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Two-item *same-different* concept learning in pigeons

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We report the first successful demonstration of a simultaneous, two-item *same-different* (S/D) discrimination by 6 pigeons, in which nonpictorial color and shape stimuli were used. This study was conducted because the majority of recently successful demonstrations of S/D discrimination in pigeons have employed displays with more than two items. Two pairs of stimulus items were simultaneously presented on a touch screen equipped computer monitor. Pigeons were reinforced for consistently pecking at either the *same* (i.e., identical) or the *different* (i.e., nonidentical) pair of items. These pairs were created from combinations of simple colored shapes drawn from a pool of six colors and six shapes. After acquiring the discrimination with item pairs that differed redundantly in both the shape and the color dimensions, the pigeons were tested for transfer to items that varied in only one of these dimensions. Although both dimensions contributed to the discrimination, greater control was exhibited by the color dimension. Most important, the discrimination transferred in tests with novel colored, shaped, and sized items, suggesting that the mechanisms involved were not stimulus specific but were more generalized in nature. These results suggest that the capacity to judge S/D relations is present in pigeons even when only two stimuli are used to implement this contrast.

One hallmark of human intelligence is our ability to use abstract concepts to classify the relations among objects and events in the world. The power of human language is based on our ability to construct open-ended categories and utilize relational rules. Comparative psychologists have long sought to understand the types of intelligence other species share with us (Cook, 2001; Darwin, 1897; Wasserman, 1993), which may provide insight into the mechanisms of intelligence in both human and nonhuman animals. In recent years, our research has focused on how pigeons perceive and conceptualize the regularities associated with *same* and *different* (S/D) relations among sets of visual items.

Zentall and Hogan (1974, 1976, 1978) provided some of the earliest demonstrations of S/D conceptual behavior in pigeons, using the matching-to-sample and the oddity-from-sample tasks. In Zentall and Hogan (1974, Experiment 1), pigeons were trained either to select a comparison color (e.g., red) that matched the sample color (red; matching-to-sample task) or to select the non-matching comparison (e.g., green; oddity-from-sample task). After training on one set of colors (red and green), the pigeons were then trained on a novel pair of colors

(blue and yellow). Of the pigeons that were trained on the matching task with red-green stimuli, half were trained on a matching task with blue-yellow stimuli, whereas the rest were trained on the oddity task. Likewise, half the pigeons trained to select the odd color initially were trained on the oddity task with the new colors, whereas the rest of the pigeons were shifted to the matching task. The pigeons that had received the same type of training for both discriminations acquired the blue-yellow discrimination more rapidly than did the birds that had been shifted. This savings effect suggests that the pigeons acquired the concept of identity or oddity during the first training phase, which then transferred to the second training phase. Subsequent experiments extended this result for transfers across discriminations of color, brightness, and shape.

Premack (1983) criticized this work on the basis that matching-to-sample may be solved on the basis of similarity. He suggested that the two-item S/D task is better suited to studying conceptual behavior because solutions to S/D judgments require the use of an abstract code. In an S/D task, the subject has to respond *same* when a set of stimuli are identical and *different* if one or more of the stimuli are different from the others. After this discrimination has been learned, the degree to which this behavior transfers to novel situations having *same* and *different* relations is taken as evidence of concept formation. Although pigeons have been shown to transfer matching behavior to novel exemplars or dimensions (at least as assessed by a savings

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effect on acquisition; see, e.g., Zentall & Hogan, 1974, 1976, 1978), until recently it has proven quite difficult to show generalized S/D behavior in the pigeon.

A handful of mixed reports suggest that pigeons may be able to solve a two-item S/D discrimination. Santiago and Wright (1984) successfully trained 2 pigeons to make an S/D choice with fixed sets of color slides. On each trial, two slides were presented on the display, and the pigeons were reinforced for pecking one key when the pictures were identical and another key when they were different. Following training, the pigeons were tested with transfer trials in which novel pictures were used. Their performance was significantly above chance (averaging around 60%–65%), suggesting that two pictures are sufficient for generating an S/D concept. One problem with this study was that there was also abundant evidence of item-specific learning during the acquisition of this task (see Wright, Santiago, & Sand, 1984, for further explorations of this issue). Wright (1997, 2001) has since established that there is a tradeoff between item-specific learning and conceptual learning strategies, and thus their transfer results may have underestimated the degree of concept formation. An additional concern was that transfer trials appeared to have been directly substituted for baseline trials in a fixed sequence of *same* and *different* trials that was used repeatedly each session. This procedural detail further complicates the interpretation of the transfer results, since any contribution related to memorizing the fixed order of right–left responses would have inflated their estimates of discrimination transfer (Wright et al., 1984).

Edwards, Jagielo, and Zentall (1983) trained pigeons to make one response when shown a pair of matching shapes (a plus or a circle) and another response when this pair of shapes was different. The pigeons showed no evidence of first-trial transfer to colored stimuli but did show savings in learning the color task in comparison with a group for which the response contingencies had been reversed. Similar results were obtained in a second experiment in which combinations of steady/intermittent flashes of white light were used. Besides the poor immediate transfer, their study was complicated by the need to use only a limited subset of different configurations during training (e.g., plus–circle was used, but not circle–plus). When these withheld *different* configurations were eventually tested, the pigeons strongly responded on the *same* key. This indicates that performance here was being controlled by item-specific associations, and not by the item relations. Nevertheless, the savings in subsequent acquisition do suggest some contribution of a conceptual representation to the task. However, Wilson, Mackintosh, and Boakes (1985, Experiment 3) failed to find any evidence for conceptual transfer in pigeons with a similar procedure, and Pearce (1988) found no evidence for relational learning with a go/no-go procedure involving discriminations of bar height.

