Pigeon Same–Different Concept Learning With Multiple Stimulus Classes

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Two experiments examined the acquisition and transfer of a complex same–different discrimination by pigeons. With the use of a 2-alternative choice task, 5 pigeons were reinforced for discriminating odd-item *Different* displays, in which a contrasting target was present, from *Same* displays, in which all elements were identical. Four different types of same–different displays were concurrently tested. The display types differed in their configuration (texture vs. visual search organization), the nature of their elements (small and large colored shapes; pictures of birds, flowers, fish, and humans), and the processing demands required by their global–local element arrangement. Despite these differences, the pigeons learned to discriminate all 4 display types at the same rate and showed positive discrimination transfer to novel examples of each type, suggesting that a single generalized rule was used to discriminate all display types. These results provide some of the strongest evidence yet that pigeons, like many primates, can learn an abstract, visually mediated same–different concept.

One of the most fundamental psychological discriminations of interest to psychologists for the last century has been the capacity of organisms to detect identity and nonidentity relations (Delius, 1994; Link, 1992, provides an excellent historical review). A popular and powerful means of studying these relations is through the use of the same–different task. In this task the subject is asked to respond *same* when two or more stimuli are identical and *different* if one or more of the stimuli are different from the others. This task has been successfully used in studying a wide range of issues in humans. In nonhuman animals, its use for the investigation of the perception and conceptualization of these relations has been far more limited, but it has been most successfully used with primates (King, 1973; Oden, Thompson, & Premack, 1990; Premack, 1983; Robinson, 1955, 1960; Sands, Lincoln, & Wright, 1982; Shyan, Wright, Cook, & Jitsumori, 1987; Thompson & Oden, 1996; Thompson, Oden, & Boysen, 1997; Wright, Cook, & Kendrick, 1989; Wright, Santiago, & Sands, 1984). In the case of nonprimates, early attempts to use same–different choice procedures with pigeons, for instance, have met with only limited success in teaching these animals the generalized concept of Same and Different (Edwards, Jagielo, & Zentall, 1983; Fetterman, 1991; Santiago & Wright, 1984).

Figure 1. Representative examples of the four display types concurrently used to train and test the pigeons in Experiments 1 and 2. The left column shows examples of Same displays for each display type (the example for the feature display type depicts a shape Same display). The right column shows examples of Different displays for each display type (the examples for the texture, feature, and geometric display types depict shape Different displays).

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Recently, Cook, Cavoto, and Cavoto (1995) and Wasserman, Hugart, and Kirkpatrick-Steger (1995) offered evidence that pigeons may have an underestimated capacity for making generalized same–different discriminations. In both studies, pigeons were trained in a same–different choice task that used large numbers of multielement textured displays (cf. Blough & Franklin, 1985; Cook, 1992a; Cook, Cavoto, & Cavoto, 1996). If all of the elements in a display were identical, the pigeons were required to report a *same* response, but if they differed in their color (Cook et al., 1995) or their shape (Cook et al., 1995; Wasserman et al., 1995), a *different* response was required. Both studies found that pigeons could learn this choice discrimination, and more importantly transfer it to novel examples of the Same and Different displays. This latter outcome suggests that pigeons, and perhaps birds as a class (see Pepperberg, 1987), might be indeed capable of forming and using an abstract same–different rule.

One key issue of concern with these newer observations, however, was whether this transfer represented a true application of an abstract rule by the pigeons, or might have instead been mediated by lower level mechanisms sensitive to common perceptual features shared by the training and transfer displays. Because both studies used textured stimuli, early visual processes designed to detect visual homogeneity and difference (Cook, 1992b; 1993b), for example, could have made important contributions to these results. For instance, the pigeons might have learned to discriminate between Same and Different displays on the basis of a simple perceptual difference—such as the presence or absence of contrasting target "edges" (Cook et al., 1995; see texture examples in Figure 1) or the regularity of the contours formed by the array of repeated icon-based elements (Wasserman et al., 1995)—rather than the abstract Same or Different relations of the component elements. Both groups argued against this perceptual alternative by suggesting that the generalization decrement observed during the transfer tests of these studies would not have been expected if the pigeons were only using such low-level features to judge the displays.

Nevertheless, because of the important implications of these observations for our understanding of avian cognition and intelligence, the experiments reported in this article were directed at clarifying the nature of the effective stimuli in multielement same–different discriminations. The general strategy was to train and test the pigeons with a very wide variety of stimuli, so that no single perceptual feature could consistently be used to differentiate the Same and Different classes of displays. The pigeons were again required to make same–different choice judgments, but this time while being concurrently trained and tested with four separate classes of stimuli.

Examples of Same and Different displays for each of the four stimulus classes, hereafter referred to as the texture, feature, geometric, and object display types, are depicted in Figure 1 (additional examples can be found at Robert G. Cook's website; see author note). The *texture display type* was exactly the same as that tested by Cook et al. (1995). Its inclusion permitted direct comparison between the current study and that previous one. As in Cook et al. (1995), the Same displays in our experiments consisted of the repetition

of a single element throughout the 24 × 16 array. In the Different displays, an 8 × 7 region of contrasting elements (differing in either color or shape) was randomly located within this larger matrix. The identity of the eight colors and eight shapes making up these displays were randomized from trial to trial.

Besides the texture displays, three additional types of displays were tested. The *feature display type* was similar overall to the texture display in its general organization. That is, the Different displays of this type contained an odd, contrasting target region that did not exist in the Same displays. An inspection of the examples in Figure 1, however, will reveal the interesting challenge of this display type. A critical difference between the texture and feature display types was the presence of local irrelevant variation in the latter, such that the identity of the local elements forming the globally contrasting target and distractor regions of this display type varied at random with these regions. As a result, the pigeons could only discriminate the presence or absence of the odd target region on the basis of a global evaluation of the display's overall structure, and not merely the presence or absence of local differences. For instance, in the example of the Same display in Figure 1 for this display type, the pigeons would need to ignore the irrelevant variation in the display (i.e., not respond to the differences among the blue and red circles) and respond instead to the global sameness of the repeated shape across the entire display in order to make an accurate choice. Thus, unlike Cook et al.'s (1995) pigeons, the present pigeons did not have the option of discriminating the displays on the basis of only a local examination of elements in the displays (see Cook, 1992b; Cook et al., 1996).

Besides these two types of textured displays, we also introduced two types of visual search displays. The *geometric display type* was, overall, approximately the same size as the texture displays, but consisted of a 3 × 2 array of larger geometric shapes. This display type was included to see if the previous same–different findings (Cook et al., 1995) could be extended to stimuli composed of a smaller number of more widely spaced elements in which the contrasting difference was defined by a single element, rather than by a block of smaller elements. The contribution of each of these factors should be to reduce the contributions of low-level perceptual grouping to the discrimination of these sparser displays (Beck, 1966).

