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THE STRUCTURE OF PIGEON MULTIPLE-CLASS SAME–DIFFERENT LEARNING

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Three experiments examined the structure of the decision framework used by pigeons in learning a multiple-class same–different task. Using a same–different choice task requiring the discrimination of odd-item different displays (one or more of the display's component elements differed) from same displays (all display components identical), pigeons were concurrently trained with sets of four discriminable display types. In each experiment, the consistent group was tested such that the same and different displays of four display types were consistently mapped onto their choice alternatives. The inconsistent group received a conflicting mapping of the same and different displays and the choice alternatives that differed across the four display types but were consistent within a display type. Experiment 1 tested experienced pigeons, and Experiment 2 tested naive pigeons. In both experiments, the consistent group learned their discrimination faster and to a higher level of choice accuracy than did the inconsistent group, which performed poorly in general. Only in the consistent group was the discrimination transferred to novel stimuli, indicative of concept formation in that group. A third experiment documented that the different display classes were discriminable from one another. These results suggest that pigeons attempt to generate a single discriminative rule when learning this type of task, and that this general rule can cover a large variety of stimulus elements and organizations, consistent with previous evidence suggesting that pigeons may be capable of learning relatively unbounded relational same–different concepts.

Key words: same–different discrimination, concept learning, stimulus relations, decision theory, pigeons

How do pigeons learn about the causal relations between the events and patterns of their world? The answer to this question has centered around two primary ideas. The first is that animals learn and memorize the relations among specific stimuli, responses, and outcomes. This associative tradition has proven to be a profitable account for much of the learned behavior observed in widely separated groups of animals. The second idea is that at least some animals also extract and use more generalized representations of their past experience, abstracting patterns and rules that can then be broadly applied to both familiar and novel situations. As humans, we are experts, detecting and abstracting the general patterns in the world's particulars and then using this information to guide our behavior. In pigeons, similar conceptual behavior was first recognized in the analysis of picture recognition and categorization (Herrnstein & Loveland, 1964). Since then, abundant evidence has been collected to show that pigeons can categorize pictures of a wide variety of different objects based on their common properties and family resemblance (Cook, Wright, & Kendrick, 1990; Herrnstein & de Villiers, 1980; Wasserman, Kiedinger, & Bhatt, 1988). More recently, increasing attention has been devoted to whether pigeons can also learn to conceptualize the possible relations between two or more stimuli (same–different: Cook, in press; Cook, Katz, & Cavoto, 1997; entropy: Young & Wasserman, 1997, 2001; matching: Wright, 1997, 2001; acquired equivalence: Urcuioli, 1996, 2001). In the present article, we focus on how pigeons internally represent their solution to learning a demanding multiple-class same–different discrimination.

The detection and recognition of difference and identity are among the most fundamental of psychological discriminations and are central to advanced intellectual functions and behavior, forming the basis for our appreciation of language, mathematics, analogical reasoning, social relations, and fine arts. How is this capacity distributed in the animal kingdom? Some have suggested that

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the appreciation of such same–different relations may be critically tied to human verbal behavior (Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Premack, 1978, 1983) or at least is limited to primates (Tomasello, 2000). Earlier research with pigeons had led some to suggest that this relational concept might be beyond their intellectual faculties (Mackintosh, Wilson, & Boakes, 1985; Pearce, 1991; Premack, 1978, 1983; Wright, Santiago, Urcuioli, & Sands, 1983). Recently, we have collected new evidence that has led us to suggest that pigeons may indeed be able to conceptualize such relations and apply them appropriately to novel stimuli (Cook, in press; Cook, Cavoto, & Cavoto, 1995; Cook et al., 1997; Cook, Katz, & Kelly, 1999; Cook & Wixted, 1997). Such results suggest that this key component of intelligence is more broadly distributed among groups of animals than previously suspected.

