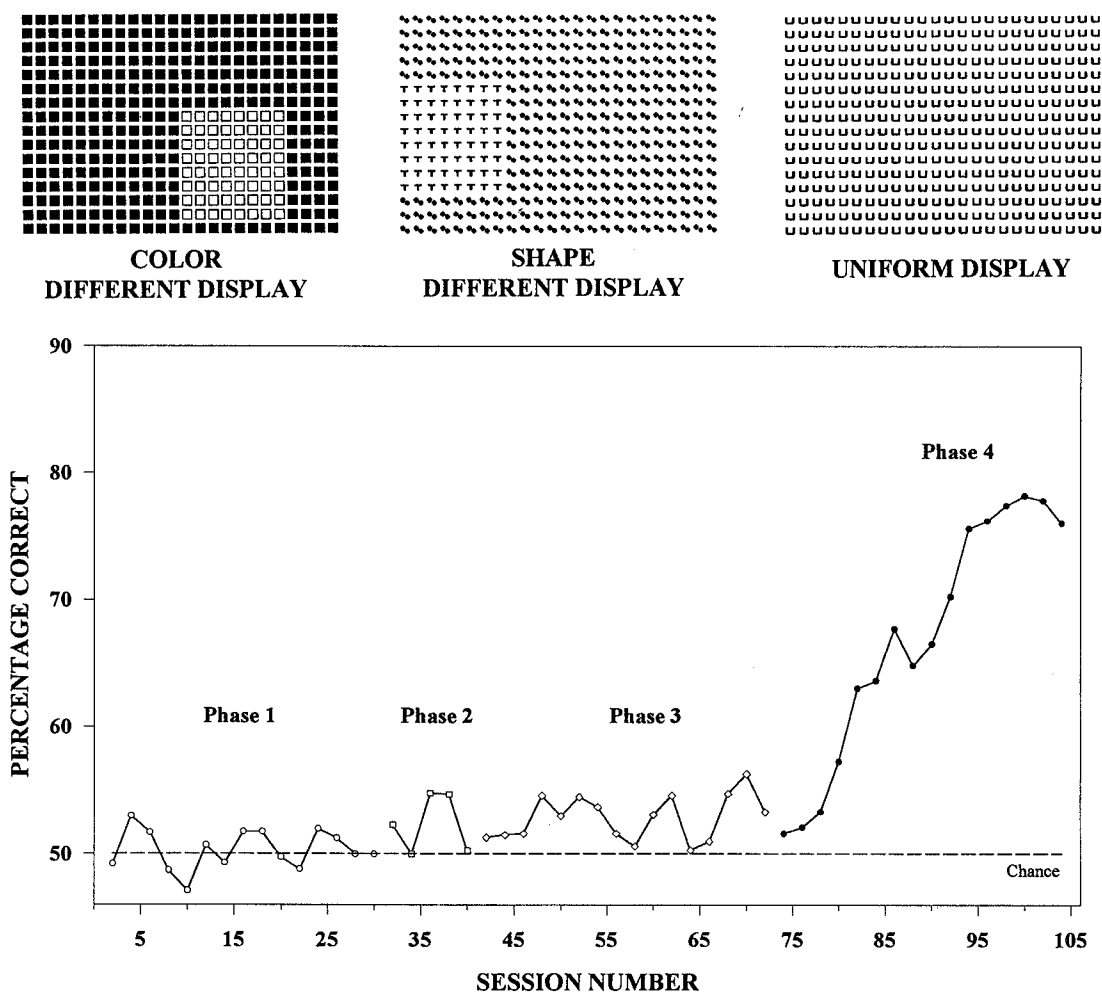


Figure 1. Examples of color different, shape different, and uniform displays tested in this experiment. Colors are shown here as different gray levels. The contours around the individual elements are for illustrative purposes and were not part of the actual displays. The location of the target region in the different displays was randomly determined on each trial. The bottom panel shows mean accuracy for the 4 birds across the four phases of discrimination training. Each point represents the mean of two successive training sessions. The gaps and different symbols mark the points at which changes in the testing procedures were made. The dotted line represents chance performance in the task.

displays as they were being presented for the first time during training, forming a continuous on-line test of discrimination transfer during acquisition. The same was not possible with the uniform stimuli as these were repeated on average every 1.35 sessions.

Figure 2 displays the percentage of correct responses to the initial presentation of these "novel" different displays (filled circles) and the uniform displays (open circles) over the first 21 sessions of Phase 4. For the analysis and discussion of this issue, we assumed that true discrimination learning began at the introduction of the TD-FR procedure, and, consequently, references to first-time or novel presentations are relative to that marker. Even if counted from the earlier introduction of the incorrect choice, however, these different displays were seen at best only three to five widely separated times prior to the start of the TD-FR phase.