Although it has been difficult to demonstrate that pigeons can generalize an S/D discrimination involving two-item displays to novel exemplars, displays involving

S/D relations among larger sets of items have been more successful. For instance, we have found that pigeons are capable of learning and applying an S/D concept across a wide variety of simultaneously presented visual items (Cook, 2002a, 2002b; Cook, Cavoto, & Cavoto, 1995; Cook, Katz, & Cavoto, 1997; Cook, Katz, & Kelly, 1999; Cook & Wixted, 1997) and successively presented items (Cook, Kelly, & Katz, 2003). In these studies, pigeons have been shown to learn an S/D classification with up to five different multidimensional classes, ranging from smaller, densely packed textural elements (i.e., items) to more sparse arrays of geometrics, objects, and photographs (Cook, 2002a; Cook et al., 1997; Cook et al., 1999; examples of these different stimulus classes can be seen in the articles and on line at www.pigeon.psy.tufts.edu). Furthermore, the pace of S/D learning with these different stimulus classes proceeds at the same rate, suggesting that the same common discrimination framework or decision criterion is applied across all of these distinct types (Cook, 2002a; Cook et al., 1997). In addition to learning a single, broadly applied rule, we have consistently found that pigeons can transfer this solution to novel exemplars from both within (Cook et al., 1995; Cook et al., 1997) and outside (Cook et al., 1999) the range of stimuli experienced during training. Recently, we found that they can also learn and transfer this behavior when trained and tested with successively presented photographic and video stimuli (Cook et al., 2003). As a whole, these results seem most consistent with the hypothesis that pigeons can detect, recognize, and abstract S/D visual relations in a variety of different test procedures.

One key issue with these findings, however, is that multiple items have consistently been used in making the S/D contrasts. In Cook et al.'s (1997) tests, for example, the displays consisted of 3×2 arrays of larger colored shapes, photographs, or pictures, with a single item being either the same as or different from the remaining five items, or 24×16 arrays of small, colored shape elements (i.e., items), with a small 8×7 block of elements that was either the same as or different from the background in terms of color or shape.

Similarly, Wasserman, Hugart, and Kirkpatrick-Steger (1995) and Young, Wasserman, and Garner (1997) have used S/D displays consisting of multiple items. In their research, pigeons were tested with simultaneous or successive presentations of either 16 small icons that were the same or 16 small icons that were completely different, after which the animals were required to make a *same* or a *different* choice response. Young and Wasserman have consistently found that this type of multiple-item training results in the pigeons' coming to be controlled by item variability, or the *entropy* of the displays, rather than by a true S/D concept (e.g., Young et al., 1997; Young, Wasserman, Hilfens, & Dalrymple, 1999). Regardless of the exact mechanisms involved, both of these lines of S/D research have the common factor of using multiple items that are the same or different in creating their displays.

This markedly contrasts with the study of S/D behavior in Haplorhine primates (D'Amato, Salmon, & Colombo, 1985; Oden, Thompson, & Premack, 1988, 1990; Premack, 1971, 1976; Sands, Lincoln, & Wright, 1982; Wright et al., 1984), which typically involves only two items that are the same or different. Of the nonprimate species tested, only a few birds, such as parrots (Pepperberg, 1987) and corvids (Wilson et al., 1985), and cetaceans, such as dolphins (Herman, Pack, & Morrel-Samuels, 1993; Mercado, Killebrew, Pack, Macha, & Herman, 2000), appear to transfer two-item S/D discriminations to novel stimuli. This reliance on more complex, multi-item displays raises the issue of whether the pigeons are performing the S/D discrimination in the same way as primates. The natural question is, therefore, whether pigeons can also discriminate S/D relations with only two items, or whether multiple items are always necessary for demonstrating successful transfer results in these S/D designs?

In this article, we report a new procedure that successfully demonstrates two-item simultaneous S/D discrimination and transfer in pigeons. The task involves simultaneously presenting two sets of paired items on the computer screen, with each pair consisting of two colored shapes.¹ One pair of these colored shapes was identical, whereas the other pair differed in both the color and the shape of each item. For example, the pigeons might see two red circles on the left side of the screen and a yellow square and a blue chevron on the right side of the screen (Figure 1). The task for each pigeon is to consistently choose the *same* or the *different* pair to obtain food reinforcement (3 pigeons had to peck at the *same* pair, and 3 had to peck at the *different* pair). After learning this simultaneous S/D task, in Experiment 1 we tested for conceptual transfer by examining performance with novel colors, and in Experiment 2 we tested the pigeons with novel shapes. Some aspects of our procedure that

may have contributed to successful transfer are that we employed more training exemplars, increasing the overall set size, and varied the stimuli on two dimensions (color and shape), rather than on one. Furthermore, our pigeons were required to respond directly to the correct stimulus, rather than to a separate response key, which may have promoted greater attention to the features of the stimuli.

EXPERIMENT 1

In the first experiment, 6 pigeons were trained to discriminate pairs of items that were the same or different. On each trial, a *same* pair and a *different* pair of items were presented on the right and the left halves, respectively, of the display (counterbalanced across trials), with a large space between them so that they would be perceived as separate pairs of stimuli. Three pigeons received reinforcement for selecting the *same* pair on the display, whereas the remaining 3 pigeons were reinforced for selecting the *different* pair. To increase the chances of successful acquisition, the stimuli of the *different* pair redundantly differed in both color and shape during initial training.