In a same–different 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. After learning this discrimination, the degree to which this behavior transfers to novel situations is taken as evidence of concept formation. We have found that pigeons can readily learn same–different discriminations and transfer this learning to novel stimuli from both within (Cook et al., 1997) and between (Cook et al., 1999) a variety of display types (see Figure 1) and in both simultaneous and successive stimulus-presentation procedures (Cook, in press). This article reports three new experiments that provide further evidence to support the hypothesis that pigeons can form generalized relational concepts.

These experiments specifically explore the structure of the decision space used by pigeons when learning a multiple-class same–different task. The experiments grew directly from Cook et al.'s (1997) experiments on same–different learning with different classes or types of stimulus displays. To test perceptually based alternative accounts of our earlier same–different research (Cook et al., 1995), Cook et al. (1997) trained pigeons to make same–different discriminations using four different stimulus classes or display types (see top four rows of Figure 1). The *texture, feature, geometric,* and *object* display types were used to create a very large and highly variable stimulus set of polymorphic, global same–different contrasts such that no simple set of perceptual features consistently separated the same and different displays, thus leaving only the same–different relations of the component elements to guide discriminative behavior. Pigeons easily learned to classify same and different displays formed by any of the four types of these multidimensional stimuli and transferred this learned behavior to displays created from novel exemplars of each type. Further, the rate of learning was the same across all four display types, suggesting that a single common discriminative rule was being learned and applied to the classification of all of the stimuli regardless of display type.

The present experiments directly examine this latter conclusion by asking empirically if only a single discriminative rule was being acquired during the learning of this task. If the pigeons were learning a generalized same–different concept, then only a single rule or criterion should be created that divides the stimulus space into regions of relational sameness and difference (Cook & Wixted, 1997; see Herbranson, Fremouw, & Shimp, 1999, for more on rule learning and use in categorization experiments). Presumably, the equivalent rates of learning across display types observed by Cook et al. (1997) reflected the creation of such a single rule. Of course, an alternative account is that the pigeons were learning multiple and independent discriminative rules, one for each distinct display type, and they just happened to do so at the same rate. The latter account suggests that no generalized concept was being formed for the entire set of stimuli. Rather, in this view, the pigeons solved the relations present in each display type as separate and independent problems based on features specific to that display type and unrelated to detecting the higher order relations of same and different in the displays (e.g., Mackintosh, 2000).

To investigate the issue of whether the pigeons were seeing this task as a single problem solved by a generalized rule or as several independent problems each with its own solution, we used a variation of the pseudoconcept strategy often employed in picture-categorization experiments (e.g., Dittrich & Lea,