The *object display type* was similar to the geometric display type in organization, but its elements consisted of digitized depictions of natural objects (flowers, birds, fish, and humans). This type was included for several reasons. Besides adding to the range of stimuli tested, these displays also encouraged the pigeons to process the displays globally, because each object was made of multiple parts that differed in their shape and color details. As such, to successfully judge these displays, these local details have to be ignored or integrated into a judgment based on the entirety of the object image. In addition, despite their popularity, little is yet understood about what animals extract and interpret from complex multidimensional pictorial stimuli (Cook, 1993a; D'Amato & Van Sant, 1988; Fetterman, 1996; Watanabe, Lea, & Dittrich, 1993). Our recent focus on textured stimuli
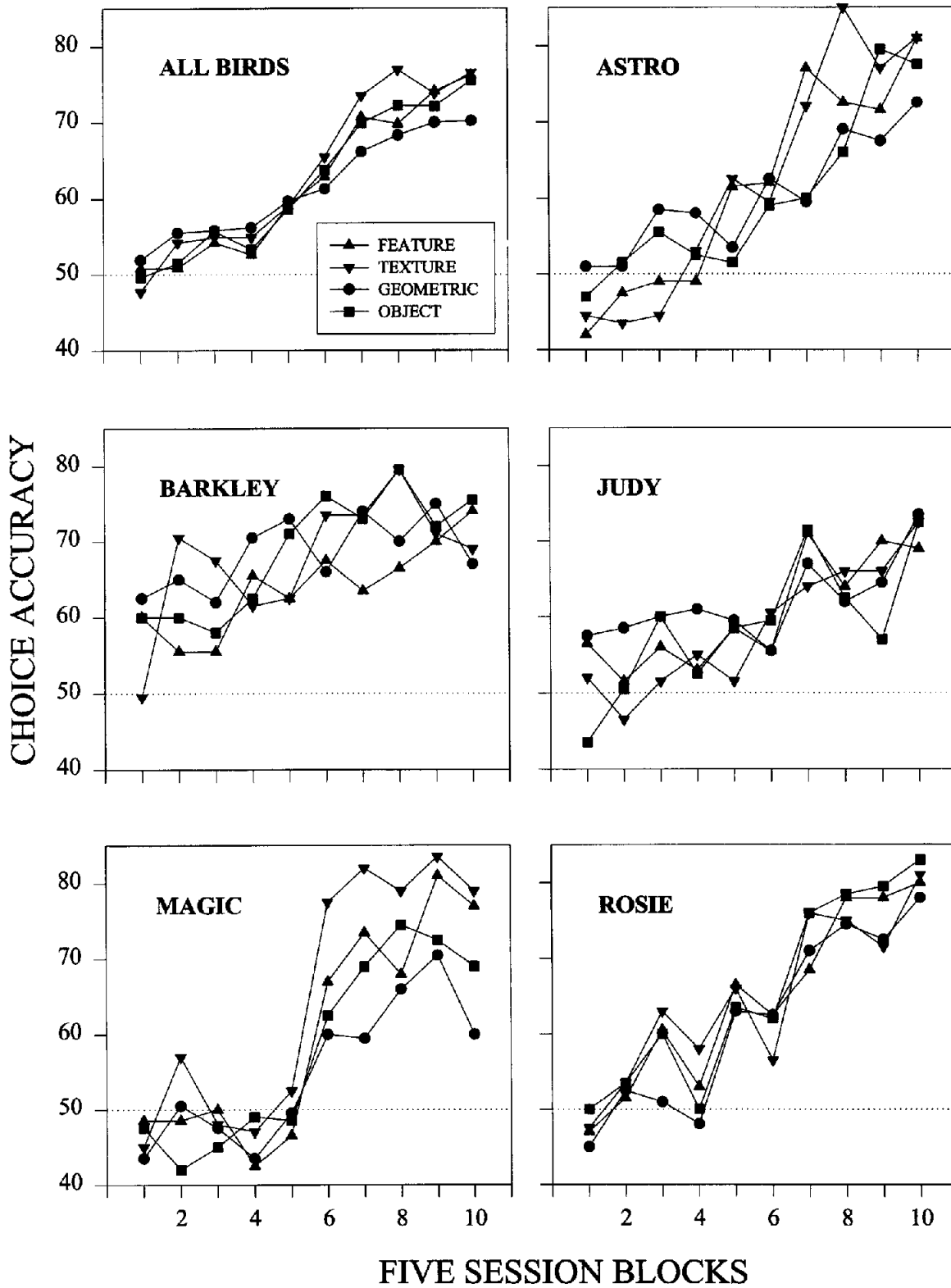
Figure 2. The upper left panel shows mean choice accuracy for feature, texture, geometric, and object displays during acquisition in Experiment 1. The dotted reference line depicts chance performance in the task. The five remaining panels show the acquisition results for the 5 individual pigeons.
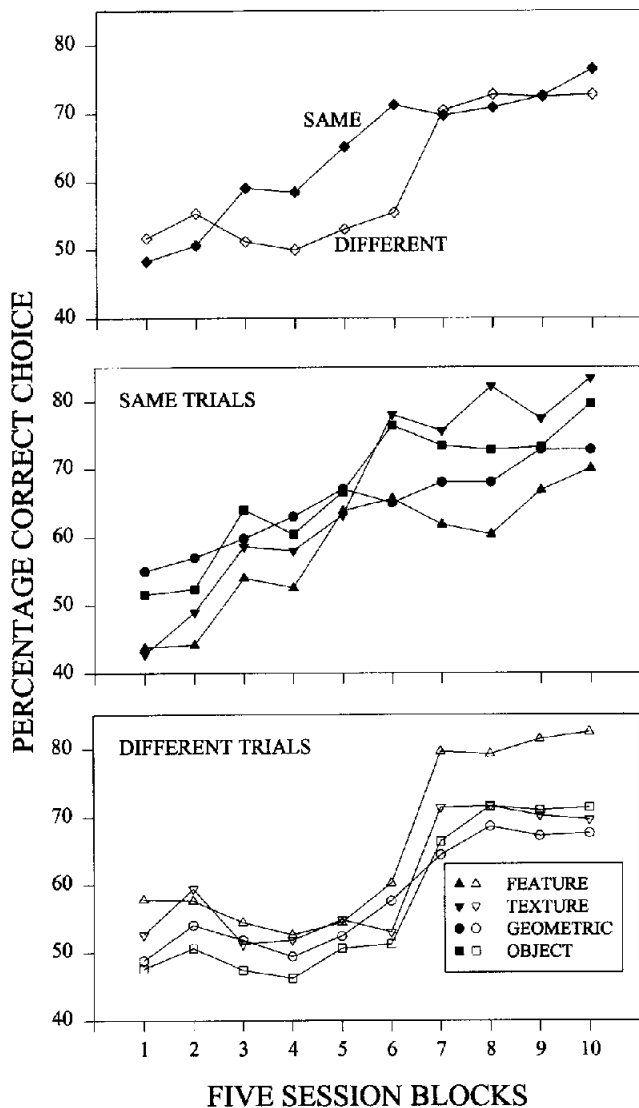
Figure 3. The top panel shows mean percentage correct choice on Same and Different trials in Experiment 1 collapsed over all four display types across discrimination training. The middle and bottom panels show mean percentage correct choice for Same and Different trials respectively for each display type.

was brought about in part because of such concerns, as these precisely controlled synthetic stimuli of moderate complexity seemed ideal for bridging the gap between visual discriminations too simple to reveal much about visual cognition (e.g., red vs. green blobs) and discriminations too complex to be properly controlled or analyzed (e.g., many natural categorization experiments). Given our strong grounding in how pigeons perceive and process textured displays, it now seemed appropriate to tackle the intriguing, but still vexing, question of what pigeons see in pictures and photographs. The object display type was added with this eventual goal in mind.

Taken in conjunction, this expanded set of display types—with their larger number and greater variety of ill-defined,

polymorphic, global, same–different contrasts—breaks the correlation between the perceptual features and conceptual status of the displays that existed in the simpler contrasts used by Cook et al. (1995). Compared with that study, these new displays (a) dramatically increase the numbers of both Different and Same displays, (b) increase the types of configurations in which they are tested (texture vs. visual search displays), (c) expand and extend the range of contrasts presented from abstract shapes and colors of different sizes (texture and geometric) to more realistic renderings of real objects (object), and (d) include simple unidimensional contrasts (texture and geometric) and complex multidimensional contrasts (object and feature). Additionally, each of the three new display types either encouraged (geometric and object) or required (feature) their discrimination to be done on the basis of the global integration of larger scale spatial properties and not local features. Given these properties, any simple perceptual feature hypothesis would be hard pressed to account for any positive transfer observed with novel same–different exemplars of the various display types.

Experiment 1

Experiment 1 looked at the acquisition and steady-state performance of a same–different choice discrimination involving the four separate display types. The experiment used the hopper-choice procedure developed by Cook et al. (1995). In this discrimination task, the pigeons indicate whether a difference is present in a display by choosing between two choice alternatives. These alternatives consist of two choice hoppers located on the right and left side of the chamber, which are used to replace the choice side keys traditionally used in conditional discriminations. After presenting the discriminative stimulus on a trial, these two choice hoppers are both illuminated (but not raised) to indicate that a choice can now be made. A pigeon then indicates its reaction to the discriminative stimulus by entering its head into one of the two hoppers, with one used to indicate the different response, the other the same response (computer-controlled sensors located within each hopper register this choice behavior). If the entered hopper is correct, it is then raised by the computer, allowing the pigeon access to its grain contents, whereas the choice of the incorrect hopper leads to an immediate dark time out.