Following acquisition, two tests were conducted. Because training was done with redundant compound stimuli that varied in both color and shape, the first test examined how each of these dimensions contributed to discrimination. To examine this, we transferred the pigeons to an exclusively *shape-different* condition (e.g., two red circles vs. a red square and a red star) and an exclusively *color-different* condition (e.g., two red circles vs. a blue circle and a yellow circle). These tests were done using familiar colors and shapes from training. To test for evidence of relational control, in the second test we examined discrimination transfer to novel color stimuli. The color dimension was tested first, because this dimen-

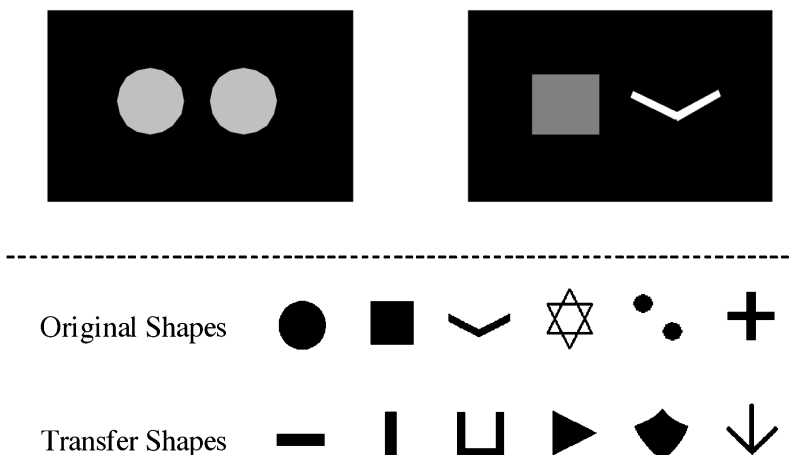


Figure 1. An example of a *redundant* display, in which the left pair of items exemplifies the relational property *same* and the right pair of items exemplifies the relational property *different* in the dimensions of both color and shape.

sion initially showed greater control of the discrimination in the prior test. In Experiment 2, we examined the training and transfer testing with the shape dimension.

Method

Subjects

Four experienced and 2 experimentally naive male White Carneaux pigeons (*Columba livia*; Palmetto Pigeon Plant, Sumter, SC) were tested. The experienced birds had previously served in an unpublished experiment involving mixtures of six pictures that none of the 4 pigeons had learned. The pigeons were maintained at 80%–85% of their free-feeding weights during testing and had free access to water and grit in their home cages, housed in a colony room with a 12:12-h light:dark cycle.

Apparatus

Testing was conducted in a flat-black Plexiglas chamber (38 cm wide \times 36 cm deep \times 38 cm high). All the stimuli were presented by computer on a color monitor (NEC MultiSync C500; Wooddale, IL) visible through a 29 \times 22 cm viewing window in the middle of the front panel of the chamber. The viewing window's bottom edge was 15 cm above the chamber floor. Pecks to the monitor screen were detected by an infrared touch screen (originally purchased from Carroll Touch Systems but now distributed by Elo TouchSystems, Fremont, CA) mounted into the front panel. A 28-V houselight was located in the ceiling of the box and was illuminated at all times, except when an incorrect choice was made. A food hopper was located in the center of the front panel, its access hole flush to the floor. All experimental events were controlled and recorded with a 486-class computer. A video card controlled the monitor in the SVGA graphics mode (800 \times 600 pixels). Computer-controlled relays operated the hopper and houselight.

Procedure

Stimulus displays. Displays were composed of combinations of items from a set of six different geometric shapes (triangle, square, chevron, circle, vertical line, and horizontal line) and six different colors (blue, green, red, purple, brown, and yellow). Each item was between 3.0 and 5.5 cm in size, depending on its shape. For example, the pigeon might have been presented with two blue circles. The values were selected because of their known discriminability from each other, on the basis of earlier research (Cook et al., 1997). Each display was approximately 20 \times 5 cm (w \times h) and consisted of two pairs of shapes presented on the computer screen (Figure 1). One pair of adjacent items was presented on the right side of the display, midway between the upper and on the lower boundaries of the screen. The other pair of adjacent items was presented on the left side of the display in a similar manner. The average distance between the items of a pair was 4.5 cm center to center, whereas the average distance between the right and the left pairs of items was 15.5 cm center to center. On each trial, one pair consisted of a pair of identical items (*same* pair), whereas the other pair consisted of two items that redundantly differed from one another in color and shape (*different* pair). No common colors or shapes were shared between the *same* and the *different* pairs. For example, a trial might present two blue circles on the left side of the screen and a green square and a pink star on the right side of the screen. The right/left location of the *same* and the *different* pairs was counterbalanced within a session. The location of the correct pair was randomized on each trial. In total, 450 *different* pairs (900 after left–right counterbalancing) and 36 *same* pairs were used during training. When combinations of *same* and *different* pairs are taken into account, there were 32,400 unique entire displays available for use.

Initial training. The experimentally naive pigeons were first trained to retrieve mixed grain from the hopper and then were auto-shaped to peck a centrally presented white 2.5-cm circular ready signal. The experienced birds proceeded immediately to discrimi-

nation training. Once responding to this ready signal had been established, training displays were added to the sequence of events. Only the correct pair of items was shown during this phase of training. Each of these stimulus display auto-shaping trials started with a peck to the ready signal, followed by the presentation of a display for 15 sec or until the pigeon made one peck at the stimulus. Either event caused the hopper to be illuminated and raised for 2.5 sec. As soon as all the pigeons were consistently responding to the stimulus displays, discrimination training was initiated (see the experimental design in Table 1).

Discrimination training. Discrimination training began when both the correct and the incorrect pairs were presented together. Three pigeons (1 experimentally naive and 2 experienced subjects) were reinforced for pecking at the *different* pair, whereas the other 3 pigeons were reinforced for selecting the *same* pair within a display. If the incorrect pair (i.e., the *same* pair for the first 3 pigeons and the *different* pair for the latter 3 pigeons) was chosen, the overhead houselight was extinguished for a 15-sec time-out, and no reinforcement was provided. A 3-sec intertrial interval followed either outcome.

Daily training sessions consisted of 180 trials. Over the first 18 training sessions, the peck requirement for a choice was gradually increased to the final value of 10 pecks (FR-10). Training continued until each pigeon reached a criterion of 80% choice accuracy for 2 consecutive sessions.