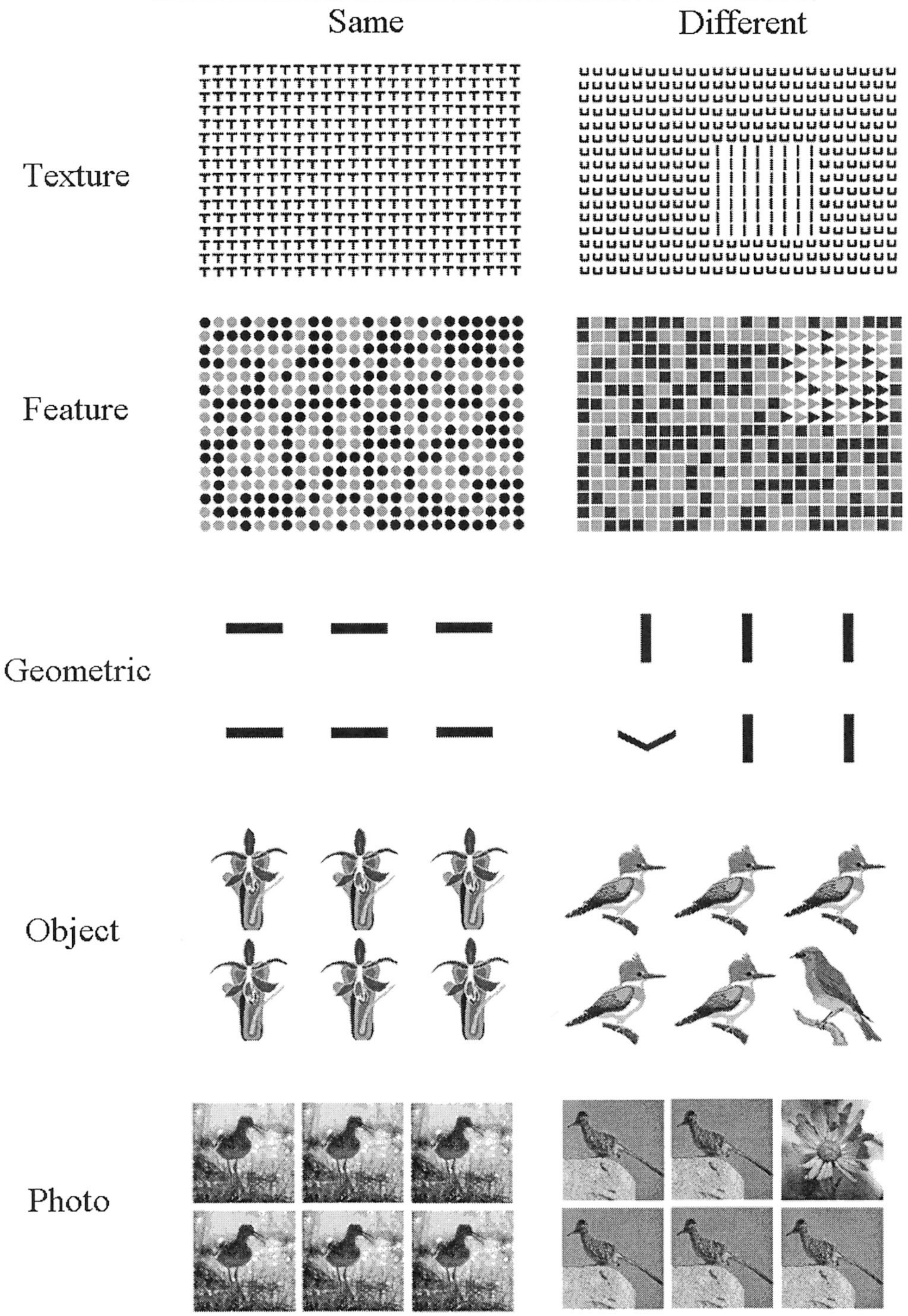

Fig. 1. Representative examples of the five display types tested in these experiments. The left column shows examples of same displays for each display type (the example for the feature display type depicts a shape-same display). The right column shows examples of different displays for each display type (the examples for the texture, feature, and geometric display types depict shape-different displays).

1993; Sturdy, Phillmore, Price, & Weisman, 1999; Wasserman et al., 1988; Watanabe, 1993). In pseudoconcept experiments, one group of animals is tested in a standard picture-categorization task (e.g., birds vs. mammals), and a second group is tested in a pseudoconcept control condition with the same pictures, but with their ''categorical'' membership randomly assigned. If the animals in the true categorization condition learn faster than those in the pseudoconcept condition, it indicates that an emergent commonality exists among the members of the categories that overrides the independent learning of the specific images tested. If the two groups learn at the same rate, however, it suggests that category membership is not a strong factor and that the independent learning of each exemplar drives the discrimination.

A variation of this strategy was employed in the first two experiments reported here. We tested two groups of pigeons using different subsets of Cook et al.'s (1997, 1999) display types (Experiment 1: texture, feature, geometric, object, photo; Experiment 2: texture, geometric, object, photo; Figure 1). For the consistent group, same and different in all display types were consistently mapped onto their respective choice alternatives. That is, the correct response to all same displays, regardless of display type, was assigned or mapped to a single choice alternative (e.g., the right choice hopper), whereas the correct response to all different displays, regardless of display type, was mapped to the other alternative (e.g., the left choice hopper). For the inconsistent group, the correct choice alternatives to the same and different displays were inconsistently mapped across display types but were consistently mapped within a display type. For example, the correct response for the same displays of the texture and geometric display types and the different displays of the object and photo display types might be mapped to one choice alternative, and the correct response for different displays of the texture and geometric display types and the same displays of the object and photo display types would be mapped to the other choice alternative. If the pigeons were learning a set of separate, independent rules or specific feature-based solutions for each display type, then this inconsistent mapping should present no problem in learning the task, and there should be no difference in the rates of acquisition between the consistent and inconsistent groups. If, on the other hand, the pigeons were trying to learn one generalized discriminative rule that can be broadly applied across all stimulus classes, then the consistent group should learn much faster than the inconsistent group. This is because the conflicting, nonlinear mappings in the latter condition should interfere with using the relational commonality bonding the same and different displays of the various display types.

