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# Acquisition and Transfer of Visual Texture Discriminations by Pigeons

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Two experiments investigated texture discrimination in pigeons. In a simultaneous conditional-discrimination procedure, pigeons were reinforced for pecking at a small *target* region of identically colored form elements embedded in a larger region of *distractor* elements. These regions differed in either color or shape or differed redundantly in both dimensions. Pigeons readily acquired these discriminations and showed substantial positive discrimination transfer to new displays composed from novel recombinations of training colors and shapes, novel colors and shapes, and novel spatial organizations. The global organization of these displays appeared to be the chief property mediating performance. This suggests that pigeons have mechanisms for perceptually grouping regions of similar colors and shapes, and these mechanisms may be similar to the preattentive visual mechanisms proposed for human texture segregation.

Because of their diurnal aerial niche and small brains, birds are of particular interest and importance to an understanding of the evolution and mechanisms of vision. Derived from different reptilian lineages over 150 million years ago, the anatomically dissimilar avian and mammalian visual systems have both evolved the capacity for rapid and accurate perception of the visual world (Donovan, 1978; Emmerton, 1983; Pearson, 1972; Waldvogel, 1990). As such, the comparative investigation of avian visual cognition can enhance understanding of the structures and processes of the mammalian visual system, as well as those of other animals (Ewert, 1987; Reichardt, 1986). The experiments reported in this article are the first in a program aimed at better understanding how birds process visual texture stimuli.

Visual textures are hierarchical stimuli composed of perceptually distinct global regions that are derived from the grouping of similar small elements (see Figure 1). Humans can rapidly perceive the global differences in many kinds of texture stimuli (Beck, 1966, 1982; Julesz, 1975, 1981). The effortless nature of such texture discriminations suggests that the underlying perceptual mechanisms are located early in the stream of visual processing and are parallel and preattentive in character (Beck, 1982; Broadbent, 1977; Julesz, 1981; Marr, 1982; Treisman & Gelade, 1980; Watt, 1988). As a result, the study of human texture segregation has significantly increased understanding of many fundamental visual processes. These include the following: the generation of figure-ground relations, the vocabulary of basic visual features, the grouping mechanisms of explicit and subjective contour generation, and the relative contributions of preattentive and attentive visual processes to perception (e.g., Beck, 1966, 1982; Grossberg & Mingolla, 1985; Julesz, 1981). Despite its indisputable theoretical importance, texture discrimination has only been examined sparingly in pigeons (Blough & Franklin, 1985).

The experiments reported here were designed to investigate the visual and conceptual foundations of texture discrimination in pigeons and the relation of texture discrimination in pigeons to texture perception in humans. Computer-generated texture stimuli analogous to those previously tested with humans were presented to pigeons with a simultaneous conditional-discrimination procedure. The pigeons had to locate and peck at a smaller *target* region of colored shapes embedded within a larger array of *distractor* elements to receive food reinforcement. The elements of these two regions could differ in shape (e.g., red triangles in red circles), color (e.g., green squares in red squares), or both shape and color (e.g., green circles in red triangles). In Experiment 1, I examined the acquisition and transfer of texture discriminations using a *quadrant placement* procedure, in which the target region was randomly located in one of four quadrants of the stimulus display. In Experiment 2, I examined the acquisition and transfer of texture discriminations using a *random-placement* procedure, in which the target region was randomly located anywhere within the texture display.

My objectives in these experiments were to understand how pigeons perceive and discriminate such stimuli. Like humans, would the pigeons rapidly perceive the global or regional properties of these displays and use them as the effective basis for their response? If so, how similar are the underlying visual and conceptual mechanisms to those of humans? To research these questions, pigeons were challenged to discriminate large numbers of textured displays possessing consistent regional organizations but composed of local elements that changed unpredictably from display to display. How readily the pigeons learned such visual discriminations, and the nature of their transfer to new displays, could then be used to establish the relative importance of global and local properties in the birds' perception and responses to these textured stimuli.

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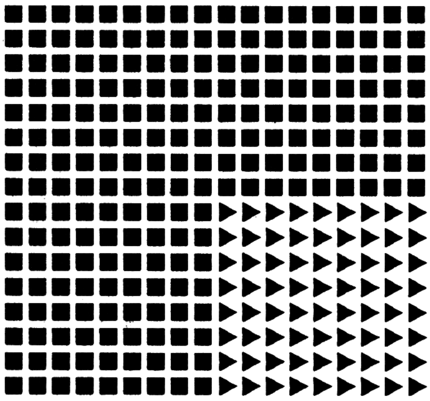
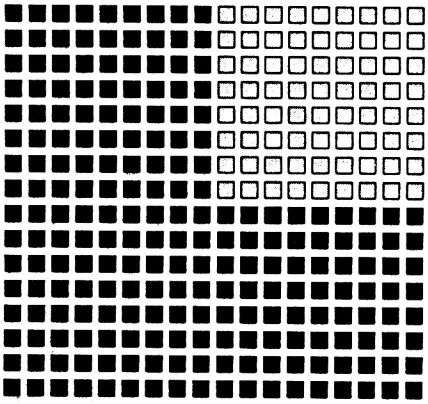


SHAPE



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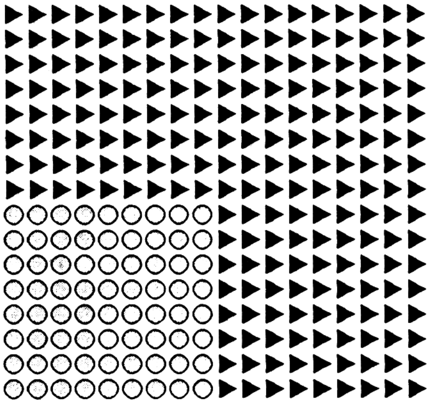

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*Figure 1.* Representative examples of the shape, color, and redundant displays examined with the quadrant placement procedure in Experiment 1. (Colors are shown as different shades of gray. The contours around the individual elements are for illustrative purposes and were not part of the actual displays. The location of the target quadrant was randomly determined on each of the trials. Four colors and four shapes were used in generating the training displays of Experiment 1).

Because experimental procedures capable of producing highly generalizable visual discriminations would also be advantageous for future investigations of other theoretically interesting texture discriminations (Caelli, 1982; Enns & Resnick, 1990; Julesz, 1981; Ramachandran, 1988; Sutter, Beck, & Graham, 1989; Treisman & Gelade, 1980), an ancillary objective of this research was to inquire into factors that might be beneficial in this regard. A critical factor in the development of generalized visual discriminations by pigeons appears to be the number of stimuli experienced during training (Lombardi, Fachinelli, & Delius, 1984; Wright, Cook, Rivera, Sands, & Delius, 1988). Relatively large numbers of training stimuli seem to produce generalized conditional discriminations that transfer to novel stimuli (Lombardi et al., 1984; Santiago & Wright, 1984; Wright et al., 1988), whereas smaller numbers of training stimuli seem to produce limited conditional discriminations that are more stimulus specific (Berryman, Cumming, Cohen, & Johnson, 1965; Cumming & Berryman, 1961; Cumming, Berryman, & Cohen, 1965; Farthing & Opuda, 1974; Holmes, 1979; Santi, 1978, 1982; but see Urcuioli, 1977; Urcuioli & Nevin, 1975).

It should be noted, however, that those studies that have produced generalized discriminations in pigeons have also used complex visual stimuli, such as photographs of natural objects and landscapes (Santiago & Wright, 1984), digitized images of natural objects (Wright et al., 1988), or complicated geometric forms (Lombardi et al., 1984). Conversely, the studies producing stimulus-specific conditional discriminations have tended to use only patches of colors or simple forms as stimuli.

In both experiments described here, I examined the learning of conditional discriminations involving large numbers of training stimuli. As the relevant differences within these stimuli were based only on color and shape properties, these experiments can help to disentangle the exact roles of stimulus complexity and the number of training exemplars in the formation of generalized discriminations by pigeons.

## Experiment 1

The acquisition and transfer of color and shape texture discriminations were examined in Experiment 1. The textured stimuli consisted of a square array of small colored shapes or elements. One randomly chosen quadrant of the array was designated the target quadrant and differed from three remaining distractor quadrants in either color, shape, or both dimensions (Figure 1). To receive food reinforcement, the pigeons were required to peck the odd target quadrant. Using a simultaneous conditional-discrimination procedure, 4 naive pigeons were initially trained to discriminate 12 color, 12 shape, and 12 redundant texture displays. The target and distractor regions of these training stimuli were composed of elements made by the selected combination of four different colors and shapes.

Following successful acquisition of this quadrant target-detection task, two transfer tests with novel texture displays were conducted. These transfer tests revealed the extent to which display-specific and display-independent properties governed the target-directed behavior of the pigeons. In the first test, displays composed of elements generated from novel recombinations of the four colors and shapes used during training were examined. Two types of recombinations were investigated. The first type reversed the target and distractor roles of previously paired elements, and the second type tested specific, not previously paired, elements.