Transfer to color-only and shape-only displays. To determine the relative degree of control exerted by the color and the shape dimensions in the redundant training stimuli, the pigeons were tested with novel nonreinforced probe trials consisting of exclusively color or shape differences. Ten pecks at either the *same* or the *different* pair ended a trial without reinforcement or time-out. Two test sessions were conducted. Each session consisted of baseline trials and 16 probe trials (8 color only and 8 shape only). The same shape (circle) was used on all the color-only probe trials; likewise, the same color (blue) was used on all the shape-only probe trials. Probe trials were randomly inserted into each session after the 20th trial.

Incorporation of color-only and the shape-only displays into training. After the completion of testing, color- and shape-only trials were introduced into daily discrimination training. Each 180-trial session contained 60 redundant (color and shape differences), 60 color-only, and 60 shape-only trials.

Novel color transfer test. After 10 sessions, we administered a series of probe trials in which novel colors were used. Six novel colors (light yellow, light orange, violet, white, aquamarine, and magenta; selected to be as different as possible from the training values) were used to create *same* and *different* test displays. These novel-color combinations were implemented using familiar shapes from the training set. Four familiar shapes were used in all, with 2 test sessions conducted with each shape. Each of these 8 sessions consisted of six novel-color probe trials, with each novel color assigned to one *same* pair and two *different* pairs in each test session (left/right position counterbalanced across sessions). Due to the limited number of test trials, not all novel combinations of colors were tested, although each color was tested once with each of the other five colors in each test session. These probe trials were randomly intermixed with the 180 baseline trials (redundant, color, and shape) in each session after the 20th trial in each session. Neither reinforcement nor time-outs occurred on these novel probe trials. The first round of color transfer testing consisted of 4 sessions (on 2 sessions we used the square as the combined shape on transfer trials, and on 2 sessions we used the circle). Twenty weeks later, a second round of color transfer testing was conducted. These sessions were identical to the first round of testing, except that on 2 sessions we used the star as the shape for transfer trials, and on 2 sessions we used the plus sign. The second test was done after the completion of the shape transfer tests in Experiment 2 and was designed to check for continued transfer to the color dimension at that time. Because the results of these two test phases were not significantly dif-

Table 1
Design of Experiment 1 and Shape Transfer of Experiment 2

Group (<i>n</i>)	Discrimination Training (Redundant)	Transfer to Color and Shape Only	Color, Shape, Redundant Training	Novel Color (Experiment 1) or Shape (Experiment 2) Transfer
Sessions	Average = 23	2	10	8
Trials/session	180	196	180	186
D+ (3)	Reinforced for pecking <i>different</i> pair	Test trials: 8 color only 8 shape only Baseline trials: 180 redundant	Baseline trials: 60 color only 60 shape only 60 redundant	Test trials: 6 novel color Baseline trials: 60 color only 60 shape only 60 redundant
S+ (3)	Reinforced for pecking <i>same</i> pair	Test trials: 8 color only 8 shape only Baseline trials: 180 redundant	Baseline trials: 60 color only 60 shape only 60 redundant	Test trials: 6 novel color Baseline trials: 60 color only 60 shape only 60 redundant
Colors	Blue, green red, purple, brown, yellow			Experiment 1 test trial colors: gold, light orange, violet, white, aquamarine, magenta
Shapes	Square, chevron, circle, star, double-dot, plus (see Figure 1)			Experiment 2 test trial shapes: arrow, shield, U-shape, triangle, vertical line, horizontal line (see Figure 1)

ferent from one another, they are combined here for the purposes of exposition.

Results and Discussion

All the pigeons were able to acquire the discrimination, reaching the 80% criterion level of accuracy within a range of 13–28 sessions (see Figure 2). Accuracy significantly improved over training sessions, as supported by a one-way repeated measures analysis of variance

(ANOVA) comparing the first and the last session performances of all the pigeons [$F(1,5) = 212.43, p < .001$]. The 3 pigeons (1C, 3M, and 4R) for which the *different* pair of items was the S+ reached criterion more rapidly than did the 3 pigeons (2D, 5S, and 6J) for which the *same* pair of items served as the S+ [$t(4) = 3.27, p < .05$]. One possible interpretation of this facilitated acquisition for responding to the *different* pair is that the latter is psychologically more salient than the *same* pair, perhaps

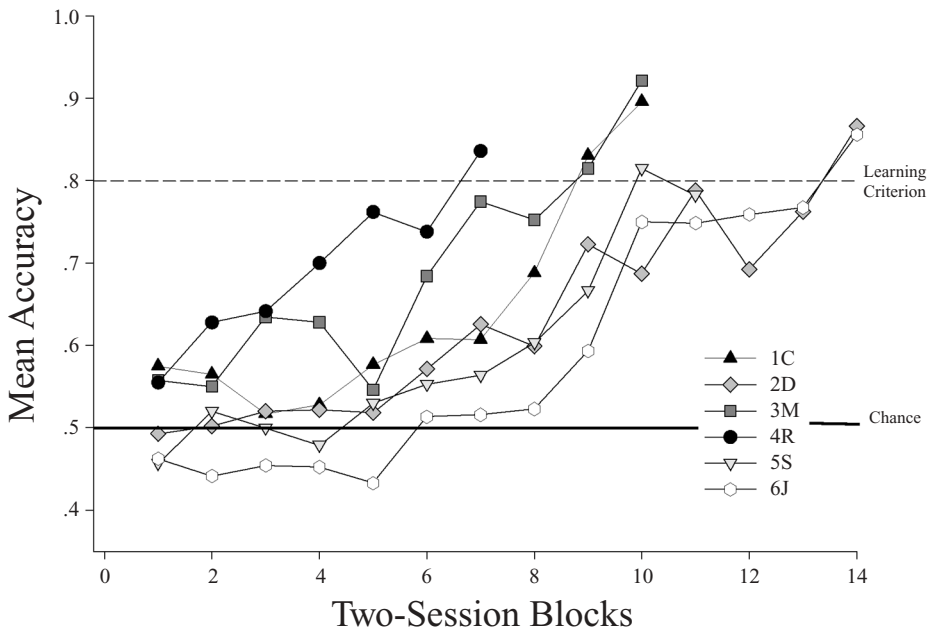


Figure 2. Mean accuracy for each bird across two-session blocks during initial training. The solid line indicates a chance level of performance, and the dashed line indicates the acquisition criterion level of performance.

because the featural contrasts created by adjacent, but dissimilar, colors and shapes attracted attention to this pair's location more easily.