EXPERIMENT 1

Using 5 experienced pigeons previously trained to perform the same–different task using only texture stimuli (Cook et al., 1995; Cook & Wixted, 1997), we introduced four new display types (feature, geometric, object, photo) for the first time. For 2 of these pigeons, the responses to the four new display types were consistently mapped to the already-learned same and different responses acquired during that pigeon's previous training. For the remaining 3 pigeons, the responses to the four new display types were inconsistently mapped to the previously learned same and different choice alternatives, with each pigeon having a different mapping (see Table 1). We then followed their choices with these new display types for 100 sessions to compare the effects of the different mapping assignments on acquisition in each of the conditions.

Method

Subjects. Five experienced male White Carneau pigeons were tested (Cook et al., 1995; Cook & Wixted, 1997). No additional training was needed, because they had participated daily in a same–different task using just the texture display type for the prior 5 years (>200,000 trials). They were maintained at 80% of their free-feeding weights in a colony room with a 12:12 hr light/dark cycle and had free access to water and grit in their home cages.

Apparatus. Testing was conducted in a flat-black Plexiglas chamber (39 cm wide by 33 cm deep by 41 cm high). All stimuli were presented by a computer on a color monitor (NEC Multisync 2A; Wooddale, IL) visible

Table 1

Choice hopper assignments for display types in Experiment 1.

Pigeon	Stimulus class	Left	Right
Consistent group			
1K	Texture	Same	Different
	Feature	Same	Different
	Geometric	Same	Different
	Object	Same	Different
	Photo	Same	Different
2E	Texture	Different	Same
	Feature	Different	Same
	Geometric	Different	Same
	Object	Different	Same
	Photo	Different	Same
Inconsistent group			
3B	Texture	Different	Same
	Feature	Different	Same
	Geometric	Same	Different
	Object	Different	Same
	Photo	Same	Different
4E	Texture	Same	Different
	Feature	Different	Same
	Geometric	Same	Different
	Object	Different	Same
	Photo	Same	Different
5G	Texture	Same	Different
	Feature	Different	Same
	Geometric	Same	Different
	Object	Same	Different
	Photo	Different	Same

through a viewing window (26 cm by 18 cm) in the middle of the front panel. The window's bottom edge was 20 cm above the chamber floor. A thin piece of glass mounted in this window protected the monitor. Pecks to the monitor screen were detected by an infrared light-emitting diode (LED) touch screen (resolution of 80 × 48 locations; EMS Systems, Champaign, IL) mounted behind a Plexiglas ledge (40 mm wide) that went around the inside edge of the viewing window. A 28-V houselight was located in the ceiling and was illuminated at all times, except when an incorrect choice was made. Identical food hoppers (Coulbourn E14-10, Lehigh Valley, PA) were located in the right and left walls of the chamber, each 3 cm from the front panel and flush with the floor. Infrared LEDs mounted 2.5 cm in front of each hopper detected the approach of a pigeon's head into the opening. Experimental events were controlled by an IBM-compatible computer equipped with a video card (VGA Wonder, ATI Technologies, Scarborough, Ontario) in SVGA graphics mode (800 × 600 pixels).