Our first goal for this experiment was quite practical. Given the increased complexity of the displays, we simply wanted to see if the pigeons could even learn the discrimination. Given success, our second goal was more theoretical. We wanted to examine the rate and pattern of acquisition over the four different stimulus classes to understand how the pigeons learned the task. For instance, the pigeons might learn to perform the four discriminations on the basis of only a single common rule, such as a generalized same–different rule. If so, the common-rule hypothesis predicts that task acquisition should proceed at the same rate for all four display types. Alternatively, the pigeons might learn the task as four separate and unrelated discriminations. In the extreme, this hypothesis predicts that each display type
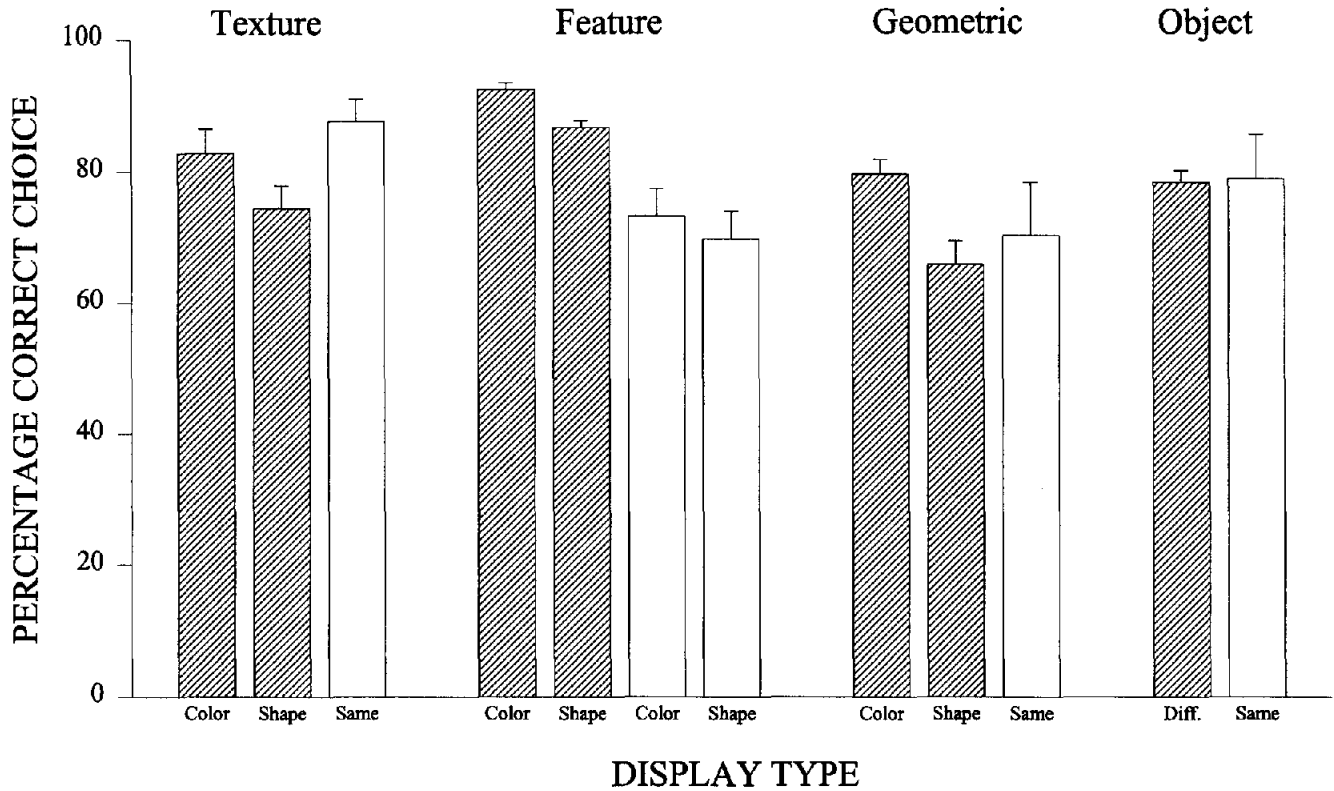
Figure 4. Mean steady-state percentage correct choice with the four display types in Experiment 1 following the completion of discrimination training (30 total sessions). The open bars depict performance with Same displays and hatched bars show performance with Different (Diff.) displays (divided by dimension where appropriate).

should be learned at a different rate. Another possible outcome is that one factor shared in common by some of the displays, such as their general organization, might be the critical determinant of the rate of learning. For example, the two texture discriminations (texture and feature displays) might be learned at a different rate than the two visual search displays (geometric and object displays). A last possibility is that the pigeons might learn to discriminate texture displays but be unable to extend this choice behavior to the three new display types. This outcome would be more consistent with a simple perceptual-driven interpretation of Cook et al.'s (1995) acquisition and transfer results.

Method

Animals

Five naive male White Carneaux pigeons (*Columba livia;* Palmetto Pigeon Plant, Sumter, SC) were tested in the experiment. They were maintained at 80% of their free-feeding weights during testing. During this period, they had free access to water and grit in their home cages, which were housed in a colony room with a 12-hr light–dark cycle.

Apparatus

Testing was conducted in a flat-black Plexiglas chamber (38.0 cm wide × 36.0 cm deep × 39.3 cm high). All stimuli were

presented by computer on a color monitor (COMPAQ 151FS; Houston, TX) visible through a 27.5 × 21.0 cm viewing window in the middle of the front panel. The viewing window's bottom edge was 18.0 cm above the chamber floor. Mounted in this window, 2.0 cm in front of the color monitor, was a touchscreen (Elographics AccuTouch Model E274-SFC; Oak Ridge, TN), which was used to detect pecks to the monitor screen. A clear thin acetate sheet was placed in front of the touchscreen to protect it. A 28-V houselight was located in the ceiling of the box and illuminated at all times, except when an incorrect choice was made. Identical food hoppers (Coulbourn #E14-10, Allentown, PA) were located in the center of the front panel and the right and left walls of the chamber. The side hoppers were located 3.5 cm from the front panel with their openings flush to the floor. The center hopper was not used in these experiments and was inactive. Infrared LEDs mounted 1.5 cm within each hopper were used to detect a pigeon's head within the opening.

Experimental events were controlled and recorded with a 486-class computer. A video card (VGA Wonder; ATI Technologies, Scarborough, Ontario, Canada) controlled the monitor in the SVGA graphics mode (800 × 600 pixels). Computer-controlled relays (Metrabyte, Taunton, MA) operated the hoppers and houselight. Stimulus and event programming were done with QuickBasic (1989) with an attached graphics library (GX Graphics, 1993).

Procedure

Basic display organizations. All displays were 18.0 × 12.0 cm in size, arranged in either a *texture* or a *visual search* organization,
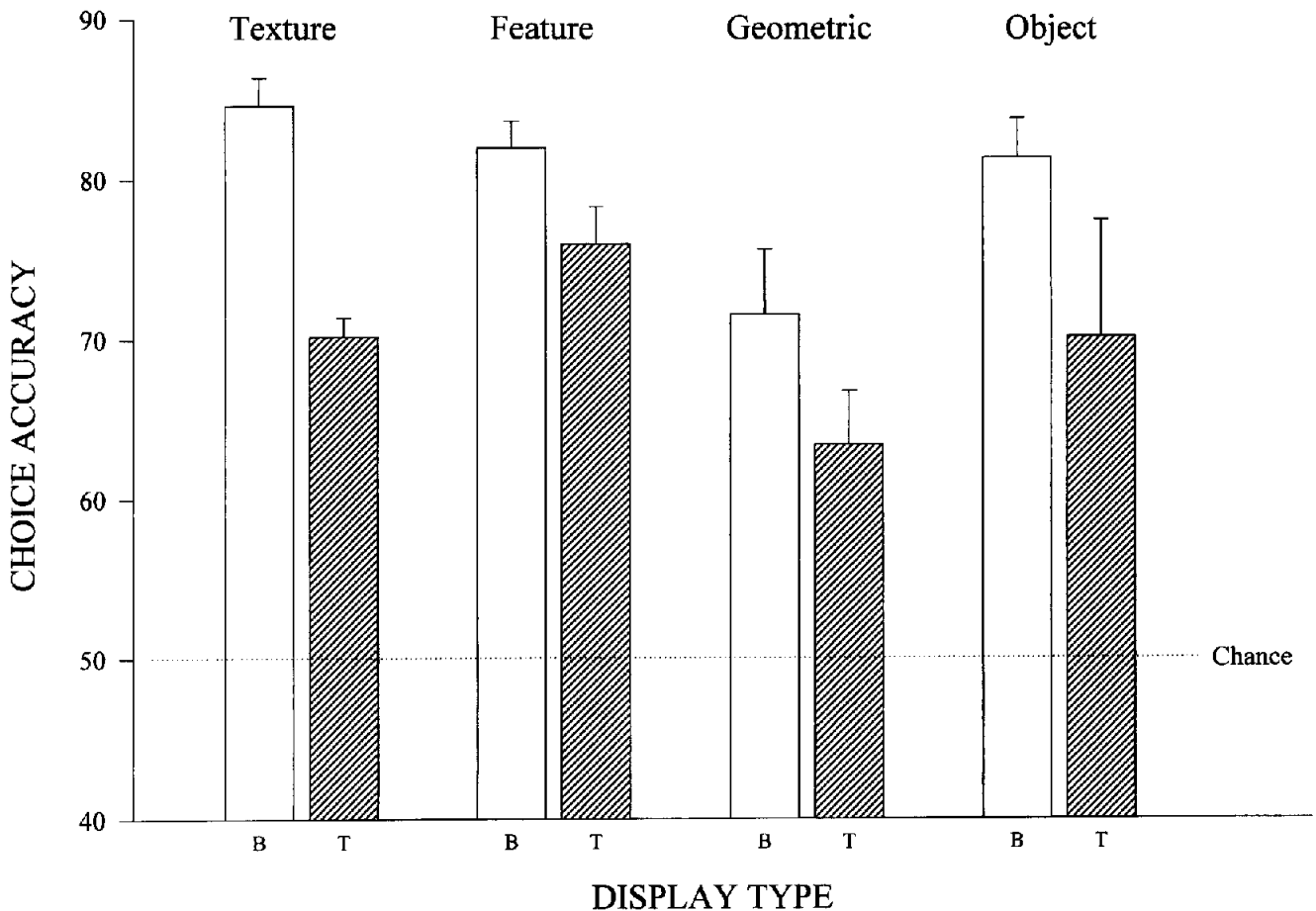
Figure 5. Mean choice accuracy on baseline (B) and nonreinforced transfer (T) trials for each display type as collected in Tests 1A and 1B of Experiment 2. The dotted reference line represents chance performance in the task.