Following discrimination acquisition with redundant displays, the probe tests examining the degree of control exerted by color and shape suggested that both dimensions initially controlled choice responding (see Figure 3). For 5 of the 6 pigeons, both dimensions showed evidence of a shared control over choice behavior, with the 6th pigeon being primarily controlled by the shape dimension. Overall, the mean accuracy values for both the shape- and the color-only probes were 75%, and both values were significantly greater than would be expected by chance [0.5 ; $t(5) = 5.4$, $p < .001$; see Figure 3].

Figure 3 also shows, however, that after color- and shape-only trials were incorporated into daily training, shared control by both dimensions disappeared. In this case, accuracy with the color-only trials increased and remained high, whereas accuracy with shape-only displays deteriorated. A one-way repeated measures ANOVA computed on choice accuracy across all 10 postintroduction sessions revealed a main effect of trial type [$F(2,9) = 31.01$, $p < .001$]. The pigeons were significantly more accurate on color-only trials than on shape-only trials [$F(1,15) = 32.5$, $p < .001$] and significantly more accurate on redundant trials than on either color-only trials [$F(1,15) = 5.1$, $p < .05$] or shape-only trials [$F(1,15) = 57.1$, $p < .001$]. Although control by color clearly increased over this period of testing, the shape dimension still contributed to redundant display performance. This partial control by shape is suggested by the pigeons' poor, but still significantly above chance, performance

on shape-only displays [$t(5) = 9.53$, $p < .001$] and the significantly higher accuracy of redundant display performance over that with single-dimension color displays. Neither of these results could be accounted for by the exclusive processing of color information. Why the color dimension comes to dominate performance at this point in training after sharing more equally during the initial probe test is puzzling. If anything, one might have expected the opposite, with early control exerted by the typically more dominant color dimension and shape becoming a factor only after the advent of differential reinforcement specifically for that dimension. One interesting possibility is that the now explicit differential reinforcement for both dimensions broke the previously configural compound stimulus (Pearce, 1987) apart into separate elements (Brown, 1987), allowing for greater competing control or attention to the separate dimensions and resulting in the more characteristic color dominance.

Choice accuracy on the important novel-color test trials ($64\% \pm 6\%$ SEM) was significantly above chance [50% ; $t(5) = 4.47$, $p < .01$]. This above-chance transfer indicates that the pigeons had not memorized reinforced responses to the training stimuli and suggests that they were responding relationally to the sameness and difference of the novel pairs of color values. In comparison with the baseline trials ($79\% \pm 3\%$ SEM), color transfer trial accuracy was significantly lower [$t(5) = 4.97$, $p < .01$]. We found no significant effect of the common irrelevant shape (circle, square, plus, and star) on either the transfer or the color-only training trials ($F_s < 2.0$, $p_s > .15$). The decline in performance on the transfer trials is typical of these kinds of experiments. This may

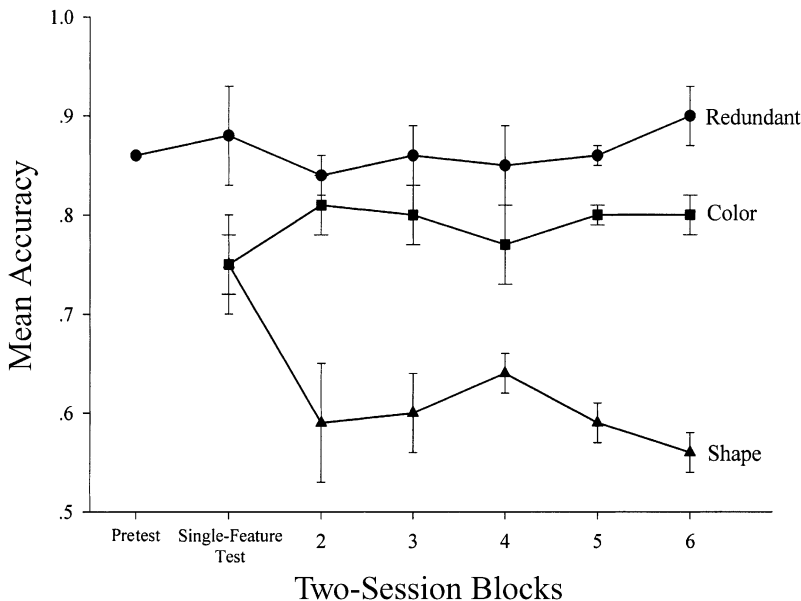


Figure 3. Mean accuracy on the last session prior to transfer testing (pretest; baseline redundant trials only), during transfer test sessions (baseline redundant trials; color-only and shape-only probe trials), and during posttransfer testing (in two-session blocks) for redundant, color-different, and shape-different baseline trials.

represent the effects of incomplete concept formation or interference from stimulus-specific memorization processes (see Wright, 1997, 2001). Furthermore, it may also represent the effects of neophobia toward the novel color values. If so, it may have caused attention to shift to the familiar, but uninformative, shape values, which would have also reduced transfer accuracy.

In summary, in Experiment 1, we found a difference in the rate of learning between the *different+* and the *same+* conditions, with the former condition being learned more quickly. Although the color and shape dimensions seemed to have contributed to early performance, as indicated by the single-feature probe tests, control by the color dimension increased and shape performance declined with the explicit and independent training of each dimension. Of most importance to the goals outlined in the introduction, these data provide clear evidence of above-chance transfer to novel color values in a simultaneous two-item S/D discrimination.