Procedure

Basic display organizations. All of the displays tested in this experiment were based on the procedures described in Cook et al. (1997). As such, each is only briefly outlined below, and any differences from that study are noted. All displays were 18 cm by 12 cm and were arranged in either a *texture* or a *visual search* organization. The texture and feature displays were configured using the texture organization, consisting of 384 small elements (3 to 6 mm) arranged in a 24 × 16 matrix at 0.75 cm intervals (see top two rows of Figure 1). The different displays for this organization contained a randomly located 8 × 7 target region within a surrounding region of distractor elements. The geometric and object displays were configured using the visual search organization. They consisted of six large elements (3 to 5.5 cm) arranged in a 3 × 2 matrix at 6-cm intervals. The different displays in this organization contained a single target element randomly located within the surrounding set of distractor elements.

Texture display type. Sixty-four elements, derived from the pairwise combination of eight different shapes and eight different colors, were used to make the texture displays. The colors and shapes tested were the same as those used by Cook et al. (1997). The same displays were made by repeating one of these 64 elements at all 384 locations in the array. The different displays were made by randomly selecting combinations of target and distractor elements that contrasted in either color or shape. All together, 448 color-different, 448 shape-different, and 64 same texture displays could be generated and tested.

Feature display type. These 64 elements were also used to create the feature displays. The different displays of this type were made by a mixture of four elements. The selection and arrangement of these four elements were such that the global difference between the two elements forming the target and the two elements forming the distractor regions differed consistently in either their color or their shape (for more details, see Cook, 1992; Cook et al., 1997). The local mixture of the two elements within these contrasting regions was spatially randomized along the globally irrelevant dimension (color in shape-relevant displays; shape in color-relevant displays). The number of feature displays depends on how they are counted. Given the randomization of the component elements on each trial, the exact repetition of a feature display rarely occurred. Discounting this factor, there were 1,568 color-different, 1,568 shape-different, 224 color-same, and 224 shape-same feature displays of this type.

Geometric display type. The same 64 elements were used to create these displays, except that the eight shapes were 10 times larger than in the two above display types. The different displays were made by combining these elements so that the target element differed from the five distractor elements in terms of either color or shape. The same displays were made by repeating the identical element six times within each display. All together, 448 color-different, 448 shape-different, and 64 same geometric displays could be created and used.

Object display type. This display type was made from semirealistic pictures of eight objects selected from two categories: birds and flowers. These objects were created from Corel graphics clip art, with each image scaled to a size ranging from 4.5 to 5.5 cm. These were presented as either 256-level color or 24-level gray scale PCX images using the visual search organization. Displays were always composed with images that were either all color or all gray scale. All together, 56 color-different, 56 gray scale-different, 8 color-same, and 8 gray scale-same object displays could be created and used.

Photo display type. This display type was composed of photographic images arranged using the visual search organization. Each element was a 200 × 200 pixel 256-color or 24-gray scale photo selected from commercial image packages. Eight color photos and eight gray scale photos were tested, with four exemplars each of the categories of cars and buildings. Displays were always composed with images that were either all color or all gray scale. All together, 56 color-different, 56 gray scale-different, 8 color-same, and 8 gray scale-same displays could be created and used.

Discrimination testing. Each trial began with a peck to the ready signal, followed by presentation of a randomly selected same or different display from one of the five display types. A target-directed fixed-ratio (TD-FR) procedure was employed for presenting the displays. In this procedure, the pigeons were required to peck five times at the odd target of the different displays to enter the choice phase. Pecks to the distractor area of the different displays were recorded, but did not count toward the completion of the TD-FR requirement. Because same displays had no target area, the number of pecks required to enter the choice phase of these trials was individually yoked to prior different trials of that display type. This ensured that an equivalent number of pecks were made to same and different displays. The number of pecks made on individual different trials of each display type was retained and used on the same trials of that type as they were randomly scheduled to appear. If no responses were retained due to the chance randomization of trials, the mean number of responses from previous different trials of that display type from earlier in the session was used. When a same trial was the first one of a session, five pecks were required to enter the choice phase.