and displayed on a black screen background. The texture and feature display types were configured by using the texture organization (see Figure 1). This consisted of 384 small elements (3–6 mm in size) arranged in a 24 × 16 matrix at 0.75 cm intervals. The Different displays of this organization contained a randomly located 8 × 7 *target* region that contrasted with the surrounding region of *distractor* elements. The geometric and object display types were configured by using the visual search organization. They consisted of 6 large elements (3.0–5.5 cm in size) arranged in a 3 × 2 matrix at 6.0 cm intervals. The Different displays in this organization contained a single randomly located target element that contrasted with the surrounding set of five distractor elements. The next four sections describe in more detail the separate display types. Examples of Same and Different displays of each type are presented in Figure 1.

Texture displays. The texture display type was constructed in the same way as described in Cook et al. (1995). Sixty-four elements derived from the pairwise combination of eight different shapes (U, T, triangle, square, chevron, circle, vertical line, horizontal line) and eight different colors (blue, green, cyan, red, purple, brown, orange, yellow) were used to make these displays. The Same displays of this type were made by repeating one of these 64 elements at all 384 locations within the stimulus array. The Different displays of this type were made by the pairwise combination of target and distractor region elements that differed in either

color or shape. For example, a color Different display might consist of a target region of repeated blue triangles embedded within a distractor region of repeated red triangles. A shape Different display might consist of a target region of green circles embedded within a background of repeated green chevrons. Altogether there were 448 color Different, 448 shape Different, and 64 Same texture displays that could be generated and tested.

Feature displays. The feature display type was constructed in the same manner as originally described by Cook (1992b; Experiment 1). The same 64 elements described above were used to create these displays as well. The Different displays of this type were made by combining a mixture of four elements. The selection and arrangement of these four elements was such that the global difference between the two elements forming each of the target and distractor regions consistently differed in either their color or shape. The local mixture of the two elements within these regions, however, was spatially randomized along the globally irrelevant dimension. For instance, a color Different display of this type might consist of a target region of randomly mixed blue Us and blue Ts embedded within a distractor region of randomly mixed red Us and red Ts. A shape Different display might consist of a target region of red squares and blue squares embedded within a background of red vertical lines and blue vertical lines. Same displays of this type were composed from a randomized mixture of two elements so that their global identity was the same along either color or shape

Figure 6. Summary of the hierarchical cluster analysis for the 24 bird and flower stimuli tested with the object display type shortly after Experiment 2.

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dimension, but locally varied on the other dimension. For instance, a color Same display might consist of a randomized mixture of red Ts and red Us, whereas a shape Same display might consist of a randomized array of yellow Ts and purple Ts.

The number of feature displays depends greatly on how they are counted. Given that the spatial locations of the elements forming each region were randomized on every trial, the exact repetition of a feature display rarely, if ever, occurred (i.e., the displays were trial-unique). Discounting this spatial randomization, there were 1,568 color Different, 1,568 shape Different, 224 color Same, and 224 shape Same feature displays.

Geometric displays. The geometric display type was new to this experiment. The same 64 elements were used to create these displays, except that the sizes of the shapes were increased proportionally by approximately a factor of 10. The Different displays were made by combining these elements so that the target element differed from its five distractors in terms of either its color or shape. For instance, a color Different display might consist of a blue T placed among a set of five red Ts, and a shape Different display might consist of a green U among a set of five green circles. The Same displays were made by repeating the identical element six times within each display. Altogether there were 448 color Different, 448 shape Different, and 64 Same geometric displays that could be generated.

Object displays. The object display type was new to this experiment. These displays were made from semirealistic color renderings of four different birds (kingfisher, parrot, gamehen, bluebird) and four different flowers (dogwood, aztec, drawfpet, azalea). These bird and flower pictures were presented in 256-color PCX format images as created from the clip art provided with Corel graphics software (Corel Draw Version 4, 1993; for ease of replication the assigned names given here are the same as in this software's image library). Each image was scaled to a similar size ranging from 4.5 to 5.5 cm. From these eight images there were 56 Different displays (e.g., a kingfisher among a set of 5 bluebirds) and 8 Same displays that could be generated of this type.

Initial training. The pigeons were first trained to eat from the two hoppers and then autoshaped to peck a centrally presented white 2.5 cm circular ready signal by using randomized presentations of both hoppers. Once responding to this ready signal was established, randomly generated Same and Different stimulus displays of each type (see procedure below in *Discrimination training*) were added to the sequence of events. These stimulus display autoshaping trials each started with a peck to the ready signal followed by the presentation of a display for 15 s or until it was pecked once. Either event caused the correct choice hopper to be illuminated and raised for 2 s when entered by the pigeon. For 3 pigeons, the right hopper was designated correct for Different displays and the left hopper for Same displays. This was reversed for the other 2 pigeons. Once a pigeon was consistently responding to the stimulus displays (120–400 trials), discrimination training was started.

Discrimination training. Discrimination training was instituted by simultaneously illuminating both the incorrect and correct hoppers following the presentation of a stimulus display. Each trial began with a peck to the ready signal, followed by presentation of a randomly generated Same or Different display, at which point the left and right choice hoppers were illuminated, allowing a choice to be made. The stimulus display remained visible until the pigeon made a choice. If the correct hopper was entered, it was raised for 2 s. If the incorrect hopper was entered, the hopper lights were turned off and the overhead houselight extinguished for 15 s. An 8-s intertrial interval (ITI) followed either outcome. Daily training sessions consisted of 128 discrimination trials. Each of the four display types was tested 32 times (16 randomly selected Same and

16 randomly selected Different trials [8 color and 8 shape, except for object displays]). The testing order of the 128 randomly selected displays was randomized every session.

A target-directed fixed response (TD-FR) procedure was used in presenting the stimulus displays. This procedure was first developed and used successfully by Cook et al. (1995). In this procedure, the pigeons were required to peck five times at the target of the Different displays to enter a trial's choice phase. Pecks to the distractor area of the Different displays were recorded but not counted toward completion of the TD-FR requirement. Because Same displays have no target area to peck, the number of pecks required to enter the choice phase of these trials was individually yoked to prior Different trials of that specific display type, so as to ensure that an equivalent number of pecks were made to each trial type. The number of pecks made on individual Different trials of each display type were kept in a push-down stack and used on the Same trials of that type as they were randomly scheduled to appear. If this stack was temporarily empty due to the chance randomization of trials, the mean number of responses during that particular session for previous Different trials of that display type was used instead. When a Same trial occurred first in a session, five pecks were required to enter the choice phase. During the initial training sessions only a single target peck was required on Different trials, and this was gradually increased over the next five to eight sessions, depending on the pigeon, to the final value of five target pecks. Training was conducted 6 days a week.

For addressing those issues related to task acquisition in the analyses below, we used the first 50 sessions of the training after the pigeons reached a TD-FR of two. This period was selected because all of the pigeons learned the discrimination within this time frame. We then used the next 30 training sessions, with some very minor changes in procedures (see the *Method* section of Experiment 2), to examine issues related to the steady-state processing of the display types as the pigeons appeared to have reached a stable level of discrimination over this time period. For a portion of these 30 sessions, transfer tests involving novel stimuli were conducted. These transfer test trials were excluded from the analyses presented below and are separately discussed in the Experiment 2. One final general note is that all statistical tests of the data in this article were evaluated using an alpha level of $p < .05$.