As early as the 15th TD-FR session, the birds were responding accurately to these transfer stimuli. The mean percentage of different hopper responses over the 15th to 21st TD-FR session was 76% (based on approximately 140 observations from each bird over these sessions). This value was reliably above chance (50%), $t(3) = 7.79$. All reported statistical tests were evaluated using an alpha level of $p \leq .05$. Over this same 7-session period, mean performance with different displays presented for a second (72%) or third

(72%) time, as marked from the start of Phase 4, was at the same level as first-time presentations. To confirm that the increase in correct responding to "novel" different displays was not an artifact of a response bias but a true increase in the birds' discrimination of these stimuli, Figure 2 includes the mean proportion of correct responses to the uniform displays over this same period.

We next looked at the birds' pecking responses to the uniform and different displays during the TD-FR training phase. For most trials, the birds typically needed five, six, or seven pecks to fulfill the five peck requirement. Depending on the similarity of the color or shapes involved, locating the target took considerably more pecks for some of the different displays, highly skewing the distribution of responses per trial. Based on the last eight sessions of the TD-FR training phase, the modal number of pecks to the uniform and different displays was 5, with a median of 8.5 pecks each, and means of 13.7 and 14.1 pecks, respectively. We also looked at the temporal properties of these pecking responses to each display type and found no reliable differences in either the interresponse time (936 ms for different displays and 1,065 ms for uniform displays) or the time taken to initiate pecking at each display type (1.78 s for different and 2.15 s for uniform displays).

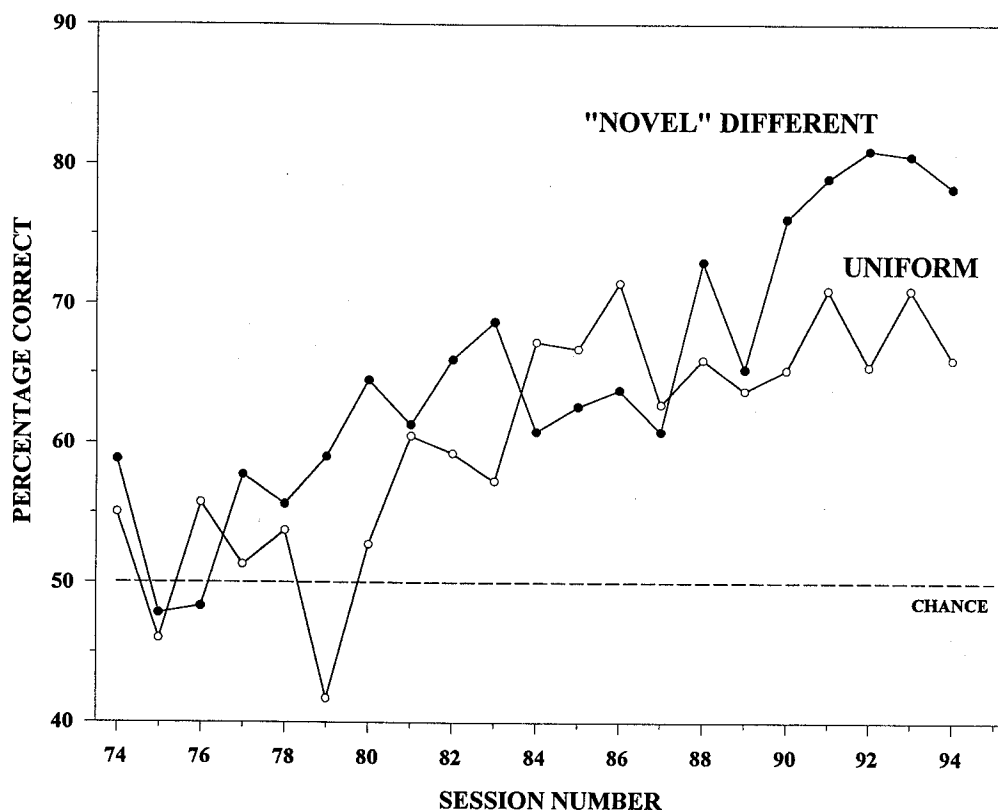


Figure 2. Mean percentage of correct hopper choices for the first presentation of "novel" different displays (filled circles) and uniform displays (open circles) during the first 21 sessions of the fourth training phase. The dotted reference line represents chance performance in the task.