The second set of transfer tests examined displays composed with novel colors or shapes (see Figure 2). Novel colors and shapes were added successively and configured with a new irrelevant shape or color value on each test trial. This procedure allowed for the continuous measurement of discrimination transfer to novel displays over an unusually extended period of 19 consecutive sessions.

## *Method*

*Subjects.* Four naive White Carneaux pigeons were used. They were maintained at 80% of their free-feeding weights and had free access to water and grit in their home cages.

*Apparatus.* A flat-black plywood chamber (36 cm wide × 32 cm deep × 38 cm high) held the pigeons in front of a black Plexiglas front panel (36 cm wide × 38 cm high). A 28-V houselight (No. 1812) was located in the center of the ceiling and was illuminated at all times, except when an incorrect response was made. A food hopper was located in the middle of the front panel, with its access hole flush to the chamber floor. A Multisync II color monitor (NEC, Wooddale, IL) was located immediately behind the front panel and was visible through a 26 × 18 cm glass window. The bottom edge of this window was 20 cm above the chamber floor.

All experimental events were controlled and recorded with an AT-class microcomputer. All stimuli were generated by computer and presented directly to the pigeons on the color monitor. Stimulus generation and event programming were executed using QuickBasic (Microsoft, Redmond, WA) and a separate graphics library (Hydrex Graphics, Houston, TX). Computer-controlled relays (Metrabyte, Taunton, MA) governed the operation of the hopper and houselight. A VEGA Deluxe color video card (Video-7, Milpitas, CA) controlled the monitor in the enhanced graphics mode (EGA; 640 × 350 pixels; all coordinates in this article follow a column by row format). The two display pages of this mode were used as shutters for the control of stimulus onset and offset.

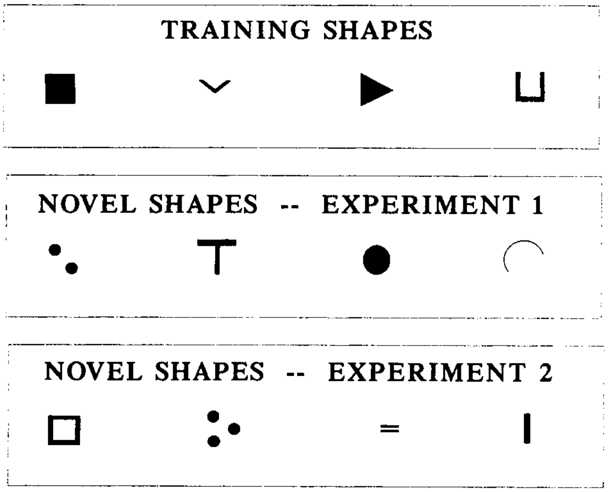

*Figure 2.* Examples of the 12 shapes used in Experiments 1 and 2. (Eleven colors were also tested. The top row depicts the 4 shape stimuli used to generate the training displays of Experiment 1. The second row shows the 4 shapes introduced in the novel value transfer test of Experiment 1. The 8 shapes of rows 1 and 2 were used to generate the training displays of Experiment 2. The third row shows the 4 shapes used in the novel value transfer tests of Experiment 2.)

Pecking responses to the monitor were detected by an infrared LED touchscreen (EMS Systems, Champaign, IL). This touchscreen was mounted behind a 40-mm ledge of Plexiglas around the inside edge of the viewing window. The resolution of the touchscreen was 96 × 48 spatial locations. A peck was defined as penetration and withdrawal from the LED matrix by the beak.

*Stimulus generation.* Quadrant placement texture displays were 13.5 × 12 cm and consisted of 288 separate elements arranged in an 18 × 16 element array at 0.75-cm intervals. Individual elements were 3 to 6 mm in size, depending on their shape. Elements of this size have been found to be readily discriminable by pigeons in many types of visual discriminations (D. S. Blough, 1977, 1979, 1989; Cook, Riley, & Brown, 1992; Honig, 1991; Jenkins & Sainsbury, 1970).

Each texture array was conceptually divided into four quadrants (9 × 8 elements each). Three of these quadrants were composed of identical elements and designated the distractor quadrants. In color displays, the elements of the target quadrant differed in color, but not in shape, from those of the distractor quadrants. In shape displays, the target and distractor elements differed in shape but not in color. In redundant displays, the target and distractor elements differed in both color and shape. The location of the target quadrant was randomly determined for each trial.

Training was conducted with 12 color, 12 shape, and 12 redundant stimuli. The elements of these 36 textures were made from combinations of four colors, blue, green, cyan, or red, using EGA palette 1, 2, 3, or 4, and four shapes, square (S), triangle (TRI), U, or chevron (CH). These colors and shapes were used equally often in the composition of the 36 training stimuli, but not in every combination.

For example, the 12 color training displays were selected from a total set of 48 color texture stimuli (12 color combinations [4 target colors × 4 distractor colors] × 4 irrelevant shapes, excluding uniform displays). The 12 color training displays were generated using only 8 of the 12 combinations of colors. These 8 combinations were then combined with four irrelevant shapes, so that each shape was used three times in the 12 stimuli. As a result of this procedure, 36 color texture stimuli were available for the novel recombination transfer tests described later. The term *irrelevant* in this context refers only to that dimensional value held constant in a particular display. The discrimination of color and shape differences between displays of a session was always relevant to reinforcement.

The 12 shape texture stimuli were composed in the same manner, leaving 36 shape texture stimuli available for transfer testing. The 12 redundant trials were made from elements used in making the 12 shape and 12 color training stimuli and selected so that element combinations set aside for transfer testing were not presented.

*Discrimination-training procedures.* The pigeons were first autoshaped to peck a white circular ready signal after a brief period of hopper training. Once consistent responding to the ready signal was established, the texture stimuli were introduced. Texture stimulus autoshaping trials started with a peck to the ready signal, darkening the screen for 0.4 s, followed by the presentation of a texture stimulus. The texture stimulus was then displayed for 20 s or until the stimulus was pecked. Either condition caused the food hopper to be raised for 2.5 s. These texture autoshaping trials were separated by a 10-s intertrial interval (ITI).

Texture autoshaping sessions consisted of four 36-trial blocks (144 total trials per daily session). Each block involved one presentation of each of the 36 training stimuli. The order of presentation within a block was randomized. All birds were immediately responding to the texture stimuli after one or two sessions, at which point true discrimination training began.

The daily 144-trial discrimination-training sessions were conducted in a highly similar manner, except that food reinforcement now depended on pecking the target region of the texture display. Each discrimination trial started with a peck to the ready signal, which darkened the screen for 0.4 s, and was followed by a texture display. If the pigeon pecked five times at the target quadrant, the texture display was turned off and the hopper was raised for 2.5 s. If the first five pecks were to the distractors, the texture display was turned off and the houselight was extinguished for 15 s. A 5-s ITI followed either trial outcome. The accuracy, time, and spatial location of all pecks were recorded. The first and second training sessions used only one and three pecks to the texture stimuli, respectively.

Pecks at the target quadrant and the adjacent row and column of distractor elements were counted as target-directed responses. As a result, the expected value of accuracy given chance responding was 27%, as determined by the area of touchscreen programmed to detect target-directed responses. This particular estimate also assumes that successive pecks within each trial are not independent of one another. If successive pecks were treated as independent and randomly located events, then the estimated chance value would diminish considerably. As all pecks within a trial tended to cluster around the location of the first, both the pigeons' pecking behavior and their initial levels of accuracy suggested that the more conservative value was the most appropriate.

*Novel recombination transfer test.* Discrimination-training sessions were conducted daily until a pigeon recorded five sessions with an overall target detection accuracy of 65% or greater, at which point transfer testing began. The first transfer test examined the 36 novel color and 36 novel shape displays that could be derived from the untested combinations of the four training colors and shapes. This transfer test consisted of four 7-session blocks. Block 1 is described below in detail. The remaining three blocks were identical in design.

In Block 1, I tested those novel recombination displays involving the green and square values. These 9 color and 9 shape test displays differed from the training displays in one of two ways. For each dimension, four of the transfer displays reversed the target and distractor elements of a display used during training; (e.g., red U target-green U distractor display during training; green U-red U display during testing), and the remaining five transfer displays changed the irrelevant color or shape value that had been used during training (e.g., red U-green U during training; red square-green square during testing). The seven 162-trial sessions of Block 1 consisted of three 54-trial blocks (18 test and 36 training displays). The order of stimulus presentation in each 54-trial block was randomized. The reinforcement contingencies and temporal parameters were the same as during acquisition.

In each of the three remaining 7-session blocks, a different set of 18 novel recombination displays was tested in the same way. In Block 2, I tested the novel displays derived from the red and U values, in Block 3, I tested the cyan and CH values, and in Block 4, I tested the blue and TRI values.

*Novel value transfer test.* In this phase, I tested displays made with novel colors and shapes. This phase consisted of four multisession blocks, each one a test of a new color and shape. As described next, the organization of the trials varied slightly for each block.