Results

Acquisition

How and in what way did the four different display types affect the rate of learning this same–different discrimination? The summary answer is that the pigeons showed little difficulty in learning this complex discrimination, with there being little or no influence attributable to the structural differences of the four display types. This can be seen in the upper left panel of Figure 2, which shows the mean learning curve for the separate display types over the 50 training sessions. A repeated measures analysis of variance (ANOVA; Display Type × 5-Session Block) of overall choice accuracy confirmed this conclusion, revealing a significant main effect of 5-session block, $F(9, 36) = 21.4$, but no significant main effect of display type, $F(3, 12) = 0.7$, or its interaction with block, $F(27, 108) = 1.2$. Apparently the distinct attributes of the four display types did not influence the rate of learning this choice discrimination.

Examination of the individual pigeons' data (the five

remaining panels of Figure 2) further supports this conclusion, as they show no consistent differences among the display types during acquisition for 4 of the 5 pigeons. Separate ANOVAs (Display Type × 10 Blocks [5 sessions in each]) of accuracy for each individual pigeon revealed no significant main effect of display type or its interaction with block, except in the case of one pigeon, Magic. Unlike the other pigeons, whose learning was gradual and incremental, Magic rapidly improved with all display types at one time, learning to perform the discrimination over just a few sessions after an initial period of chance performance. This rapid accuracy increase was simultaneously accompanied by the emergence of clear differences among the display types at this point (see *Posttraining Performance* below), and was responsible for the significant Display Type × Block interaction in this pigeon's data.

We next examined choice behavior separately for Same and Different trial types. The top panel of Figure 3 shows mean performance on Same and Different trials collapsed across display type. It shows that accurate choice responding for these two trial types emerged at different points during training, with increased correct responding on Same trials generally occurring about 15–20 sessions prior to an increase on Different trials. This was confirmed by an ANOVA (Trial Type [Same vs. Different] × 5-Session Block) of these data, which found a significant Trial Type × 5-Session Block interaction, $F(9, 27) = 3.9$. The middle and bottom panels show Same and Different responding, respectively, broken down by display type. A comparison of performance across the two panels shows that this difference between trial types occurred with each of the display types.

These lower two panels also contain another interesting feature of these acquisition data in that learning seemed to occur in two distinct phases with slightly different characteristics. The first phase occurred over the first 25 or so sessions during which the probability of a correct Same response gradually increased for all display types at the same rate, whereas there was little or no corresponding change in the probability of a correct Different response. The second phase occured over the last 25 sessions during which the probability of a correct Different response increased rapidly for all display types at the same time, at which point clear differences in the levels of correct Same responding emerged among the display types.

To examine these effects further we divided the data into two 25-session blocks and conducted a repeated measures ANOVA (Trial Type × Display Type × 25-Session Block). This ANOVA revealed a significant effect of block, $F(1, 4) = 33.5$, as accuracy was improving overall. There was also a significant Trial Type × Block interaction, $F(1, 4) = 8.0$, reflecting the earlier onset of correct responding on Same trials in comparison with Different trials. Finally, there was a significant Block × Trial Type × Display Type interaction, $F(3, 12) = 3.3$. This three-way interaction reflects the emergence of greater differences in the levels of correct Same responding as a function of display type over the two 25-session blocks than for corresponding levels of Different responding. This latter interaction can be understood by looking at separate ANOVAs (Display Type × 5-

Session Blocks) of Same and Different choice behavior within these two 25-session blocks. For just Same trials, there was no significant effect of display type or its interaction with blocks over the first 25 sessions. Correct responding simply increased for all display types at the same rate, $F(4, 16) = 6.6$. Given the chance-like levels of accuracy on Different trials over these first 25 sessions, it is not surprising that there was no significant effect in a similar ANOVA of this trial type. Separate ANOVAs for Same and Different displays over the last 25 sessions, however, revealed a slightly different picture. For Same trials, a significant effect of display type, $F(3, 12) = 5.4$, now emerged, but there was no main effect of block or its interaction with display type. For the Different trials, this analysis confirmed the general increase in accuracy over blocks, $F(4, 16) = 3.3$, for this time period. Although differences in the levels of Different responding as a function of display type also seemed to emerge at this point, especially with the feature display type (see lower panel of Figure 3), the main effect of display type was only marginally significant in this analysis.

Posttraining Performance

We next examined the succeeding 30 sessions of training to see if any and what types of display type differences might emerge following acquisition. A repeated measures ANOVA (Display Type × Trial Type × 6-Session Block) of choice accuracy during these posttraining sessions revealed no reliable effect of block or its interactions with display type or trial type, suggesting that the pigeons had indeed reached a relatively stable level of performance over these sessions. As hinted at by the analyses from the second half of acquisition above, the contrasting nature of the four display types did begin to have effects on the pigeons' choice performance once the task was learned, as indicated in this analysis by the presence of both a significant main effect of display type, $F(3, 12) = 5.9$, and a significant Display Type × Trial Type interaction, $F(3, 12) = 9.2$.

To help understand this latter interaction, Figure 4 shows the percentage of correct choices for each display type broken down by Same and Different trial type for both color and shape differences. For the texture displays, Same trial accuracy was higher than with the color Different displays, which in turn was higher than with shape Different displays. This is the same pattern as found by Cook et al. (1995). This pattern was reversed for Same and Different trials of the feature displays. In this display type the Same trials were responded to less accurately than the color Different and shape Different displays. For the geometric display type, Same trials supported lower levels of correct responding than color Different trials, with geometric shape Different displays supporting the lowest level of performance recorded in the experiment. In the case of the multidimensional object displays, the level of Same trial accuracy was the same as on Different trials. Lastly, analyses of the object display type as divided according to its categorical properties (birds and flowers) revealed no significant accuracy differences between displays made up of entirely just birds

(78%) or flowers (78%), or between different displays composed of objects drawn from the same category (bird in birds or flower in flowers = 77%) or from the two different categories (bird in flowers or flower in birds = 79%).

Discussion

Experiment 1 established that pigeons can readily learn a same–different discrimination even when being concurrently tested with four diverse sets of dissimilar display types. Moreover, no effects of the four display types were found on the rate and general pattern (Same responding improving prior to Different responding) of learning the discrimination, although differences in steady-state performance did emerge once the pigeons had learned the task.

The most important of these findings is the similar rate of learning seen across the four display types. It suggests that the pigeons were not independently learning four separate discriminations, but were learning a single type of discrimination that was applied to all of the different display types at the same time. The comparable ways in which the Same and Different components of the task were learned with each display type also point to a common foundation underlying all of performance. Because there was no simple relation between the perceptual features of the stimuli and their conceptual assignment as Same and Different displays, unlike Cook et al. (1995), the singular nature of this learned discrimination seems difficult to attribute to any simple feature-analytic account based on how the displays were perceived. Several competing alternatives for describing this single mechanism are considered later in the General Discussion.

We believe that the inherently smaller number of Same displays that can be formed in any same–different discrimination may be responsible for the initially higher accuracy observed with Same trials. Despite their considerable number, the Same displays had to be repeated more frequently than Different displays in the present experiment. This repetition may have encouraged the pigeons to initially try to memorize their responses to these specific displays. Depending on how the Same displays are counted, their quantity was within the range of items that pigeons have been shown to be able to memorize (Vaughan & Greene, 1984). Of course, this memorization strategy would fail, or at least be very difficult and time consuming, when applied to the other half of the present discrimination involving the very large number of Different displays. This difficulty may have forced the pigeons to give up on this first approach and switch to a more conceptual-based strategy at a later point in training.

The difference in the pigeons' reactions to the Same and Different displays at various points during training offers some evidence for this kind of conjecture (see Figure 3). For instance, during the early stages of acquisition, the rates and levels of correct responding for all four types of Same displays were basically identical, perhaps reflective of the pigeons' initial strategy of trying to memorize each of these displays and their associated responses. Only with the later recognition of the common relational property that united

the vast numbers of Different displays did the pigeons begin responding accurately to these types of trials. It may be significant that at the pivotal juncture in training where this recognition seemed to occur with Different displays, differences in the pigeons' performance with the Same displays of each display type also begin to emerge. This may signal the point at which the pigeons were forced to reorganize their working representation of how to process and treat the Same displays, shifting from an exemplar-based to a rule-based strategy in the processing of this trial type. Although these speculations about the acquisition of this same–different task must remain tentative, the comparable rate and pattern of learning across all of the display types nevertheless argues that, whatever its form, the same mechanism was being used to discriminate all of the multiple classes of stimuli.