Novel Transfer: Test 1

Evidence of positive transfer to novel displays was found in this first test. Averaged over the 4 birds, choice accuracy on novel transfer trials was 75% in the critical first test session (69% for different displays and 81% for uniform displays [first uniform presentations = 75% and second uniform presentations = 88%]). Mean transfer accuracy over all four transfer sessions was 73% (68% for different and 79% for uniform displays). Both the first- and fourth-session measures of transfer performance were significantly above chance, $t(3) > 4.3$. Although above chance, transfer performance was not equal to baseline performance with the training displays (81%) over these same sessions, $F(1, 3) = 11.1$, in a Baseline versus Transfer \times four Test Sessions repeated measures analysis of variance (ANOVA). This ANOVA also revealed that neither transfer nor baseline accuracy significantly changed over the four test sessions, $F(3, 9) = 0.28$.

Analyzed by dimension, transfer accuracy with color differences (76%; color different and uniform trials) was slightly greater than with shape differences (70%; shape different and uniform trials), although this difference was not reliable. Transfer accuracy with each dimension was significantly above chance, $t(3) > 4.3$, but significantly lower than corresponding baseline performance (color = 83%, and shape = 79%), $t(3) > 4.3$.

Novel Transfer: Test 2

The outcomes for this second test were similar to those of the first. Over the four sessions, mean transfer accuracy with these trial-unique novel stimuli was 68% and significantly above chance, $t(3) = 6.1$. A repeated measures ANOVA (Baseline vs. Transfer \times four Test Sessions) confirmed again that transfer performance was reliably poorer than baseline performance (80%), $F(1, 3) = 11.2$. Unlike Test 1, transfer and baseline performance did significantly interact with the test sessions variable, $F(3, 9) = 4.4$. This interaction appeared to be due to differences in discriminability among the element combinations tested in each session and a slightly elevated level of transfer performance in the fourth test session.

Analyzed by dimension, mean transfer accuracy with color differences (72%; color different and uniform trials) was again greater than with shape differences (64%; shape different and uniform trials), with both values significantly below corresponding baseline values (color = 83%, and shape = 79%), $t(3) > 4.3$. Transfer accuracy with the color differences was significantly above chance, $t(3) = 9.9$, but not with the shape differences, $t(3) = 2.9$. The latter result was due to 1 bird's failure to transfer to novel shape displays in the second test (M accuracy = 53%). This same bird exhibited poor transfer to shape differences in the first test as well (M accuracy = 63%). This bird's failure was restricted to shape, however, as it showed strong evidence of transfer to color differences (M accuracy = 75%). To determine if the 3 remaining birds transferred to novel shape

differences in Test 2, individual single-mean t tests that were based on transfer scores from each of the four sessions were conducted. These tests revealed that each of these 3 birds performed significantly above chance with novel shape differences in Test 2, $t(3) > 4.3$ (3 birds' mean transfer accuracy for shape differences = 68%).

Differential-Outcomes Tests

The reversal and elimination of the differential outcomes did not adversely affect accuracy. Mean accuracy was 83% for the two baseline sessions before the hopper reversal, 82% for the two hopper-reversed sessions, and 81% for the two sessions just after reversal when mixed grain was used to replace both grain types. An ANOVA comparing accuracy across these three conditions (differential outcomes present vs. hopper reversal vs. mixed grain replacement) as a function of display type revealed no significant main effect of condition, $F(2, 6) < 1$, or its interaction with display type, $F(2, 6) < 1$.

Discussion

The pigeons in this experiment quickly learned to discriminate between the uniform and different stimuli, at least as marked by the introduction of the TD-FR contingency, modifying their choice behavior contingent on whether a target-distractor contrast was present in the display or not. More important, the discrimination readily transferred to novel stimuli of each texture type, with high levels of transfer observed to novel different displays during acquisition itself and during the two transfer tests that used novel color and shape differences. This positive transfer to novel stimuli indicates the birds used a generalized principle to solve the task on the basis of the nominally *same* and *different* texture stimuli and rules out any account invoking stimulus-specific if-then rules as the means by which they learned the discrimination (e.g., Carter & Werner, 1978). The critical question is what feature associated with the stimuli is responsible for this categorical discrimination of the textured displays?