Block 1 introduced and tested the color purple (EGA color no. 5) and the double dot figure (DD) and consisted of five 156-trial sessions. In each session, eight novel color and eight novel shape displays were tested in three 52-trial blocks (16 test displays and 36 training displays). For each dimension, the test displays were formed by combining the novel value, in both a target and distractor role, with each of the four training values. These eight color and eight shape differences were then configured with a different irrelevant value in each of the five sessions of Block 1. The shape transfer trials were configured with the colors green, cyan, blue, red, and purple, and the color transfer trials were configured with the shapes TRI, U, S, CH, and DD, respectively, over the five sessions. The reinforcement contingencies and temporal parameters were the same as previously used.

Block 2 introduced the brown (EGA color no. 20) and T values and consisted of six 168-trial sessions. Each session tested 10 new color and 10 shape displays in three 56-trial blocks (20 test displays and 36 training displays). The test displays were made by combining each dimension's novel value with the four corresponding training values and the novel value from Block 1. As in Block 1, the test displays were configured with different irrelevant values in each session. The shape transfer trials were configured with the colors blue, green, cyan, red, purple, and brown, and the color transfer trials were configured with the shapes S, TRI, U, CH, DD, and T over the six sessions, respectively.

Block 3 introduced the gray (EGA color no. 7) and circle (CIR) values. Block 3 consisted of four sessions. The test displays were constructed in the same way as the previous two blocks. The first three sessions tested the 12 novel color and 12 shape displays twice in each session, but configured with a different irrelevant value each time. These three sessions each consisted of one 84-trial block (48 test and 36 training displays). The fourth session tested the novel displays in combination with the remaining seventh irrelevant value, presenting the 24 test displays once and the 36 training trials twice. The four sessions of shape transfer trials were configured with the colors blue and green, purple and brown, red and cyan, and gray, and the color transfer trials were configured with the shapes TRI and S, T and DD, CH and U, and CIR.

Block 4 introduced the orange (EGA color no. 52) and arc (A) values and consisted of four 92-trial sessions. Each session tested the 14 new color and 14 shape displays twice, each time with a different irrelevant value. Over the four sessions, the shape transfer trials were configured with the colors blue and green, red and cyan, purple and brown, and gray and orange, and the color transfer trials were configured with the shapes TRI and S, CH and U, DD and T, and CIR and A.

## Results

*Acquisition.* Acquisition of the task was rapid and apparently easy for the birds. Figure 3 displays the mean target-detection accuracy for the color, shape, and redundant displays over the first 19 sessions. Averaging over all three display types, it took a mean of 13.25 sessions to reach the 65% criterion. Unless otherwise noted, all subsequently described statistical tests used a significance level of $p \leq .05$. Repeated measures analyses of variance (ANOVAs, Dimension × Sessions) comparing color, shape, and redundant-display accuracy revealed that the shape discrimination was learned significantly slower than either the color, Dimension × Sessions interaction, $F(18, 54) = 2.45$, or the redundant discrimination, Dimension × Sessions interaction, $F(18, 54) = 2.05$. Accuracy with redundant displays was significantly better than with color displays, $F(1, 3) = 11.60$, and there was no significant interaction over sessions for these two conditions.

*Novel recombination transfer.* The birds transferred readily to the novel recombination of previous displays, although overall performance was below that of the baseline trials. Only the first two sessions of each block were analyzed to minimize any effects of display repetition. A repeated measures ANOVA (Blocks [1–4] × Trial Type [baseline or transfer] × Dimension [color or shape] × Sessions [first or second]) revealed no significant changes in accuracy over the four blocks of testing ($F < 1$) or over the first two sessions of these blocks ($F < 1$). Over the four blocks, accuracy on both color (73.2%) and shape transfer trials (52.9%) was significantly above chance (27%); for color, $t(3) = 24.0$, and for shape, $t(3) = 6.7$.

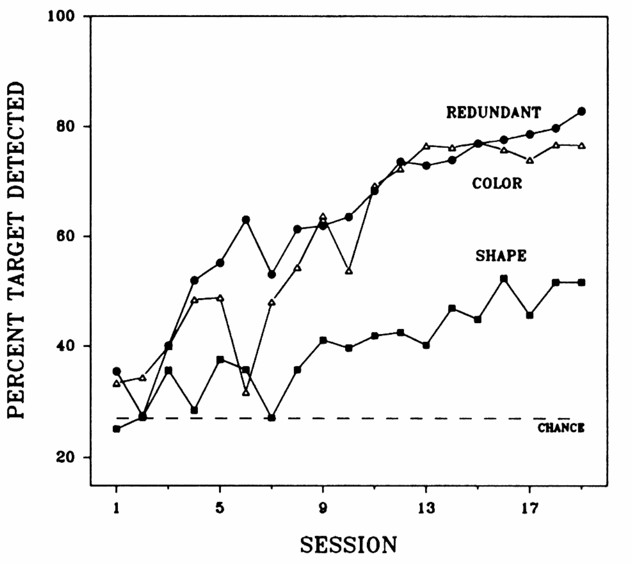

*Figure 3.* Mean accuracy (%) over the first 19 training sessions for color, shape, and redundant displays in Experiment 1. (The broken reference line represents chance performance.)

However, accuracy on transfer trials was below that for color (84.8%) and shape (58.8%) training trials. The difference in overall accuracy between recombination trials (63.1%) and baseline trials (71.8%) was significant, $F(1, 3) = 31.70$.

Figure 4 displays mean accuracy for baseline and transfer trials, divided according to whether their recombination had reversed the target and distractor region of a training display (RR) or changed the display's irrelevant component (IRR). Repeated measures ANOVAs comparing these conditions found that IRR and RR transfer trial accuracy did not significantly differ for color texture discriminations and that both conditions supported significantly less accurate performance than baseline trials. For the shape texture discriminations, accuracy was significantly lower only for IRR trials and did not differ between baseline and RR trials.

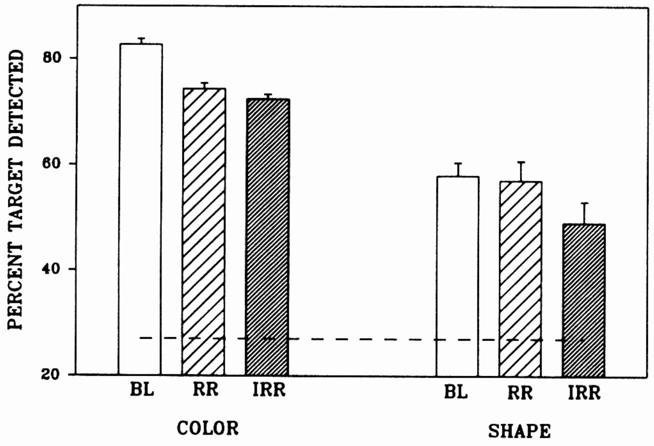

*Figure 4.* Mean accuracy (%) for the color and shape recombination transfer test of Experiment 1 for baseline training trials (BL) and the transfer trials divided according to whether their element recombination had reversed the target and distractor regions (RR) of a previous training display or changed the irrelevant (IRR) dimensional component of the display. (The broken line represents chance performance.)

*Novel value transfer.* The pigeons also transferred readily to novel texture displays, but again overall accuracy was below that of the baseline trials. Figure 5 shows mean target-detection accuracy and first-peck reaction time (RT) for both baseline and novel transfer trials over the 19 test sessions. Separate repeated measures ANOVAs for accuracy and RT were conducted (Trial Type [baseline or transfer] × Dimension [color or shape] × Blocks [1–4]). Baseline accuracy (74.1%) was significantly higher than novel transfer accuracy (58.2%), $F(1, 3) = 48.03$, but both color accuracy (64.4%) and shape transfer accuracy (52.0%) were significantly above chance, $t(3) = 10.3$, and $t(3) = 20.3$.

The lower panel of Figure 5 shows that substantial changes in first-peck RT also occurred during testing, especially for the transfer trials. RTs on transfer trials were considerably slower than RTs on baseline trials during the first half of testing, but with further testing RTs eventually converged toward baseline levels. This was confirmed by a significant Trial Type × Blocks interaction, $F(3, 9) = 4.09$. RTs for color (540 ms) and shape (563 ms) displays did not significantly differ from one another, $F(1, 3) < 1$.

Lastly, the role of element familiarity in forming the target and distractor regions of these transfer displays was examined. The regions of each display were classified by whether they were composed of the training elements (high familiarity), novel elements (novel), or repetitions of recently presented novel elements (low). The novel designation was used only for novel displays during their initial block of testing, and the low-exposure designation was assigned to these novel values when they were tested again in any subsequent block. This resulted in four types of transfer trials with novel–high, high–novel, novel–low, and low–novel target status and distractor status pairs, in addition to the training trials, which were designated high–high.