After completing the TD-FR requirement, the left and right choice hoppers were illuminated, but not raised, allowing a choice to be made. The stimulus display remained visible until a choice was made. 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 was extinguished for 15 s. An 8-s intertrial interval (ITI) followed either outcome. Daily sessions consisted of 160 trials, with each display type presented 32 times (16 same and 16 different trials) within each session. The testing order of these 160 displays was also randomized every session. The first 10 sessions of training consisted of 192 trials, with 32 additional texture trials added beyond those just described. Two pigeons were tested in the consistent condition, and 3 pigeons were tested in the inconsistent condition. The right–left mappings to the choice hoppers are listed in Table 1 for each pigeon and display type.

Results

Shown in Figure 2 are the results from the 100 sessions of training for each individual pigeon. The consistent pigeons learned to discriminate the four new display types faster and to a higher level of accuracy than did the inconsistent pigeons. A closer examination of Figure 2 reveals, however, that different patterns of performance emerged, depending on response mappings among the display types, that need to be considered in more detail. This was especially true for performance involving the texture and feature display types.

Two of the 3 pigeons ((1K and 3B) for which the texture and feature choice assignments corresponded with one another, showed immediate transfer to the feature display type upon its introduction and showed levels of performance well above chance with this type over the entirety of testing. The 3rd pigeon (2E) seemed to treat the feature displays just like the other three new display types, showing gradual improvement in choice accuracy over training. For the 2 remaining pigeons (4E and 5G), the choice assignments of the feature and texture displays were in direct conflict. This proved to be problematic not only in learning what to do with the same and different feature displays but also in maintaining performance with the previously learned texture displays. For 4E, it immediately reduced same–different texture discrimination to almost chance levels, with only a slow recovery of choice accuracy towards the end of training. In the 10 sessions immediately prior to the introduction of the new display types, this pigeon's accuracy with texture displays had been 88.4%, indicating that the drop in accuracy with texture displays coincided with the introduction of the new stimuli. For 5G, the feature displays were treated at first as if they were texture stimuli. This is suggested by the significantly below-chance accuracy for the feature display type (Figure 2). But just like with Pigeon 4E, the conflicting mapping between texture and feature stimuli resulted in the deterioration of texture same–different accuracy with time (Figure 2). Overall, these patterns of performance across pigeons indicate that the feature and texture display types were being perceived as similar to one other, resulting in almost immediate transfer when mapped consistently with one another or producing interference when in conflict. Because of this complication, further analyses of the learning differences between the two groups were conducted using only the geometric, object, and photo display types, which did not seem to suffer from the same similarity problem.

Figure 3 shows the acquisition results in 10-session blocks for the two groups as a function of mean choice accuracy averaged over the geometric, object, and photo display types. Overall, the consistent group learned these three display types significantly faster and to a higher level of accuracy than did the inconsistent group. This was confirmed by the presence a significant Group × Block interaction, $F(1, 9) = 3.7$, in a mixed analysis of variance (ANOVA) of these data. The large difference in mean choice accuracy over the last 10 sessions of training (consistent = 78%, inconsistent = 54%) further confirms this difference between the groups. An analysis of choice accuracy among the three display types involving just the consistent group (repeated measures ANOVA of Display Type × 10-Session Blocks) further revealed that there were no significant main effects of display type or its interaction with blocks, indicating that the rates of acquisition for these three display types were not significantly different from one another.

Discussion

This experiment revealed that the consistency of mapping of the choice alternatives and display types dramatically affected the rate of learning this multiple-class same–different discrimination. The consistent pigeons showed a pattern of acquisition basically similar to that reported before (Cook et al., 1997), with both pigeons learning to discriminate the same and different displays at approximately the same rate for all of the different display types. In contrast, the inconsistent pigeons failed to learn the entire discrimination, generally showing little ability to discriminate at above chance levels even after 100 sessions of training with the object, geometric, and photo display types. As outlined in the introduction, the implication of this inconsistent interference effect is that it suggests that a single rule is predominantly involved in learning this type of same–different discrimination, as suggested by Cook et al. (1997).