Whereas the separate display types had little impact on the learning of the task, differences did emerge in the pigeons' reactions to a display upon its solution. These steady-state differences most likely reflect the perceptual differences that surely existed among the display types. For instance, the analyses of the postacquisition data suggest that the local differences present in the feature displays did make a slight contribution to the pigeons' same–different judgments of this display type. In comparison with the texture displays, the feature displays supported slightly higher levels of Different responding and lower levels of Same responding. Given their otherwise identical global organization, this relative trade-off between Same and Different responses suggests that the local differences in the feature displays were not being entirely ignored. Despite this, the high level of accuracy with this display type verifies the spatially global nature of the discrimination learned by the pigeons. This point is similarly made by the high accuracy with the object display type as well.

Experiment 2

Although the similar rate and form of learning over the separate display types in Experiment 1 strongly indicate the acquisition and application of a single common rule, they provide only indirect evidence concerning whether this rule would generalize to novel stimuli. In one sense the pigeons probably did transfer to novel stimuli almost daily, because even well into training some of the Different displays of each session would have been by chance not previously tested (see Cook et al., 1995, for concrete evidence of this kind of transfer in their experiments). Nevertheless, we next examined discrimination transfer to novel exemplars of each display type to provide direct evidence for the use of a generalized rule. If a single generalized rule was indeed being used, then the pigeons should show positive transfer across all four display types. On the other hand, if the pigeons failed to transfer to one or more of the display types, then it would suggest instead that different, nongeneral, discrimination rules had been learned for one or more of the display types.

Because of the scope of the concurrent stimulus discriminations being tested in this task, a series of transfer tests was conducted. This was done to avoid disrupting the pigeons'

performance by introducing too much novelty at one time. The first test (Test 1A) examined transfer to novel texture and feature displays involving both the color and shape dimensions. This was done to replicate and extend the exclusively texture-based same–different transfer reported by Cook et al. (1995). Successful transfer in this test would ensure that the present pigeons were performing at least the same kind of discrimination as reported in that study. One major change from Cook et al.'s (1995) procedure was that responses on novel transfer trials were not reinforced in this experiment. The second test (Test 1B) examined transfer to novel geometric (both color and shape dimensions) and novel object displays composed from images of new birds and flowers. The last two tests (Tests 2A and 2B) further investigated the positive discrimination transfer found with the object display type in Test 1B. As such, the third test (Test 2A) replicated this transfer with another new set of bird and flower images. The fourth test (Test 2B) extended this by examining the pigeons' transfer to images from two new pictorial categories (humans and fish).

Method

Animals and Apparatus

The pigeons and apparatus were the same as in Experiment 1.

Procedure

Transfer Test 1A. The first transfer test examined discrimination with novel texture and feature display types composed from novel color and shape values. The test was conducted 5 days after the last pigeon reached a criterion of 72% overall accuracy with each display type. In the sessions just prior to the transfer tests the number of daily trials was increased to 160, now consisting of 40 trials (20 Same, 20 Different) with each display type. Also, in preparation for the upcoming nonreinforced transfer tests, a random 5% of the baseline trials had no consequence scheduled for either correct or incorrect responses. Such trials merely ended after a choice with the start of the next ITI.

Transfer testing consisted of three sessions. For each session, 16 scheduled trials were replaced at random by transfer test trials. Following a 30-trial warm-up period at the beginning of each session involving randomized selections of the four display types, the transfer trials randomly occurred within the remaining trials of a session. Each session's 16 transfer trials consisted of eight novel texture displays (four Same displays, four Different displays [two color, two shape]) and eight novel feature displays (four Same displays [two color, two shape], four Different displays [two color, two shape]).

The test displays were built from the combinations of three novel color values (pink, gray, and aquamarine) and three novel shape values (star, plus sign, and two closely spaced dots). Each session tested displays created from different combinations of two of the three values from each dimension (e.g., pink and gray; gray and aquamarine; pink and aquamarine; star and plus; star and dots; dots and plus). In a session, these color and shape combinations were then tested in combination with each of the two values of the other dimension for that session. Each dimensional value was tested once in the target role and once in the distractor role. Each session's four novel Same texture displays were simply constructed from the four color and shape combinations used that day. The four novel Same

feature displays tested each value once as the globally uniform attribute and each value twice as the locally irrelevant attribute. This combinatorial procedure resulted in the transfer displays for all sessions being completely novel, except for the need to repeat three of the Same displays once across the three sessions for the texture display type. The spatial organization of these transfer displays was identical to the baseline texture and feature displays. The identical TD-FR response requirement was used with the transfer trials as with the baseline trials. Choice responses on transfer trials were neither reinforced nor punished.

Because of the inherently greater number of Different displays that can be generated, it was necessary to repeat some of the Same displays over sessions in this and the other transfer tests described below. Because we did not initially reinforce choices on any of the transfer trials, any effect of this repetition could only be in a direction that would underestimate the level of the successful transfer. Nevertheless, we separately examined this specific issue and found no effect of repeating novel Same displays across sessions for any of the experiments reported in this article. As such, the analyses reported used all collected nonreinforced transfer observations.

Transfer Test 1B. The second test examined discrimination transfer to novel geometric and object display types and was conducted immediately following the completion of the first one. This test also consisted of three 160-trial sessions organized like in Test 1A. Each session's 16 transfer trials consisted of eight novel geometric displays (four Same displays, four Different displays [two color, two shape]) and eight novel object displays (four Same displays, four Different displays). The same three transfer shapes (proportionally enlarged) and colors used in Test 1A were used to make the novel geometric displays of this test, as the pigeons had not experienced any differential reinforcement for these dimensional values at this point. The construction of the novel geometric displays followed the same procedure as used with the texture displays in Test 1A, except that a slightly different subset of Different displays was tested by changing the identity of the irrelevant dimensional value used for each session relative to Test 1A. For the novel object displays, two new bird (bunting, chukar) and flower (gloxinia, bachelor) pictures were used. Over the three test sessions each novel picture was tested once in pairwise combination with each of the other three pictures, once in the role of the target and once in the role of distractor. The same set of four possible novel Same object displays were retested across the three test sessions.

Upon completion of Test 1B, the novel displays used in Tests 1A and 1B were retested, but choice responses were now differentially reinforced. This differential reinforcement test lasted three sessions with 32 transfer trials (8 of each display type) tested in each session. The results were identical to those of Tests 1A and 1B and are only briefly considered below.

Transfer Test 2A. Test 2A examined only transfer with novel object displays. It immediately followed the differential reinforcement test of the transfer stimulus sets used in Tests 1A and 1B. By using the same combination procedure as in Test 1B, each 160-trial session tested four Different and four Same object displays created from two new pictures of birds (mallard, rosela) and flowers (chinesel, bflower). A fourth session retested all of the 24 transfer trials (12 Different displays, 3 repetitions of the 4 Same displays), but with differential reinforcement for correct and incorrect choice responses.

Transfer Test 2B. Test 2B examined discrimination transfer to novel object displays involving four pictures selected from each of two novel categories, human figures (ftballp2, fin_line) and fish (banded, longnose), and the two familiar categories, birds (lovebird, cardinal) and flowers (crocus, hollyhoc). It was conducted 3

weeks after Test 2A and lasted 12 sessions. Again, each daily session consisted of 160 randomly constructed trials (40 of each display type), with 8 of these trials randomly replaced by transfer trials (four Same displays, four Different displays). Across the 12 sessions, the four Different displays tested in each session were unique with regard to the different combinations of pictures and their target and distractor role. Altogether, these Different displays tested combinations of pictures drawn from the familiar categories (bird and bird; flower and flower) or the novel categories (fish and fish; human and human) or from combinations of target and distractor pictures from across these categories (bird and flower, bird and fish, bird and human, flower and fish, flower and human, fish and human). Because there were only 8 novel Same trials in total it required that each of them be retested six times across the 12 sessions. As mentioned, this repetition had no discernable effect on performance. Choice responses on transfer trials were not reinforced.