EXPERIMENT 2

We next wanted to assess the generality of S/D conceptual behavior by testing the transfer of the discrimination to novel shapes. Although some initial control by the shape dimension was found in Experiment 1, it was relatively weak, as compared with control by color, at least by the end of testing. So that we could test for relational control by shape, we conducted a series of manipulations designed to improve control by the shape dimension. These manipulations included reducing the size of the items to encourage more global processing of the figural relations between the items of each pair, implementing a correction procedure, eliminating redundant displays, and increasing the frequency of testing color- and shape-only trials. Upon successfully improving performance on shape-only trials, we then tested the generality of the discrimination with displays composed of novel shapes.

Method

Subjects

The pigeons in Experiment 1 served as subjects in Experiment 2.

Procedure

Attempts to improve performance on shape displays. Due to the poor performance on shape-only displays at the end of Experiment 1, we attempted to increase shape accuracy by the following series of manipulations.

1. We reduced the size of the stimulus items to potentially encourage more global processing of the relations between the shapes and their geometry. Items reduced to 75%, 50%, and 25% of their original size were tested with differential reinforcement for 16 sessions. Each session contained 48 shape-only trials at each of the three sizes, for a total of 144 trials. Redundant and color-only trials were discontinued during size reduction training.

2. Next, the subjects were returned to discrimination training with the original-sized images. Each session contained 40 trials of each display type (redundant, color, and shape), for a total of 120 trials. After 16 baseline sessions, we began using a correction procedure that consisted of immediately repeating each display to

which the subject responded incorrectly until a correct choice was made. Data from correction trials were excluded from all the statistical analyses because performance on these trials was likely influenced by feedback from the preceding trial.

3. Finally, beginning with the ninth session after invoking the correction procedure, we stopped testing redundant trials, and the number of color- and shape-only trials per session was increased to 60 for each dimension (120 total trials). This was designed to decrease opportunity to use color as the primary means of solving the discrimination. We continued to use the correction procedure throughout this dimensional training.

Novel-shape transfer test. With the advent of the correction procedure and the omission of redundant displays, shape accuracy increased dramatically for 4 of the 6 pigeons. At this point, we assessed the degree of relational control by testing the 4 shape-sensitive pigeons with novel shapes. Six novel shapes (a horizontal line, a vertical line, a triangle, a U-shape, a shield, and an arrow; see Figure 1) were tested in an identical manner as the novel-color transfer tests. These novel shapes were presented in combination with familiar colors from the original training set. Four familiar colors were used in all, with two test sessions per color. Each session consisted of six novel-shape probe trials presented in one familiar color. Each novel shape was assigned to one *same* pair and two *different* pairs in each test session (left–right counterbalanced across sessions). Due to the limited number of test trials, not all possible combinations of shapes were used for constructing *different* pairs. However, each shape was tested once with each of the other five shapes in each test session. For example, the horizontal line appeared once with the horizontal line, the vertical line, the triangle, the U-shape, the shield, and the arrow in each session. The same combinations of shapes were repeated with each color tested (i.e., four replications). These probe trials (6 per session) were randomly intermixed with the 120 differentially reinforced training (i.e., 60 color and 60 shape) trials of each session, with the constraint that probe trials occurred after the 20th trial of each session. Neither reinforcement nor a time-out occurred following the probe trials.

Results and Discussion

Figure 4 shows the effects of the various training manipulations on shape performance. The second panel from the left shows accuracy with reduced-size displays over the 16 sessions of testing. The shape discrimination transferred reasonably well to the 75% reduction condition. There was a decline and then an improvement in the 50% condition and a generally poor performance in the 25% reduction condition. A one-way repeated measures ANOVA showed a main effect of size [$F(2,5) = 4.92$, $p < .05$]. Performance on 25% images was significantly below that on 75% images [$F(1,5) = 4.44$, $p < .05$], but no other pairwise comparisons achieved significance. Shape accuracy on original-sized items was not affected by varying the size of the images, as evidenced by a comparison between mean performance on the last five sessions prior to size training and on the first five sessions upon return to baseline training [$t(5) < 1.0$; see the third panel]. Since the 75% and 50% conditions were slightly better than baseline, part of the poor performance with the original shapes could be attributed to their size. However, the overall effect was small, and as such, we returned to testing the baseline size in order to search for a better way to enhance performance with this dimension.

Implementing the correction procedure did far more to increase shape choice accuracy (see the fourth panel

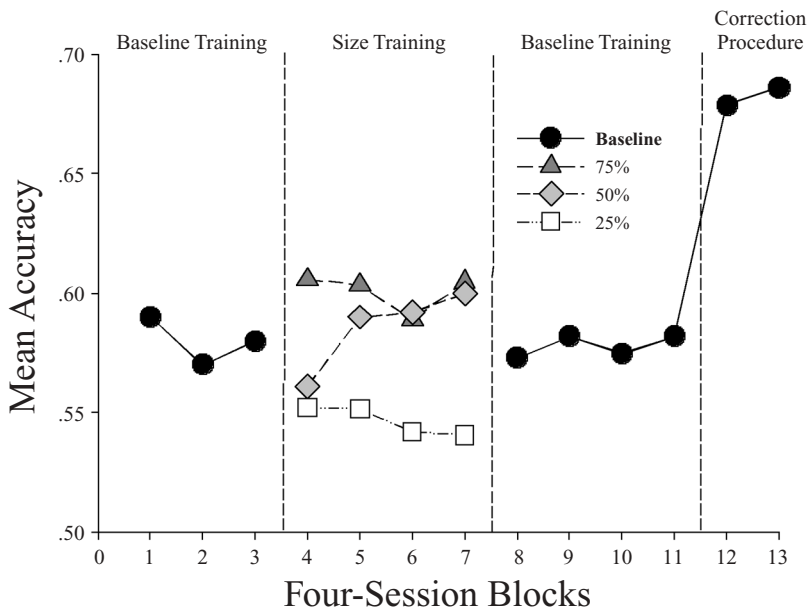


Figure 4. Mean accuracy on shape trials (four-session blocks) for baseline trials prior to size training, for items reduced to 75%, 50%, or 25% of training size, after returning to original-sized items, and after a correction procedure had been invoked.

in Figure 4). There was considerable variability, however, among the pigeons in their reaction to this procedure, with scores ranging from about 80% for some birds (e.g., 1C and 3M) to near-chance levels in others (e.g., 4R and 5S). Because the latter 2 pigeons (both experimentally naive, one that had received D+ training and the other that had received S+ training) performed poorly with the shape dimension despite additional training, they were not included in transfer tests involving novel shapes.