Accuracy with all five trial types was reliably better than chance, as shown by single mean $t$ tests with a critical value of $t(3) = 4.3$. Novel distractor elements did not significantly affect the accuracy of detecting highly familiar targets (high–high = 74.1%; high–novel = 73.3%), $t(3) = .36$. Still, novel distractor elements were noticed by the pigeons, as first-peck RT was significantly slower to such transfer displays (high–high = 504 ms; high–novel = 605 ms), $t(3) = 38.9$. When familiar elements surrounded a novel target, however, accuracy was significantly reduced and first-peck RT significantly increased in comparison with baseline trials (novel–high = 45.3%; 595 ms), $t(3) = 6.4$, and $t(3) = 11.3$. Transfer trials composed with previously exposed novel elements showed a similar, although diminished, pattern of effects, with accuracy being lower when novel elements formed the target than when they formed the distractor region (low–novel = 63.7%; novel–low = 48%).

## *Discussion*

In Experiment 1, I found that the pigeons quickly learned to locate the target quadrant of these texture stimuli. Task acquisition was fastest with the redundant displays, followed by color and then shape. Moreover, this discrimination readily

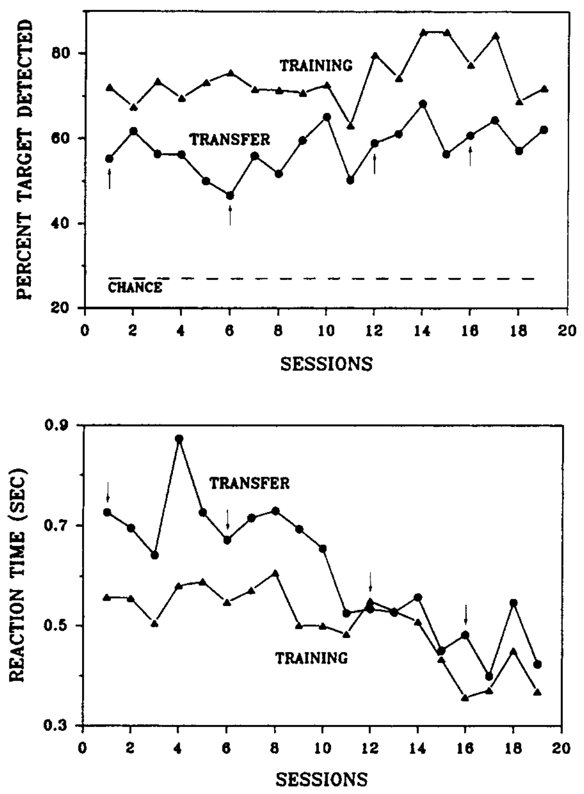

*Figure 5.* Mean accuracy (%) for transfer and baseline conditions over the 19 sessions of novel value transfer testing in Experiment 1 (top panel) and results as a function of first-peck reaction time. (The arrows indicate the first session introducing a new color and shape during the four blocks of this experiment. SEC = seconds.)

transferred to novel texture displays. Both color and shape discriminations showed positive transfer to displays formed either by novel recombinations of the training colors and shapes or with novel colors or shapes. This robust positive transfer indicates that the discrimination of the color and shape differences was based on relational properties in these displays and not specific absolute characteristics.

The proficiency of the pigeons in transferring these texture-based conditional discriminations contrasts sharply with the difficulties often exhibited in transferring other forms of conditional discrimination (Berryman et al., 1965; Cumming & Berryman, 1961; Farthing & Opuda, 1974; Holmes, 1979; Santi, 1978, 1982). Part of the reason for this surely lies in the simultaneous and highly perceptual nature of the present discrimination. The conspicuous visual difference between the adjacent regions and its reliably global organization form an immediate and obvious relational feature that could have mediated target detection, its ready acquisition, and substantial positive transfer. If so, then the pigeons, much like humans, may have been rapidly perceiving and segregating these textured displays on the basis of the displays' salient regional characteristics.

Although the high levels of positive transfer indicate that the absolute identity of the elements was not of primary importance, the results of recombination transfer tests offer evidence that the pigeons had memorized some characteristics of the training stimuli. Changes in the irrelevant dimensional value and reversal of the previous target and distractor roles both reduced accuracy relative to baseline. To detect such changes in display composition, information about those specific attributes must have been encoded for some or all of the 36 training displays. The initially slower RTs for novel displays and the general bias to peck display regions composed from familiar elements also indicate that some information about the specific nature of the color and shape training values must have been represented in memory.

Consequently, the pigeons in Experiment 1 seem to have simultaneously acquired both absolute *display-dependent* information, which interfered with the complete transfer of the discrimination to new stimuli, and relational *display-independent* information, which was responsible for the large degree of positive transfer to novel displays (see D. S. Blough, 1989, for a comparable finding). The absolute properties included memories for specific combinations of color and shape, their target and distractor roles, and the identity of the training colors and shapes. The relational properties of the displays may have incorporated the salient perceptual differences that were present in the global organization of the target and distractor regions and that formed an effective feature shared in common by every training and test display.

## Experiment 2

The purpose of Experiment 2 was to investigate performance with texture displays in which the target region was placed at random within the distractor field (see Figure 6). The quadrant procedure was examined initially because its chances of success seemed higher, but a *random-placement* procedure is superior for several reasons. It permits control over the form and size of the target, allows the use of larger distractor fields, and significantly increases the number and range of target spatial positions. The latter consideration was of most interest because the quadrant procedure permitted only four target locations and thus potentially allowed target searches to be restricted to a small and fixed set of positions.

After Experiment 1, the four quadrant-trained pigeons were transferred to the random-placement procedure. If the performance of the quadrant-trained pigeons was severely disrupted on being switched to randomly located targets, it would suggest that the limited number of target positions in Experiment 1 had been critical. If they readily transferred, on the other hand, it would indicate that their target-detection mechanisms were operating over a wide area of the display and were not tied to a few display locations.

Two new birds were also trained in Experiment 2. Their training was conducted exclusively with randomly located targets and textured displays composed with a random trial composition procedure. In this latter procedure each trial's display elements were randomly selected from a pool of 64 elements, as formed by the pairwise combination of eight colors and shapes. Accordingly, 4,032 different texture displays were available for presentation on any given trial during their training, resulting in a considerably larger and more unpredictable set of displays than was used in Experiment 1.

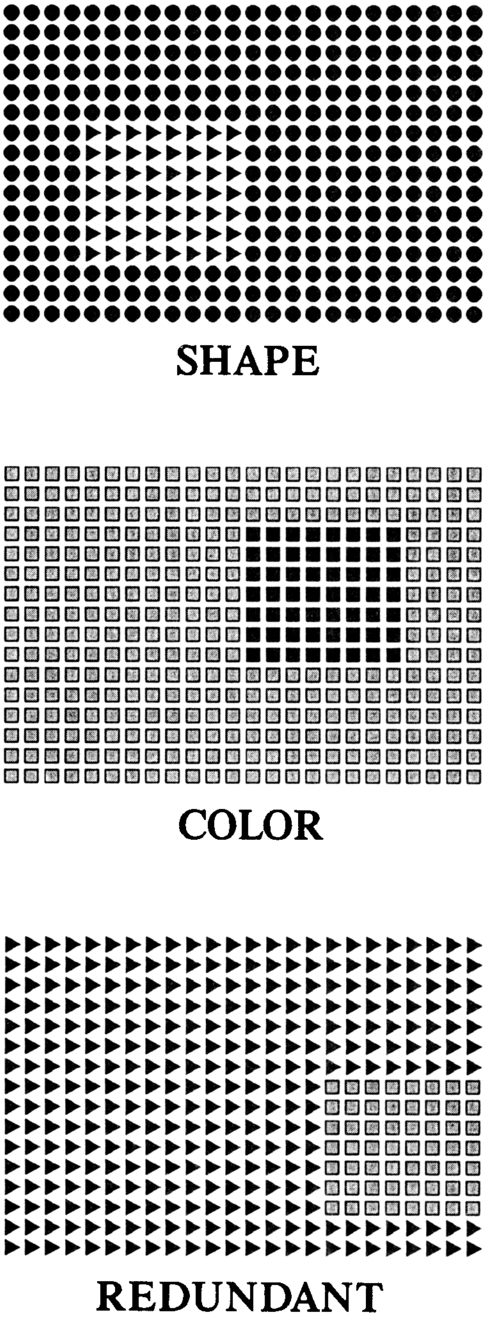

*Figure 6.* Representative examples of the shape, color, and redundant random-placement displays tested in Experiment 2. (Colors are shown as different shades of gray. The contours around the individual elements are for illustrative purposes and were not part of the actual displays. The location of the target region was randomly determined for each trial of the experiment. A total of eight colors and shapes were used to generate randomly the displays for the 2 new pigeons trained in Experiment 2.)

Would this modification facilitate or impede acquisition of the task in comparison with Experiment 1? If the quadrant task had been rapidly acquired because of the repeated presentations of specific displays or the moderate number of training stimuli (36), then task acquisition rate should be substantially slowed in Experiment 2. However, if the regional organization of displays were the salient component in learning the task, then acquisition should proceed at rates comparable to Experiment 1—despite the increased number of displays, the increased number of component elements, the overall variability of the elements, and the randomized target locations.