Results

Transfer Tests 1A and 1B

Because their goals and analyses were similar, the separately collected results of Tests 1A and 1B are combined in this section. The results are simple to summarize. Each display type supported significant discrimination transfer. The transfer results from the two tests are displayed in Figure 5, which shows mean choice accuracy on Same and Different trials for both the baseline and novel transfer trials for each display type. Mean transfer accuracy across all display types was 70%, and was found to be significantly above the chance expectation of 50%, $t(4) = 6.16$. Overall, the pigeons had a greater tendency to accurately perform with novel Same displays (76.3%) than with Different displays (64.4%). Separate analyses of same–different accuracy with each display type confirmed the presence of significantly greater than chance transfer in each case, all four $ts(4) > 3.18$. Individually, all of the pigeons showed good transfer averaged across all the display types (Astro = 74%; Barkley = 77%; Judy = 74%; Magic = 58%; Rosie = 69%). When analyzed by dimension, (texture, feature, and geometric display types only), transfer accuracy with novel color displays (74%) was slightly, but not reliably, greater than with novel shape displays (66%), and both dimensions individually supported above chance transfer for all three display types, all six $ts(4) > 3.18$.

The mean level of transfer accuracy neither declined nor improved over successive sessions within a test, as revealed by separate repeated measures ANOVAs (Sessions × Baseline/Transfer Condition × Display Type) of accuracy in Tests 1A (feature and texture only) and 1B (geometric and object only). These ANOVAs found no significant main effects of sessions, $Fs(2, 8) < 1$, or its interaction with condition, $Fs(2, 8) < 1$, in either of the tests. These analyses did confirm, however, that both tests showed evidence of generalization decrement, as transfer trial accuracy was found to be reliably lower than baseline trial accuracy, $Fs(1, 4) > 14.2$. Finally, the data from the reinforced presentations of these identical transfer trials done after the completion of Test 1B were virtually identical to those just described. Mean transfer accuracy for each display type over these

three reinforced sessions was texture = 68%, feature = 70%, geometric = 63%, object = 73%.

Transfer Tests 2A and 2B

Tests 2A and 2B were conducted with only novel object displays. The results of Test 2A with new bird and flower pictures replicated those of Test 1B. In this second round of testing, the pigeons were again significantly above chance with the unreinforced novel object displays (67%), $t(4) = 4.1$. This value did not reliably differ from the mean accuracy observed with baseline object displays (78%), $t(4) = 1.6$. There was no difference in the degree of transfer observed with the Different (69%) and Same (66%) object displays.

The results for Test 2B were similar. The pigeons were significantly above chance on the unreinforced novel object displays (69%), $t(4) = 4.3$, but this time the value was reliably below accuracy on baseline object displays (80%), $t(4) = 3.8$. Of more interest in this test was the absence of any pattern in these data that might be attributed to the categorical identity of the object pictures. First, the relative familiarity of the categories made little difference, as mean transfer accuracy with novel displays formed from only familiar categories (birds and flowers) was 67%, whereas with unfamiliar categories (humans and fish) it was 70%. Second, it did not matter on Different trials whether the target–distractor picture combinations were drawn from different categories or not, as mean accuracy with displays formed from pictures from the same category (69%) was not reliably different from those formed from different categories (69%).

Discussion

The most important result from this experiment was the clear evidence of above chance levels of transfer to novel exemplars of all four display types. The results for the texture display type replicate Cook et al.'s (1995) with a new set of pigeons, whereas the results for the geometric, feature, and object displays are new. These transfer results specifically rule out the already unlikely possibility that this learned discrimination was based on learning stimulus-specific response associations or rules for the entire set of training displays (e.g., Carter & Werner, 1978). Likewise, the results also rule out the possibility that the original discrimination was based only on judgments of the relative novelty of the Same and Different stimuli (e.g., Macphail & Reilly, 1989; see Cook et al., 1995, for a detailed discussion of this issue).

What was the basis for this positive transfer? Because it was observed across a wide variation in display types and configurations, it suggests a rule with a fair degree of scope and flexibility. As argued above, no single or simple perceptual attribute shared in common across the displays seems sufficient to account for these transfer data. Rather, the broad extent of the transfer across the display types argues for a more abstract property, one shared in common across the dissimilar display types. We think the most likely

explanation is one based on the global identity and nonidentity of the element relations in the displays. As such, we propose that the most parsimonious interpretation—of both the equivalent rate of discrimination learning across the display types and the breadth of positive transfer found in these experiments—is that the pigeons developed and used a single generalized same–different rule applied to all displays simultaneously.

Additional clues to the structure of this generalized rule come from the pattern of transfer results with the object displays. Given their basic similarity to the bird, flower, fish, and human images that pigeons have been shown to categorize (Bhatt, Wasserman, Reynolds, & Knauss, 1988; Cook, Wright, & Kendrick, 1990; Herrnstein & de Villiers, 1980; Herrnstein & Loveland, 1964; Roberts & Mazmanian, 1988), we had expected that discrimination among items from the same categories might be more difficult than discrimination of items between different categories. Neither during training nor during transfer, however, was there any evidence that *within-category* object displays were any harder to discriminate than *between-category* object displays. This result suggests that these pictorial stimuli were not being viewed as representatives of object-based categories. What then was the basis for the discrimination of these object displays?

To answer this question we conducted a hierarchical cluster analysis of the pigeons' performance with the object displays. Cluster analysis is one of several widely used multivariate techniques for detecting and modeling the psychological similarities that exist within a data set. Such techniques have been highly useful for illuminating the stimulus structure controlling an animal's behavior in a variety of discrimination tasks (Blough, 1985, 1988, 1990; Matsuzawa, 1990; Tomonaga & Matsuzawa, 1992; Sands et al., 1982). In fact, one of the advantages of the present same–different task is that it readily provides a measure of perceived similarity among sets of images. Our analysis was performed on 100 sessions of baseline performance collected soon after the completion of Experiment 2. During these additional sessions we continued to expand the pool of object images presented to the pigeons. By the end of this time, the pigeons were being tested regularly with 32 object pictures (12 birds, 12 flowers, 4 humans, and 4 fish). Because the human and fish pictures had only been added toward the end, however, the number of pairwise observations involving these images was fairly limited and they were not included in the analysis described next. From these 100 sessions, we computed the average performance across the 5 pigeons for each pairwise combination of object pictures and then submitted these values to a cluster analysis by using the average method (SPSS software package, 1995). Figure 6 shows the final clustering solution for the 12 bird and 12 flower images. Its structure is easily interpreted. Three major clusters of perceived similarity were identified. One cluster forms around those pictures best characterized as having a bluish coloration, a second centers around images having a reddish-brown cast, and a third forms around images involving combinations of greens and yellows. Thus, like the above analyses, this one provides no

evidence of any object-based categorical encoding of these images. That is, the natural divisions we see and semantically label as birds and flowers were not being used by the pigeons. Rather, these complex compound stimuli seem to be primarily discriminated along the globally dominant color or pair of colors present in each picture.

Why were these pigeons not sensitive to the object-based categorical structure of these stimuli? There is nothing inherent about these particular stimuli that should have prevented such an outcome, because both categories have been shown to support this type of psychological organization in other settings (Bhatt et al., 1988; Cook et al., 1990; Ryan & Lea, 1994). One very likely possibility could be the dimension-analytic "instructions" provided to the pigeons through the other display types. In the present setting, all of their concurrent experience with the feature, texture, and geometric display types provided explicit reinforcement for attending to exactly this type of dimensional information, perhaps resulting in the overshadowing of the object-based categorical information present in these images. In addition, the reinforcement contingencies used here would have similarly functioned to discourage the pigeons from weighting the categorical aspects of the displays as well, because attending to category membership would have been specifically punished in this context (e.g., choosing *same* to a display combining a gamehen within a set of bluebirds).

Despite these caveats, research with pigeons has repeatedly demonstrated their capacity to categorize a wide variety of pictures composed from object classes and scenes (Bhatt et al., 1988; Herrnstein, Loveland, & Cable, 1976; Lubow, 1974) and artificially constructed categories (Huber & Lenz, 1993; Lea & Harrison, 1978; Pearce, 1989). As Fetterman (1996) nicely reviews, however, there is little evidence to support the "common if tacitly held assumption that animals perceive some correspondence between photographs of objects and the objects themselves" (p. 8). Further, he adds that "although it is common to describe complex discrimination involving photographs in terms of the conceptual language game of the human species, such descriptions are probably premature, and potentially misleading" (p. 8). The present results with these "object" stimuli fit this sentiment (see also Cook, 1993a; D'Amato & Van Sant, 1988). Although more research is needed regarding this issue, the present object display results would certainly counsel caution in making categorical interpretations of results collected with colored pictorial stimuli.