In the shape transfer tests conducted with the four shape-sensitive pigeons, accuracy on the novel-shape trials ($60\% \pm 6\%$ SEM) was significantly above chance [50% ; $t(3) = 3.31$, $p < .05$]. Overall performance on novel-shape test trials was not statistically different from baseline shape trials [$67 \pm 3\%$ SEM; $F(3,12) = 2.53$, $p > .1$], with no effect of common irrelevant colors (red, purple, green, and blue) on performance with either the training or the novel displays ($F_s < 2.5$).

In summary, it was much harder to get the pigeons to perform accurately when shape was the exclusive feature defining *same* and *different*. Reducing their size helped this discrimination little. The use of a correction procedure did help the majority of the pigeons to learn this part of the task, but 2 pigeons still essentially failed to perform the discrimination exclusively on the basis of shape. Interestingly, these 2 birds were still sensitive to relational color information, however, since both transferred well during the second transfer test with novel colors described in Experiment 1 (but conducted after the shape training in Experiment 2). This suggests that their problem may have been more attentional than conceptual in nature. Interestingly, in Cook et al.'s (2003) tests

with a successive two-item procedure, the pigeons showed more difficulty in learning and transferring S/D discriminations with grayscale pictures than with fully colored versions of the same pictures. As such, shape differences not only may be perceptually more difficult for pigeons to detect, but also may be harder to conceptualize. Nevertheless, the 4 pigeons that were sensitive to shape showed above-chance transfer to novel-shape displays, consistent with the transfer observed with the color values used in Experiment 1. This type of transfer is an indication of having learned a generalized solution to this relational discrimination.

GENERAL DISCUSSION

These experiments provide some of the strongest evidence yet that pigeons can discriminate and generalize S/D relations, using only two pairs of simultaneously presented stimuli. Overall, good stimulus control and above-chance transfer was seen with pairs of colors with all the pigeons and moderate control and above-chance transfer with pairs of shapes in a majority of the pigeons. As such, these results add to the accumulating evidence that pigeons can learn the relational properties from visual elements and apply them to novel stimuli (Cook, 2002a, 2002b; Cook et al., 1995; Cook et al., 1997; Cook et al., 1999, Cook et al., 2003; Cook & Wixted, 1997). In combination with our recent results demonstrating successful S/D learning and transfer, using the successive presentation of two pictorial items (Cook et al., 2003), these results suggest that pigeons, like primates, can learn to solve relational discriminations with as few as

two items, at least under some circumstances. These results also add converging evidence with the results from earlier savings studies in which the matching-to-sample or oddity-from-sample procedures were used (e.g., Zentall & Hogan, 1974, 1976, 1978), demonstrating the capacity for the S/D concept in pigeons.

Why did our pigeons acquire and transfer this pairwise S/D discrimination, whereas others have generally failed to find successful transfer? One key difference between our procedure and those used in prior attempts may be the size and variability of the training stimulus set. In our displays, items varied among a set of six colors and six shapes, producing a total within each dimension of 36 combinations (30 different/6 same). This number is further increased when we consider that each of these combinations is crossed with the elements of the other relevant dimension, making 180 uniquely different combinations within a dimension. When combinations of both *same* and *different* pairs are also considered, over 12,960 unique dimensional displays were possible. Because these very large numbers made memorizing the displays more difficult (Cook, Levison, Gillett, & Blaisdell, in press), it may have increased the birds' attention to the information-reducing relations between the elements, rather than to their specific values (see also Santiago & Wright, 1984).

This larger set size contrasts markedly with the training sets employed in prior experiments. For example, in Experiment 3 in Wilson et al. (1985), pigeons received S/D training in which two response keys were simultaneously lit with two identical colors (mauve-mauve or blue-blue) or with two different colors (mauve-blue or blue-mauve). Reinforcement was given for pecking one key (e.g., left) when the colors were the same and the other key when they differed. After acquiring this discrimination (with some difficulty), the pigeons failed to transfer to test displays containing yellow and red key-lights. The considerable difference between the sizes of the training sets of relations in these studies may account for the difference in transfer of the discrimination to novel items. Likewise, Edwards et al. (1983) trained pigeons with only three displays (plus-plus and circle-circle as the *same* displays and plus-circle as the *different* display), and again there was no evidence of discrimination transfer.

Some of Pearce's (1988) pigeons also were trained with a large stimulus set, yet failed to acquire the discrimination. In his study, pigeons were trained in a go/no-go procedure to discriminate visual displays containing two vertical bars of the same height (S+) from displays with bars of differing heights (D-). Bar height could vary between 1 and 7 units. The pigeons learned this discrimination only if the bars were adjacent to each other and only when four of the displays (7-7, 1-7, 1-1, and 7-1) were used in training. In a subsequent experiment, the pigeons were able to learn to discriminate all combinations of bar heights if new exemplars were gradually introduced during training. However, reversal training in

which one *same* exemplar (4-4) was nonreinforced (S-) and one *different* exemplar (7-4) was reinforced (D+) did not transfer to other exemplars. Thus, performance appeared to be controlled by item-specific learning, rather than by the relations between stimuli. This may have resulted from bar height being the only dimension on which his stimuli differed. Unlike Pearce, we had more dimensions and featural variety among our stimuli. In addition, the pigeons had to actively determine which dimensional relation was relevant in each case, since each *different* pair of the transfer tests, for instance, had a relevant *different* relation (e.g., shape) and an irrelevant *same* relation (e.g., color) present at the same time. Only by comparing these values across the two dimensions could the pigeons select the correct alternative. These features of our discrimination helped prevent any one dimension from controlling performance and likely encouraged the use of generalized relations.