As in Experiment 1, the final phase of the second experiment tested all pigeons for discrimination transfer to novel displays generated using three new colors and four new shapes. These tests were specifically arranged so that each of the transfer trials tested a unique combination of color and shape values.

## *Method*

*Subjects and apparatus.* Six White Carneaux pigeons served as subjects. Two were naive to these target-detection procedures but had briefly served in, and failed to learn, a symbolic matching-to-sample task involving rotating computer-generated three-dimensional cubes and pyramids as sample stimuli. The remaining 4 subjects had participated in Experiment 1. The conditions of maintenance and testing chamber were the same as in Experiment 1.

*Stimulus generation.* Random-placement texture displays were 18 × 12 cm in size and consisted of 384 elements arranged in a 24 × 16 cm element array at 0.75-cm intervals. Two target sizes were used during the experiment. At first an 8 × 7 element target region (144 positions) was used, but later in the experiment this was reduced to a 7 × 6 region of elements (170 target positions).

Color, shape, and redundant texture stimuli were generated using the eight colors and shapes used in Experiment 1. Training displays were formed by a random trial composition procedure, in which the display's components were selected at random from the set of 64 possible elements. This made 448 shape, 448 color, and 3,136 redundant displays available for presentation during training sessions (4,032 total displays; 64 target elements [8 colors × 8 shapes] × 64 distractor elements, excluding uniform displays).

Pecks to the target region and the surrounding row of distractor elements were again considered to be target-directed responses. Despite the smaller size of the touchscreen's programmed target area, the expected value for chance responding increased with respect to Experiment 1. This was due to the greater likelihood that some portion of these randomly located targets would occupy the center, rather than the edge, of the display. Accordingly, pecks toward the center of screen were more likely to be correct than pecks toward the sides. To be as stringent as possible, above-chance target detection was only considered to have occurred if accuracy was greater than 38% correct for 8 × 7 element targets and 30% for 7 × 6 element targets. These values were derived from probe trials in which visually uniform displays were presented to the pigeons and responses were recorded as if a target had been present and also from computer simulations of random and biased animals. The performance of the 2 new pigeons at the start of training reflects the conservative nature of these values (see Figure 7). Their initial accuracy was considerably below that expected by these estimates of chance.

*Random-placement discrimination training.* The 2 procedurally naive pigeons required no hopper training or response shaping because of their previous experience. Daily training sessions consisted of 120 random-placement texture discrimination trials (40 color, 40 shape, and 40 redundant) generated by the random trial composition procedure. The timing of events within each trial and the reinforcement contingencies were the same as in Experiment 1. Starting at

Session 29, testing with the redundant displays was discontinued, and the 120 daily trials were divided evenly between color and shape trials. Starting at Session 46, the target size was reduced to 7 × 6 elements. After 60 total sessions of training, the novel value transfer tests described later were conducted.

*Quadrant to random-placement procedure transfer.* The 4 quadrant-trained pigeons were switched to the random trial composition procedure using eight colors and eight shapes on completing Experiment 1. The pigeons received 45 additional 100-trial quadrant placement sessions (40 color, 40 shape, and 20 redundant trials per session). They were then transferred to identically composed 100-trial sessions using the random target placement procedure and its larger display. All other aspects of their testing remained the same. Data from the last two quadrant and first two random placement sessions are described later.

Soon after this switch in procedures, these pigeons were tested for the effects of dimensional organization on texture discrimination (Cook, 1992a). These experiments used both the random-placement and random trial composition procedures and lasted several months. On completion, these 4 pigeons were switched to the same daily regimen then being used with the 2 new pigeons (Session 20). Testing of novel value transfer occurred 40 sessions later.

*Novel value transfer tests.* In this phase, discrimination transfer to displays generated with novel colors and shapes was examined. The first series of tests used three new colors, and the second series of tests used four new shapes.

Color transfer testing was conducted in three 3-session blocks. Each block introduced a new color in the following order: pink (EGA color no. 37), light blue (EGA color no. 25), and yellow (EGA color no. 54). Test displays were made by combining that block's new color, in both target and distractor roles, with the eight training colors and the previously tested novel colors (Blocks 2 and 3 only). After each block, its novel color was tested again only in combination with subsequent novel colors. The irrelevant shape configuring these color transfer trials was changed for each session of a block; S, TRI, and CIR were used. Each session consisted of 120 total trials. Each session's transfer trials were simply randomly mixed into randomly generated color and shape baseline trials. Event timing and reinforcement contingencies were the same as during training.

Shape transfer testing was conducted in four 3-session blocks. Each block introduced a new shape in the following order: O, triple dot, equal sign, and vertical line (see Figure 2). Test displays were again made by combining the novel shape with the eight baseline shapes and the previously tested novel shapes (Blocks 2, 3, and 4 only). After each block, a novel shape was presented again only in combination with subsequent novel shapes. The irrelevant color configuring these transfer trials changed for each session of a block. Blue, red, and green were used. Each session consisted of 120 trials of randomly intermixed shape transfer trials and randomly generated color and shape baseline trials. Four 120-trial baseline sessions separated the color and shape transfer tests.

## *Results*

*Transfer to the random-placement procedure.* The four quadrant-trained birds immediately transferred to the random-placement procedure with no loss in performance. For the last two quadrant placement sessions, mean target-detection accuracy was 63% and mean first-peck RT was 555 ms. For the first two random-placement sessions, these values were 70.6% and 507 ms. Repeated measures ANOVAs (Procedure [quadrant or random] × Display Type [redundant or color or shape] × Sessions [1 or 2]) of both dependent variables revealed no significant differences as a function of procedure or its interaction with display type.

*Acquisition with the random-placement procedure.* For the 2 new birds, task acquisition with the different display types paralleled that seen earlier with the quadrant procedure. Figure 7 shows mean accuracy for color, shape, and redundant trials during the first 19 sessions. The 2 birds reached criterion in 18.5 sessions (5 sessions of >65% overall accuracy for all three display types). Color and redundant texture discriminations were again acquired significantly more quickly than shape: color versus shape, $F(1, 1) = 145.63$, and redundant versus shape, $F(1, 1) = 700.48$. No significant difference was found between acquisition of the redundant and color discriminations.

Task acquisition with the random and quadrant procedures was then compared to investigate whether there were any differences in learning between the two experiments. The random versus quadrant placement procedure was tested as a between-groups factor in a mixed design ANOVA (Procedure [random or quadrant] × Display Type [redundant or color or shape] × Sessions). No significant effects or interactions were found between the two procedures. The main effects for sessions, $F(18, 72) = 18.23$, and display type, $F(2, 8) = 41.66$, were both highly significant.

*Novel color transfer test.* Task transfer to novel color displays was almost perfect, with little or no difference in accuracy relative to the baseline displays. The left side of Figure 8 shows the mean target-detection accuracy of all 6 pigeons for color baseline and transfer trials over the nine test sessions. Mean accuracy for the 162 color transfer trials (69.4%) was significantly above chance (30%), $t(5) = 11.2$, and was the same as with the baseline trials (70.4%). A repeated measures ANOVA (Trial Type [baseline or transfer] × Sessions) found no significant differences in accuracy between baseline and transfer conditions, $F(1, 5) < 1$, or their interaction over sessions, $F(8, 40) < 1$. Analysis of only the

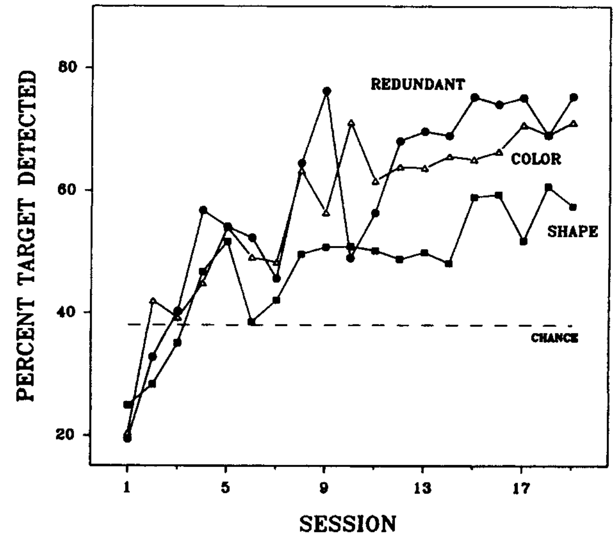

*Figure 7.* Mean accuracy (%) of the 2 new birds over the first 19 training sessions for color, shape, and redundant displays in Experiment 2. (The broken reference line represents chance performance.)