General Discussion

The major finding of the present experiments concerns the relative ease and flexibility demonstrated by these pigeons in performing a complex and demanding same–different discrimination. This discrimination required them to concurrently process very large numbers of highly variable, often ill-defined, multidimensional elements configured in four different ways. In Experiment 1, the pigeons showed little difficulty in acquiring these different display type discriminations, learning to classify the Same and Different displays of all four display types at the same rate and in the same way. In

Experiment 2, they readily transferred this discrimination to new exemplars of each of the four display types. These results expand considerably on those reported by Cook et al. (1995), which were limited to investigations of only the texture display type. Of most importance in this regard is that these new training and transfer results suggest that low-level perceptual factors are not critical to producing the type of discrimination behavior observed in multielement same–different experiments (see Young, Wasserman, & Dalrymple, in press, for a similar conclusion based on a temporally based manipulation of Wasserman et al.'s, 1995, same–different discrimination). If this type of discrimination behavior is not based exclusively on simple perceptual factors, what then is the abstract basis for this complex discrimination by the pigeons?

Cook and Wixted (1997) recently tested the applicability of using a signal detection framework to better understanding pigeon choice behavior in Cook et al.'s (1995) textured same–different procedure. Of direct relevance to the present discussion, Cook and Wixted's signal detection analyses strongly suggested the pigeons discriminated Same texture displays from shape, color, and redundant Different displays by using only a single type of information or evidence. That is, regardless of what dimension (shape, color, or redundantly from both dimensions) the Different display's contrast was made from, the pigeons seemed to base their choices on only a single common unidimensional encoding of the target information in the displays. To acknowledge the possibility that either perceptual or conceptual interpretations of this common code were possible in this texture-only context, Cook and Wixted neutrally labeled this unidimensional evidence variable as "degree of difference." Although the same type of signal detection analyses remains to be extended to the current testing context, Cook and Wixted's unidimensional interpretation is highly consistent with the proposed hypothesis that the current pigeons deployed only a single rule to discriminate the four sets of stimuli tested here. One straightforward interpretation of this similarity is that the pigeons in both cases were using a singular abstract same–different rule. But before accepting this conclusion, however, at least one other unidimensional alternative should be considered.

Young and Wasserman (1997), following up on Wasserman et al.'s (1995) observations, recently proposed a new unidimensional alternative for what the pigeons might be processing in this type of choice task. Instead of using an abstract same–different concept, these authors presented evidence suggesting their pigeons were responding to the perceived *entropy* in their icon-based Same and Different displays. Entropy is an information-theoretic concept that measures the amount of variability present among a display's component elements. A display in which all of the elements are identical (i.e., a Same display) has an entropy of zero, for example. In contrast, a display in which every single element is different from every other one (the kind of Different display tested by Wasserman et al., 1995) has the maximal possible entropy for that particular organization. In a series of experiments, Young and Wasserman (see also Young, Wasserman, & Garner, 1997) systematically varied

the number and nature of the elements used to create different types of Same and Different displays. They found that the amount of variability in these displays as described by entropy correlated quite highly with the proportion of *different* and *same* responses made by the pigeons. Given this, could this alternative unidimensional hypothesis account for the discriminations tested in Cook et al. (1995), Cook and Wixted (1997), and the present experiments? That is, could these pigeons have learned to treat the two choice hoppers as representing low and high values of display entropy rather than as Same and Different choice alternatives? Because they only used a single display type, an entropy-based account of Cook et al. (1995) and Cook and Wixted (1997) is not at odds with any of their findings.

An entropy-based account of the present experiment's results, however, is considerably more problematic. Young and Wasserman's method for computing entropy is keyed to the number of different types of elements present in the display (Young & Wasserman, 1997, Equation 1). Although this works well for describing their particular icon-based displays, it has some problems when applied to the separate display types tested here. By using their formula, for instance, it turns out that the computed entropy for the Same feature displays (entropy value = 1) is actually larger than for any of the Different displays of the other three display types (values between 0.59–0.65). This greater entropy in the feature displays is directly due to the presence of the irrelevant local variation among its elements. As such, if the pigeons were learning to respond simply on the basis of the entropy of component elements in the displays, then the resulting incompatible mapping of the feature display's entropy values relative to the other three display types should have made this former display much harder for the pigeons to learn about. This clearly was not the case.

Far more problematic for an entropy-based analysis of the present task are subsequent observations collected from these same pigeons when we varied the number of distractor elements in the object and geometric displays. In this experiment, we introduced and tested two new display organizations. In addition to the standard 3 × 2 organization, we tested 2 × 2 and 3 × 1 stimulus arrays of the geometric or object elements. Like before, the difference between Same and Different displays consisted of the presence and absence of a single odd target item. For all three of these organizations, the entropy of their Same displays is zero. But for the Different displays, the entropy is greatest in the 3 × 1 array (one target and two distractors; entropy = 0.91), intermediate for the 2 × 2 array (one target and three distractors; entropy = 0.81), and smallest for the 3 × 2 array (one target and five distractors, entropy = 0.65). Thus, if the pigeons were responding only to entropy, the proportion of different responses should be highest to the 3 × 1 arrays, followed by the 2 × 2, and then the 3 × 2 arrays. Figure 7 shows the mean results for 38 sessions testing these three display organizations. They were collected about 6 months after the completion of Experiment 2. The figure shows that the pigeons continued to respond accurately to the Same displays regardless of the number of elements, but showed a systematic decline in Different responding as the number of
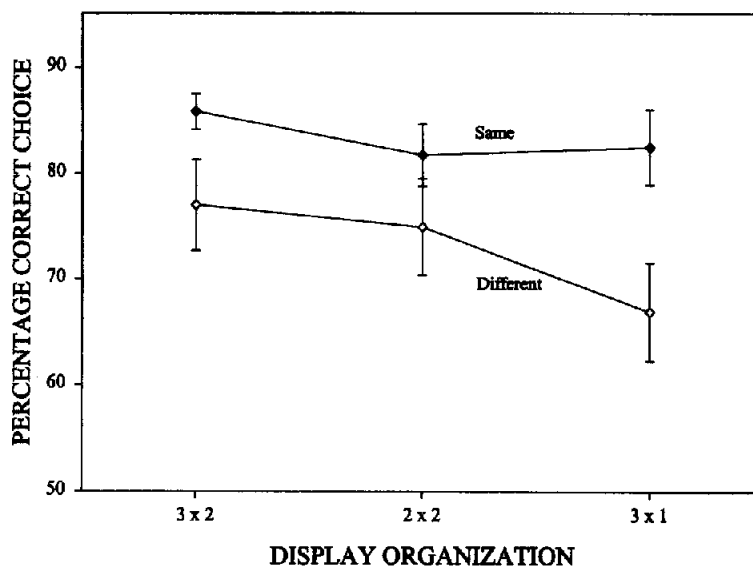
Figure 7. Mean choice accuracy for Same and Different displays as a function of display organization.

distractors in the array decreased. This difference was confirmed by a significant Trial Type × Display Organization interaction, $F(2, 8) = 6.8$, in these data. This outcome is directly opposite the one predicted by an entropy-based account of the discrimination. Rather, this pattern suggests that the present pigeons were being more strongly influenced by the relative oddity of the target in these displays (see Blough, 1989, for a similar result).

Thus, the collective pattern of results suggests that neither an entropy-based nor a perceptually based account can easily accommodate the entire set of same–different findings reported here. We propose that the most parsimonious unidimensional interpretation is that the pigeons used a single abstract same–different rule in processing each of the four display types. The acceptance of this conclusion carries the further implication that the pigeons in Wasserman et al. (1995) and Cook et al. (1995) may have learned different rules for dealing with what looked like otherwise quite comparable tasks. Perhaps because Wasserman et al. (1995) used Different displays containing the largest possible number of contrasting icons (16 different icons in a 4 × 4 array), their pigeons were more sensitized to the variability or entropy dimension in their displays. In contrast, Cook et al. (1995) and the current study used dimensional differences that resulted in generally smaller entropy differences between the Same and Different displays and which were always embodied as spatially localized contrasts, factors that may have promoted a more oddity-based evaluation of the identity relations in these displays.

In sum, the present acquisition and transfer results provide some of the strongest evidence yet collected for the existence of the ability in pigeons to learn a generalized same–different concept, at least as mediated by global differences in the color and shape dimensions. The present multiple-class same–different task will also provide an

excellent vehicle for the study of many fundamental questions about avian visual cognition, such as the relation between visual grouping and visual search, the identification of fundamental visual features, their multidimensional integration, and how these integrated features eventually become perceived as the visual objects that appear to control avian behavior in the wild. The answers to such questions will form an important advance toward a unified comparative theory of visual cognition in human and nonhuman animals.

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Dannemiller Appointed Editor of *Developmental Psychology*, 1999–2004

The Publications and Communications Board of the American Psychological Association announces the appointment of James L. Dannemiller, PhD, University of Wisconsin, as editor of *Developmental Psychology* for a 6-year term beginning in 1999.

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