One problem introduced by the use of a larger set of training stimuli is that it potentially increases the similarity between training stimuli and transfer stimuli. That is, successful transfer of a relational discrimination may partially reflect generalization of item-specific learning from training stimuli to transfer stimuli. Might this have been responsible for our transfer? A major line of thinking about human conceptual behavior is that it is exemplar driven (Brooks, 1978; Hintzman, 1988; Nosofsky, 1986; Tarr & Bülhoff, 1998) and based specifically on generalization from past experiences. We acknowledge that this theoretical possibility may be true of pigeons, too and that both pigeons and humans might not engage in concept formation but, rather, rely on similarity to past experiences to guide behavior.

One answer to this question is that we did select our training and test items to be discriminable from one another. Because of previous S/D research (Cook et al., 1997; unpublished results) in which the same colored and shaped geometric stimuli were used, we knew the similarity and accuracy relations among the elements. On the basis of these data, we had good independent evidence that our training and transfer items could be perceptually discriminated from one another, at least under conditions of differential reinforcement (Cook et al., 1997). Using a hierarchical cluster analysis, a multivariate technique for modeling the psychological similarities present within a set of data, we derived a similarity matrix from the accuracy of testing all pairwise combinations of these elements. These data were collected over 100 sessions of training, using the pigeons tested by Cook et al. (1997). These summary cluster analyses showed the pattern of the 12 shapes and the 12 colors tested in their experiment. We specifically selected stimuli for our training and test sets by attempting to maximize as best we could the perceptual separation between these items. Of course, this was guided by our human perception of these colors and shapes and may or may not reflect how the pigeons view the same color and shape relations (Blough & Blough, 1990; Wright & Cumming, 1971).

As such, we tried to minimize the role of simple generalization in accounting for our transfer results. However, we cannot summarily rule out the possibility that, despite our best attempts, the degree of similarity between our shapes and colors contributed in part to the above-chance transfer results. Of course, this limitation is true of the vast majority of concept experiments with nonhuman animals. A better design for future studies might use the technique of employing extradimensional transfer, in which one dimension is used for training and the second is used for transfer testing.

Nevertheless, the successful learning and transfer of this two-item S/D discrimination helps to eliminate alternative interpretations of our earlier S/D results with multiple items (Cook, 2002b; Cook et al., 1995; Cook et al., 1997; Cook et al., 1999). For instance, the results argue against concerns that our previous S/D results were due to the *generalized* detection of perceptual patterns or spatial anomalies within the mosaic of repeated elements in those displays. If the pigeons were only capable of using such spatial patterns to guide their S/D choice behavior, the pairwise nature of the stimuli in the present task would make the use of those spatial cues difficult or impossible (see also Cook et al., 2003). Thus, presenting a large number of multiple elements simultaneously apparently is not a necessary condition for pigeons to learn to discriminate S/D relations, although it may facilitate the formation of such discriminations by increasing the salience of the sameness and differentness of any display. Because two-item displays entail the minimal possible perceptual difference between two potentially *same* or *different* items, any perceptual strategy suggested for these pigeons could then just as readily be applied to any S/D discrimination performed by human and nonhuman primates as well.

Despite being considerably reduced, perceptual differences still (and must) remain in these displays. As such, any skeptic could generate an alternative perceptual account of any S/D data, selectively using the right set of visual features. For instance, these pairwise displays tend to emphasize the vertical symmetry between pairs more than the multiple-item displays do. Thus, as one reviewer suggested, it could be that the birds in the present task were attending to the symmetry of the displays, rather than do the S/D relations. The pigeons in the D+ condition might have been responding to the pair of stimuli that looked asymmetrical, whereas the S+ birds might have been responding to the symmetrical pair. However, the results of recent studies by Cook et al. (2003) and Young et al. (1999) in which the successive S/D procedure was used cannot be accounted for by this perceptual mechanism. Likewise, the results in Cook et al. (1997) that pigeons learn an S/D discrimination with four very different classes of stimulus displays also argues against a simple featural account. It seems that each of the tasks above would require that a different perceptual feature be invoked to account for the observed performance in each one. Occam's razor might recommend that we accept a singular relational account for

their performance across the diversity of these S/D situations, rather than have a multitude of different feature accounts tailored to each positive training and transfer result. No definitive study can rule out all perceptual alternatives to a relational task. What we can and have been trying to do is to systematically vary the conditions of the discrimination (Cook, 2002a, 2002b; Cook et al., 1995; Cook et al., 1997; Cook et al., 1999; Cook et al., 2003), with each condition specifically constructed to rule out one or more of the various nonconceptual alternatives. It is through the accumulation of this evidence that we can converge upon this issue of whether perceptual or conceptual mechanisms underlie relational behavior in pigeons or, more likely, the conditions that favor these different strategies. This study adds one more link to the accumulating web of evidence suggesting that multiple simultaneous items are not needed for pigeons to learn and transfer S/D discriminations.

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NOTE

1. Although our displays consisted of four elements, the grouping of these elements into pairs resulted effectively in displays with two items. That is, the birds could not solve the discrimination by making comparisons among any four elements in the display. Rather, reinforcement could be achieved only by (1) perceptually grouping the two elements on the left side of the screen, (2) perceptually grouping the two elements on the right side of the screen, and (3) making a comparison between the left and the right pairs of elements to determine which pair contained the reinforced relationship.

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