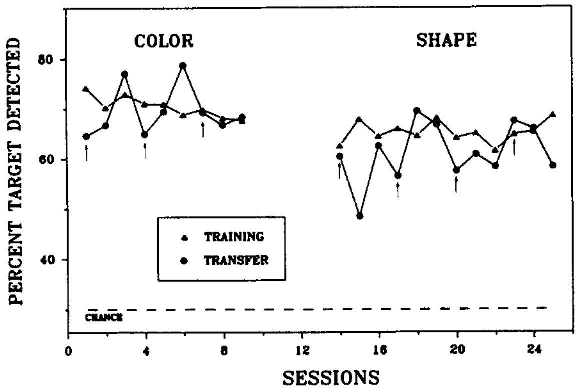

*Figure 8.* Mean accuracy (%) for color and shape transfer and baseline trials over the 21 sessions of novel value transfer testing in Experiment 2. (The arrows indicate the first session introducing a new color and shape during the different blocks of this experiment. The broken reference line represents chance performance.)

first transfer sessions with a new color also revealed no reliable difference between baseline (71.7%) and transfer (66.4%) trials, *F*(1, 5) = 1.30. Mean RTs for baseline (581 ms) and transfer trials (620 ms) were also not significantly different.

*Novel shape transfer test.* Task transfer to novel shape displays was also very good but was below that of the baseline trials and was also not as high as observed with the novel color displays. The right side of Figure 8 shows the mean accuracy for shape baseline and transfer trials over the 12 test sessions. Mean accuracy on the 228 shape transfer trials (61.3%) was significantly above chance (30%), $t(5)$ = 14.1, and only slightly below that recorded for shape baseline trials (65.2%). A repeated measures ANOVA (Trial Type [baseline or transfer] × Sessions) found no significant difference between the transfer and baseline trials in terms of accuracy, *F*(1, 5) = 5.47, and no interaction across sessions, *F*(11, 55) = 1.50. Analysis of only the first transfer sessions with a new shape found no reliable difference between accuracy on baseline trials (64.3%) and transfer trials (60.8%), *F*(1, 5) = 1.81. Mean RTs for shape baseline (618 ms) and transfer (674 ms) trials were not different.

Two additional analyses were performed. The first looked at the effects of previous experience on transfer accuracy. This analysis found no differences between the two groups of pigeons in their degree of transfer to the novel displays. The 6 pigeons were divided in two groups according to training procedure or experience (quadrant-trained and >57,000 discrimination trials vs. random-trained and <8,000 discrimination trials). Using experience as the between-groups factor, mixed design ANOVAs were conducted separately on the color and shape transfer results (Experience [quadrant or random] × Trial Type [transfer or baseline] × Sessions). These ANOVAs revealed no significant differences directly related to experience or its interaction with either trial type or sessions (*F*s < 1.10).

The final analysis looked at the effects of element novelty or familiarity on transfer performance. The elements of each display's target and distractor regions were again classified according to the three degrees of relative familiarity described earlier. Over the 21 transfer sessions, the mean accuracies for the resulting trial types were as follows: high-high, 67.8%; novel-high, 56.5%; high-novel, 72.5%; low-novel, 75%; and novel-low, 67%. Single mean *t* tests found all five values to be above chance, $ts(5) > 2.77$. In *t* tests comparing each transfer condition with the high-high baseline condition, accuracy was significantly reduced only when novel target elements were embedded within highly familiar distractors, $t(5) = 4.83$.

## *Discussion*

Despite the randomized and increased number of target locations, the increased number of color and shape elements and their randomized combination, and the corresponding increase in the number of training displays, all 6 pigeons performed this more demanding version of the texture discrimination task with apparent ease. The 4 experienced pigeons completely transferred their previous quadrant discrimination to the new random-placement procedure. Moreover, the 2 new pigeons readily learned to locate randomly placed targets within displays whose element composition was randomly determined, with their rate and order of acquisition for the redundant, color, and shape discriminations being indistinguishable from Experiment 1. Last, both sets of pigeons demonstrated almost perfect positive transfer to new texture displays composed with novel colors and shapes.

The transfer of the 4 quadrant-trained pigeons to the random-placement procedure suggests that their previously learned target-detection response had not been focused on only a few specific locations but was spatially generalized over a larger area of the displays. In addition, this procedural change did not influence the time it took to locate the target, at least as measured by first-peck RT. Had their RTs slowed considerably on being switched to the more widely distributed randomly located targets, it would have suggested that some form of serial search mechanism might have been involved in locating the targets. The ability to simultaneously discriminate visual difference across widely distributed spatial locations is one of the hallmarks of textural segregation in humans and possibly in pigeons also.

Of further interest was the fact that the 2 new pigeons learned to discriminate textures as quickly as the pigeons in Experiment 1. The top panel of Figure 9 shows the mean rates of task acquisition for Experiments 1 and 2 displayed on a per-session basis. The similar rate of task acquisition in the two experiments suggests that the large differences in the number of training displays, component elements, and compositional variability were not particularly influential factors in the learning of these texture discriminations. Moreover, because of the large difference in the number of training stimuli used for each experiment (4,302 randomly generated texture displays vs. 36 fixed stimuli), the pigeons in Experiment 2 must have learned their discrimination with considerably fewer repetitions of any specific display than the pigeons in Experiment 1.

Consider the implications of this fact for those theories of avian visual discrimination that rely on learning the absolute characteristics of individual stimuli. Such exemplar theories

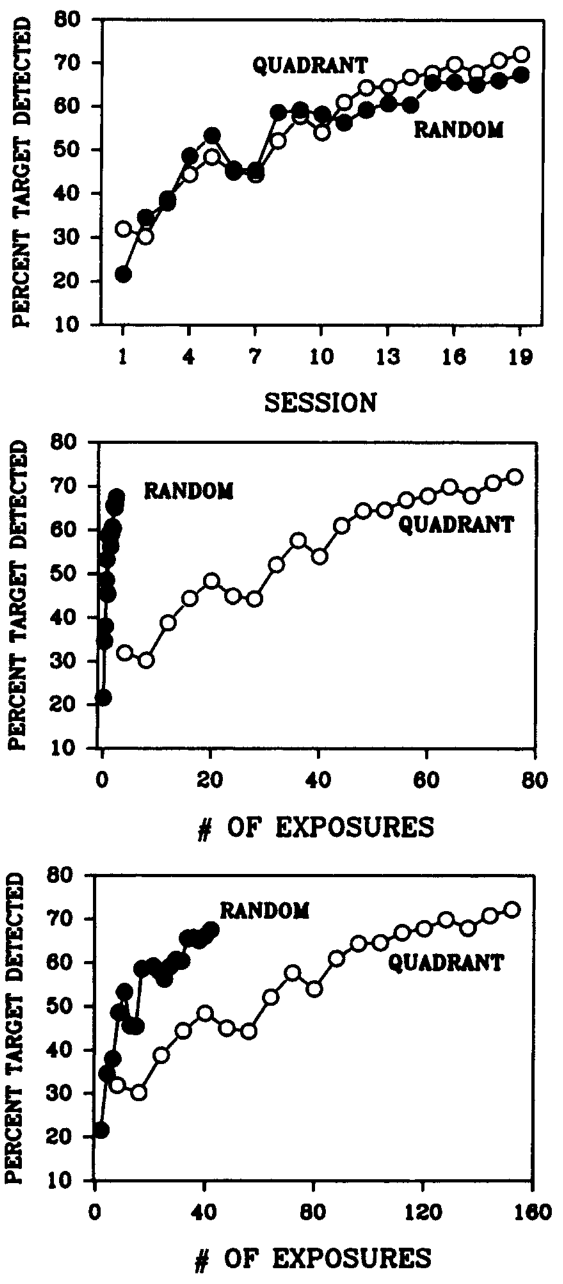

*Figure 9.* Comparison of acquisition rates for quadrant and random-placement procedures. (The top panel shows the results as a function of the number of training sessions for each procedure. The middle panel shows the same results adjusted for the rate of display repetition for specific combinations of color and shape target–distractor values. The bottom panel shows the same data adjusted for the rate of display repetition given specific combinations of colors.)

have suggested that pigeons exhaustively memorize large sets of stimulus exemplars (Heinemann, 1990) or use multiple, stimulus-specific, *if–then* rules (Carter & Werner, 1978) as the primary basis for solving visual discriminations (e.g., Vaughan & Greene, 1983). A fundamental prediction of these theories is that as the number of stimuli or rules to be learned increases, the time needed to learn the discrimination should correspondingly increase. The current results are contrary to this prediction, at least when the component elements are considered the unit of encoding.

Using only the color texture stimuli for instance, consider the extreme case in which both the color and shape attributes of each display's target and distractor regions are memorized. In Experiment 1, the 12 target–distractor color combinations and their associated irrelevant shape were presented once every 36 trials, or four times per session. In Experiment 2, the corresponding 448 color–shape combinations appeared on the average once every 448 color trials, or about once every 7.5 sessions. The middle panel of Figure 9 again displays the two acquisition curves, adjusted to reflect these differences in stimulus exposure rates. When considered on this per-exposure basis, the pigeons in Experiment 2 show a considerable and unpredicted savings in learning their supposedly more difficult discrimination.