We contemplated several possibilities over the course of this research. The first centered around differences in the number and relative familiarity of the different and uniform stimuli. Macphail and Reilly (1989) demonstrated that pigeons can be sensitive to the relative novelty of complex pictures, successfully discriminating among slides presented for the second time within a session (S-) from the first time in a session (S+). Because of the difference in the number of uniform and different displays in this experiment, a potentially similar discrimination of their relative novelty could have developed. For instance, the birds could have simply memorized the 81 most repeated displays and their associated hopper (these all happened to be uniform stimuli in the present case, but any arbitrary set of 81 stimuli would suffice given the logic of this hypothesis) and then could have responded by default to the other hopper for all remaining unfamiliar displays (see Test 1 of Wasserman,

Hugart, & Kirkpatrick-Steger, 1995). From this perspective, the critical difference between displays is not one of stimulus mixture but one driven exclusively by an animal's memory for specific familiar stimuli. This is an unlikely explanation for our results for several reasons. This perspective predicts, for example, that as different displays become increasingly familiar, accuracy should decline. We found little or no decline in performance during the second and third repetitions of different displays. Nor does this hypothesis easily account for why acquisition began so suddenly after the implementation of the TD-FR contingency—a contingency that emphasizes the critical visual feature between different and uniform displays rather than their relative frequency. More conclusive, this hypothesis is ruled out by the positive transfer results, because all transfer displays were equally novel and provided no means for responding based on memorized familiarity.

A second possibility focused on the birds' observing responses to these two classes of stimuli. Perhaps some unintended component of the target-directed response required of different trials (but absent or performed differently on uniform trials) served as the discriminative cue guiding choice rather than the stimuli per se. Control by differential sample-observing behaviors has been demonstrated before in conditional discriminations (Blough, 1959; Urcuioli, 1984; Urcuioli & Honig, 1980). Although we explicitly tried to control for this by the use of our yoking procedure, we looked for this possibility in several other ways. Review of the birds' pecking behavior revealed no systematic differences across displays that we could identify. More persuasive, we subsequently eliminated entirely the target-directed contingency with these birds, presenting these same stimuli at durations as short as 500 ms and with nondirected FRs as low as 1 (Cook, Blondeau, Cavoto, & Katz, 1995). Despite the very limited opportunities to respond to the displays in these later studies, the birds continued to accurately perform the discrimination, providing clear evidence that such response-based considerations were not critical to the birds' performance of the task.

Another alternative that we considered concerned the differential outcomes associated with each class of display. The failure of the different grains to facilitate learning or to disrupt performance when we later reversed and eliminated them from the procedure indicates that this factor also played no role in the birds' solution of the task.

Consequently, we hypothesize that the birds were categorically discriminating the stimuli based on their *uniform* and *different* visual properties, treating them as two higher order classes of stimuli in which regional or elemental relations were being abstracted and used in a generalized solution of the problem. On the basis of a similar set of observations collected using a completely different organization of multi-element *same* and *different* displays, Wasserman et al. (1995) reached a similar conclusion.

The question then becomes whether these relational properties were abstracted by the birds as the product of a more cognitive same-different conceptualization of the features in the displays or by a more low level perceptual processing of them. For example, one possible reason why the current

discrimination was so readily learned and transferred by the pigeons is that it tapped perceptual processes designed to detect and discriminate uniform surfaces and contrasting edges. Although such perceptual processes may have contributed to our results, several pieces of evidence suggest that a higher level of abstraction was also involved. The less than perfect transfer to novel stimuli found in the Wasserman et al. (1995) study and in our study indicates that these birds were sensitive to the specific identity, as well as the relational properties, of the displays. If only a perceptual abstraction were involved, then the identity of the display should have made no difference. Furthermore, the different multi-element organizations used in our study and in Wasserman et al. (1995)—with differences in the number of elements forming the displays, the visual complexity of the individual elements, the number of dimensions tested, and whether the contrasting elements were tightly aggregated or randomly distributed—suggest it was not the particulars of the perceptual arrangements that were critical to producing our otherwise similar outcomes. Rather, the success of the current study and the Wasserman et al. (1995) study seem best attributed to an increased distinctiveness of the same and different relations that were due to the larger number of elements used in these displays (see Zentall, Hogan, Edwards, & Hearst, 1980) and the concurrent use of large numbers of stimulus exemplars during training (Cook, 1992a; Kendrick, Wright, & Cook, 1990).

Further research will need to explore the exact boundaries of the same-different concept learned by the birds in our experiment and its relation to the earlier pigeon studies on this issue. One clear advantage of the present procedure in this regard is the relative ease with which the birds learned to discriminate among these complex multi-element displays. The conceptual behavior engaged in by our pigeons suggests that these animals may indeed be capable of forming generalized same-different concepts. If so, these results strengthen the limited evidence (Edwards et al., 1983; Pepperberg, 1987; Santiago & Wright, 1984; Wasserman et al., 1995) for this important cognitive capacity in birds.

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