Of course, the number of different stimuli requiring a separate memorized representation depends on the stimulus properties that are selected and processed from any display. For the present discriminations, however, any reduction in the number of memorized stimuli by processing only certain element features still creates problems for any stimulus-specific view. For instance, even if the number of different stimuli is limited to only specific combinations of the eight training colors, disregarding target–distractor role and the value of the irrelevant shape, the pigeons in Experiment 2 still learned considerably more quickly than those in Experiment 1 on a per-exposure basis (8 vs. 2.1 repetitions per session; see lower panel of Figure 9). These facts, in conjunction with the almost perfect transfer of the discrimination to displays composed with novel elements, suggest that it was not the specific elements per se that formed the effective discriminative stimulus in these displays.

A modest alteration in the perceived nature of the effective stimulus—from one based on the local elements of each display to an account based on their regional organization—more easily accommodates the results from the two experiments. In this case the key feature for the pigeons was the salient difference derived by visually grouping the elements into distinct regions, which they perhaps responded to as a simple bounded figure on a ground of distractors. It was this feature of the displays that was the most consistent characteristic possessed by every training and transfer stimulus. That the global structure of these displays may have been the critical factor in the rapid acquisition and robust transfer of these textured discriminations is perhaps not surprising. From the human visual perspective these displays produce exactly this response. Indeed, the constantly randomized nature of the local structure may have even been beneficial in this regard by quickly highlighting the stability of the global organization.

Several response rules are possible on the basis of the global properties of the displays. One possibility is that the pigeons used an abstract oddity concept to identify the smaller target region embedded within the larger distractor area (see D. S. Blough, 1989; Zentall, Hogan, Edwards, & Hearst, 1980). Such a rule might take the form, *peck the odd region of the display.* In this analysis the global perception of the array serves only to mediate a more abstract comparison of the relative areas of the two regions.

A second possibility is that the pigeons responded more directly to the perceptual differences, perhaps in the form of a feature-positive approach rule. Such simple perceptually oriented response rules as *peck the object* or *peck the boundary* could have then guided responding toward the target or its boundaries. Consistent with such an idea are analyses that have looked at where the birds pecked while performing these discriminations. Cook (1992b) found that for quadrant displays, most pecks were directed at or near the boundary between the target and distractor region on both correct and incorrect trials. Given the tendency of pigeons to peck at the controlling attribute of discriminative stimuli (Hearst & Jenkins, 1974; Jenkins & Sainsbury, 1970), such an outcome suggests that the visual discontinuity between the two regions was a salient and important factor in responding.

## General Discussion

These experiments found that pigeons readily acquired and transferred conditional texture discriminations. In fact, they exhibited an uncharacteristic flexibility to perform with very large numbers of everchanging displays—nearly 3 million by the end of Experiment 2 (132 target elements [12 shapes × 11 colors] × 132 distractor elements × 170 target locations). Acquisition of these texture discriminations appeared to require minimal repetition of specific training stimuli and transferred to a wide variety of new displays, including displays composed from novel recombinations of old display elements, novel colors and shapes, and new spatial organizations of the target and distractor regions.

This degree of flexibility suggests that the detailed local or element structure of these displays was essentially transparent to the pigeons and that it was the emergent global properties of the stimuli that primarily controlled responding. The consistent visual difference between the target and distractor regions was the common factor shared by all training and test displays, and this difference seems to account most easily for the ready and equivalent acquisition rates in the two experiments, the sheer number of stimuli that were discriminated, and the excellent transfer of the discrimination to the large number of different novel displays. These positive transfer results also indicate that a form of generalized conditional discrimination can be generated on the basis of only color and shape differences if a sufficiently large and variable set of training stimuli are used.

Overall, these findings suggest that the pigeons perceived and responded to these texture displays much like humans—with an immediate visual percept of contrasting textural regions. As such, pigeons may possess visual mechanisms that are functionally analogous to the automatic early preattentive parallel processes proposed to mediate human texture segregation (Beck, 1982; Broadbent, 1977; Julesz, 1981; Neisser, 1967; Treisman & Gelade, 1980) and can also rapidly group and segregate regions of visual space on the basis of color and shape properties. The advantages of such a process to a quickly moving diurnal aerial species seem to require little further comment.

One distinguishing characteristic of visual texture segregation in humans is its rapidity; regional differences are often perceived in less than 200 ms. To estimate just how quickly the pigeons might similarly process the relevant dimensional information from these textured displays, an additional analysis of first-peck RT was conducted. This RT surely represents the concatenation of several successive processes: display encoding, target–distractor discrimination, determination of the target's location, and the motor biomechanics of the pecking response itself. If the time of those processes unrelated to texture segregation could be subtracted from the observed RTs, the remainder would better estimate the time needed to process the relevant information from these displays. The processing times for some of these stages are clearly difficult to isolate. However, an estimate for one of the larger contributors can be identified and potentially removed from these data—the time taken for the pecking response itself.

The source of this information in the current setting comes from the interresponse intervals (IRIs) of the multiple pecks required to each display (a minimum of five per trial). Despite the multiple response opportunities, it appeared for the present experiments that almost all meaningful target processing occurred prior to the first peck. This conclusion was suggested by the fact that accuracy when measured after only the first peck (65.7%) was virtually identical to accuracy based on all pecks (66.3%; the accuracy and RT values for this analysis were collected from baseline sessions conducted shortly after Experiment 2). Apparently, little new information about the target's location was gleaned during the additional observing responses. This is also consistent with the observation that all pecks within a trial clustered around the location of the first peck. Seemingly, these later pecks only functioned to complete the experimenter's procedural requirement. The consequence is that the IRIs of these additional pecks may simply reflect peck time.

The fastest mean IRI for guaranteed Pecks 2 through 5 was 512 ms (means for Pecks 2 through 5 were 556, 536, 512, and 525 ms, respectively). The first-peck RT during these same trials was 657 ms. The difference between these two temporal values suggests, then, that initial target detection may have occurred very quickly, perhaps in as little as 150 ms. Clearly, this method of estimation assumes that no further processing of the display occurs during the execution of the peck itself. Several properties of the pecking response suggest a certain degree of validity to this assumption, as both aim and gape size are primarily determined prior to initiation, and significant durations of each peck are conducted with the eyes closed (Zeigler, Levitt, & Levine, 1980; Zweers, 1980). Although future work will need to examine these assumptions more closely, this analysis nevertheless suggests that the grouping processes underlying avian texture perception may operate within the same time frame as those that mediate human texture perception.

The present texture discrimination procedures and results share many connections with the recent experiments of the Bloughs and their associates (Allan & D. S. Blough, 1989; D. S. Blough, 1977, 1979, 1984, 1985, 1988, 1989; D. S. Blough & Franklin, 1985; P. M. Blough, 1984, 1991). The first reported research on texture discrimination by pigeons (D. S.

Blough & Franklin, 1985) and more recent work using the odd-item variation of the single-target visual search task (D. S. Blough, 1989) are the two studies of most relevance to the present results.

D. S. Blough and Franklin (1985) found that pigeons could readily discriminate a variety of coarsely textured form stimuli using a procedure with three potential target positions. They concluded that the discrimination and search processes used in their discrimination procedure were not markedly different from those of other single-target visual search tasks and suggested that the underlying processes were more attentive in nature. This conclusion was based primarily on the high correlation between the perceived similarity of alphabetic characters when tested as single items or as textured stimuli and the long first-peck RTs (908 ms) found in their experiments.

D. S. Blough and Franklin (1985) also raised the possibility that the birds might have been using a mixed strategy involving a combination of both preattentive and attentive processes, with the latter processes dominating in their experiments because of the high similarity of their shapes and the coarse nature of their displays. The results of the present experiments tend to support this mixed-strategy explanation. The use of denser textures and dissimilar shapes, and the introduction of color as a relevant dimension, seem to have promoted a more preattentive-like processing of the displays in the present experiments. If so, then these results dovetail nicely with D. S. Blough's (1989) recent findings using an odd-item variation of the visual search task. He found that under certain circumstances target search RT can decrease with increasing numbers of distractors. This contrasts with most of the previous results from pigeon visual search experiments, which have found that RT increases with distractor set size (Allan & D. S. Blough, 1989; D. S. Blough, 1977, 1979; P. M. Blough, 1984). To account for this difference, D. S. Blough (1989) suggested that preattentive perceptual mechanisms, similar in nature to those suggested by the present experiments, may have been responsible for the rapid target search with increasing numbers of distractors.

The pattern emerging from these different visual discrimination experiments suggests that the speed of target search processes varies considerably in pigeons. Under certain conditions searching can be very rapid, maybe even parallel in nature (the present experiments; D. S. Blough, 1989; Bond, 1983), whereas in other situations, searching is much slower and serial-like in character (Allan & D. S. Blough, 1989; D. S. Blough, 1977, 1979; P. M. Blough, 1984). Whether these different results reflect the operation of two separate search mechanisms or are the by-product of one mechanism, controlled by the global and local similarity of the target–distractor elements and their emergent regional or objectlike properties, remains an important issue to be clarified (e.g., D. S. Blough, 1988).

## References

Allan, S. E., & Blough, D. S. (1989). Feature-based search asymmetries in pigeons and humans. *Perception & Psychophysics, 46,* 456–464.

Beck, J. (1966). Effect of orientation and shape similarity on perceptual grouping. *Perception & Psychophysics, 2,* 491–495.

Beck, J. (1982). Textural segmentation. In J. Beck (Ed.), *Organization and representation in perception* (pp. 285–318). Hillsdale, NJ: Erlbaum.

Berryman, R., Cumming, W. W., Cohen, L. R., & Johnson, D. F. (1965). Acquisition and transfer of simultaneous oddity. *Psychological Reports, 17,* 767–775.

Blough, D. S. (1977). Visual search in pigeons: Hunt and peck method. *Science, 196,* 1013–1014.

Blough, D. S. (1979). Effects of number and form of stimuli on visual search in the pigeon. *Journal of Experimental Psychology: Animal Behavior Processes, 5,* 211–223.

Blough, D. S. (1984). Form recognition in pigeons. In H. L. Roitblat, T. G. Bever, & H. S. Terrace (Eds.), *Animal cognition* (pp. 277–289). Hillsdale, NJ: Erlbaum.

Blough, D. S. (1985). Discrimination of letters and random dot patterns by pigeons and humans. *Journal of Experimental Psychology: Animal Behavior Processes, 11,* 261–280.

Blough, D. S. (1988). Quantitative relations between visual search speed and target–distractor similarity. *Perception & Psychophysics, 43,* 57–71.

Blough, D. S. (1989). Odd-item search in pigeons: Display size and transfer effects. *Journal of Experimental Psychology: Animal Behavior Processes, 15,* 14–22.

Blough, D. S., & Franklin, J. J. (1985). Pigeon discrimination of letters and other forms in texture displays. *Perception & Psychophysics, 38,* 523–532.

Blough, P. M. (1984). Visual search in pigeons: Effects of memory set size and display variables. *Perception & Psychophysics, 35,* 344–352.

Blough, P. M. (1991). Selective attention and search images in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes, 17,* 292–298.

Bond, A. B. (1983). Visual search and selection of natural stimuli in the pigeon: The attention threshold hypothesis. *Journal of Experimental Psychology: Animal Behavior Processes, 9,* 292–306.

Broadbent, D. E. (1977). The hidden preattentive processes. *American Psychologist, 32,* 109–118.

Caelli, T. (1982). On discriminating visual textures and images. *Perception & Psychophysics, 31,* 149–159.

Carter, D. E., & Werner, T. J. (1978). Complex learning and information processing by pigeons: A critical analysis. *Journal of the Experimental Analysis of Behavior, 29,* 565–601.

Cook, R. G. (1992a). Dimensional organization and texture discrimination in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes, 18,* 354–363.

Cook, R. G. (1992b). The visual perception and processing of textures by pigeons. In W. K. Honig & G. Fetterman (Eds.), *Cognitive aspects of stimulus control* (pp. 279–299). Hillsdale, NJ: Erlbaum.

Cook, R. G., Riley, D. A., & Brown, M. F. (1992). Spatial and configural factors in compound stimulus processing by pigeons. *Animal Learning & Behavior, 20,* 41–55.

Cumming, W. W., & Berryman, R. (1961). Some data on matching behavior in the pigeon. *Journal of the Experimental Analysis of Behavior, 4,* 281–283.

Cumming, W. W., Berryman, R., & Cohen, L. R. (1965). Acquisition and transfer of zero-delay matching. *Psychological Reports, 17,* 435–445.

Donovan, W. J. (1978). Structure and function of the pigeon visual system. *Physiological Psychology, 6,* 403–437.

Emmerton, J. (1983). Functional morphology of the visual system. In M. Abs (Ed.), *Physiology and behavior of the pigeon* (pp. 221–241). San Diego, CA: Academic Press.

Enns, J. T., & Resnick, R. A. (1990). Sensitivity to three-dimensional orientation in visual search. *Psychological Science, 1,* 323–326.

Ewert, J. (1987). The neuroethology of releasing mechanisms: Prey-catching in toads. *Behavioral and Brain Sciences, 10,* 337–405.

Farthing, G. W., & Opuda, M. J. (1974). Transfer of matching-to-sample in pigeons. *Journal of the Experimental Analysis of Behavior, 21,* 199–213.

Grossberg, S., & Mingolla, E. (1985). Neural dynamics of perceptual grouping: Textures, boundaries, and emergent segmentations. *Perception & Psychophysics, 38,* 141–171.

Hearst, E., & Jenkins, H. M. (1974). *Sign tracking: The stimulus-reinforcer relation and directed action.* Austin, Texas: Psychonomic Society.

Heinemann, E. G. (1990). A memory model for decision processes in pigeons. In M. L. Commons, R. J. Herrnstein, S. Kosslyn, & D. B. Mumford (Eds.), *Quantitative analyses of behavior: Computational and clinical approaches to pattern recognition and concept formation* (pp. 109–126). Hillsdale, NJ: Erlbaum.

Holmes, P. W. (1979). Transfer of matching performance in pigeons. *Journal of the Experimental Analysis of Behavior, 31,* 103–114.

Honig, W. K. (1991). Discrimination by pigeons of mixture and uniformity in arrays of stimulus elements. *Journal of Experimental Psychology: Animal Behavior Processes, 17,* 68–80.

Jenkins, H. M., & Sainsbury, R. S. (1970). Discrimination learning with the distinctive feature on positive or negative trials. In D. Mostofsky (Ed.), *Attention: Contemporary theory and analysis* (pp. 239–274). New York: Appleton-Century-Crofts.

Julesz, B. (1975). Experiments in the visual perception of texture. *Scientific American, 212,* 34–43.

Julesz, B. (1981). Textons, the elements of texture perception and their interactions. *Nature, 290,* 91–97.

Lombardi, C. M., Fachinelli, C. C., & Delius, J. D. (1984). Oddity of visual patterns conceptualized by pigeons. *Animal Learning & Behavior, 12,* 2–6.

Marr, D. (1982). *Vision.* New York: Freeman.

Neisser, U. (1967). Cognitive psychology. New York: Appleton-Century-Crofts.

Pearson, R. (1972). *The avian brain.* New York: Academic Press.

Ramachandran, V. S. (1988). Perceiving shape from shading. *Scientific American, 256,* 76–83.

Reichardt, W. (1986). Processing of optical information by the visual system of the fly. *Vision Research, 26,* 113–126.

Santi, A. (1978). The role of physical identity of the sample and correct comparison stimulus in matching-to-sample paradigms. *Journal of the Experimental Analysis of Behavior, 29,* 511–516.

Santi, A. (1982). Hue matching and hue oddity in pigeons: Is explicit training not to peck incorrect hue combinations a sufficient condition for transfer? *Psychological Record, 32,* 61–73.

Santiago, H. C., & Wright, A. A. (1984). Pigeon memory: Same/different concept learning, serial probe recognition acquisition and probe delay effects in the serial position function. *Journal of Experimental Psychology: Animal Behavior Processes, 10,* 498–512.

Sutter, A., Beck, J., & Graham, N. (1989). Contrast and spatial variables in texture segregation: Testing a simple spatial-frequency channels model. *Perception & Psychophysics, 46,* 312–332.

Treisman, A. & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12,* 97–136.

Urcuioli, P. J. (1977). Transfer of oddity-from-sample performance in pigeons. *Journal of the Experimental Analysis of Behavior, 25,* 195–202.

Urcuioli, P. J., & Nevin, J. A. (1975). Transfer of the hue matching in pigeons. *Journal of the Experimental Analysis of Behavior, 24,* 149–155.

Vaughan, W., Jr., & Greene, S. L. (1983). Acquisition of absolute discriminations in pigeons. In M. L. Commons, R. J. Herrnstein, & A. R. Wagner (Eds.), *Quantitative analyses of behavior: Discrimination processes* (pp. 231–238). Cambridge, MA: Ballinger.

Waldvogel, J. A. (1990). The bird's eye view. *American Scientist, 78,* 342–353.

Watt, R. J. (1988). *Visual processing.* Hillsdale, NJ: Erlbaum.

Wright, A. A., Cook, R. G., Rivera, J. J., Sands, S. F., & Delius, J. D. (1988). Concept learning by pigeons: Matching-to-sample with trial-unique video picture stimuli. *Animal Learning & Behavior, 16,* 436–444.

Zeigler, H. P., Levitt, P. W., & Levine, R. R. (1980). Eating in the pigeon (*Columba livia*): Movement pattern stereotypy and stimulus control. *Journal of Comparative and Physiological Psychology, 94,* 783–794.

Zentall, T. R., Hogan, D. E., Edwards, C. A., & Hearst, E. (1980). Oddity learning in the pigeon as a function of the number of incorrect alternatives. *Journal of Experimental Psychology: Animal Behavior Processes, 6,* 278–299.

Zweers, G. A. (1980). Pecking in the pigeon (*Columba livia*). *Behaviour, 81,* 173–229.

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