One problem that may complicate this conclusion is the marked evidence that the tex-

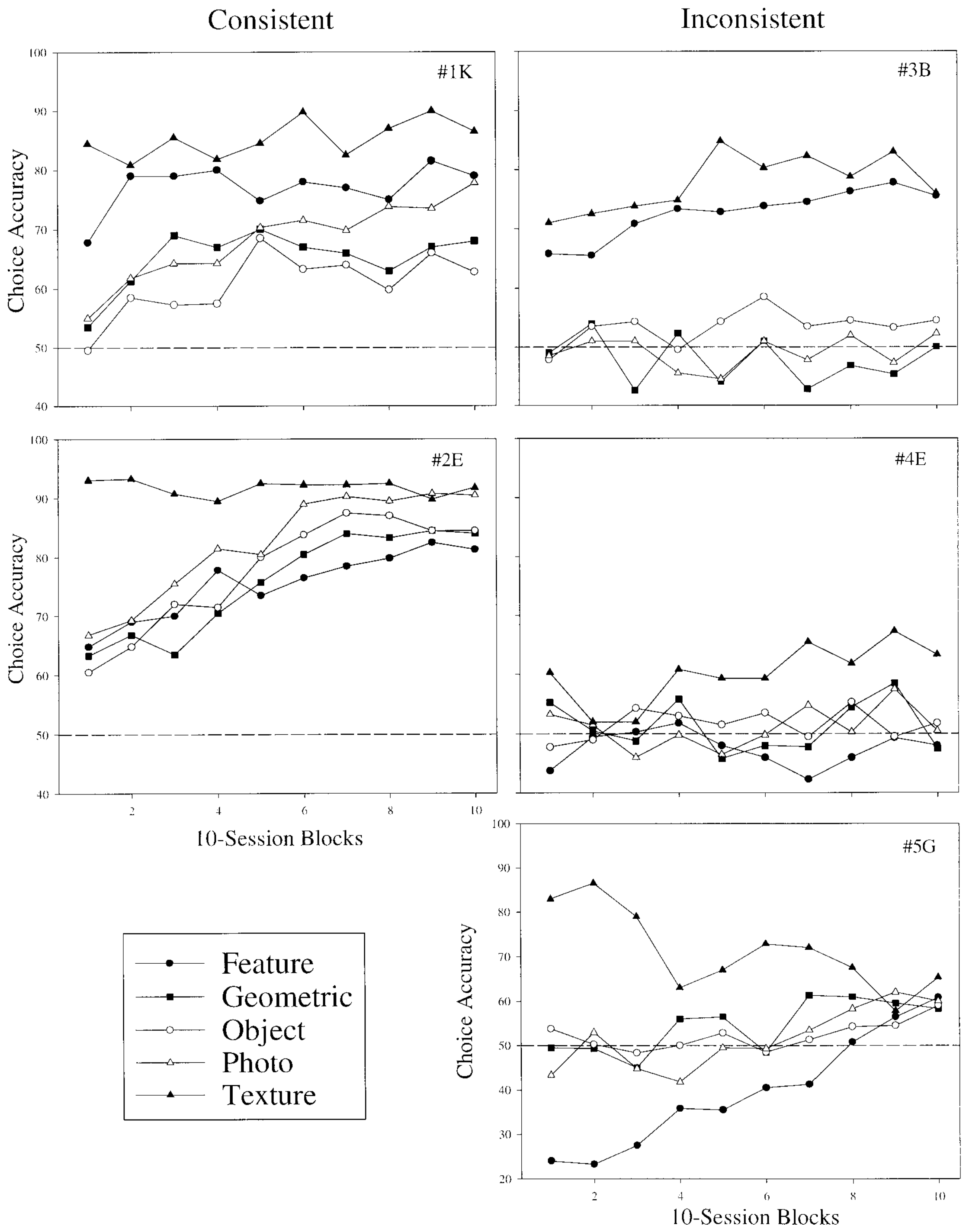

Fig. 2. Mean choice accuracy for texture, feature, geometric, object, and photo display types over the 100 training sessions for each individual pigeon. The two left panels show the acquisition data for the 2 pigeons in the consistent group. The three right panels show the acquisition data for the 3 pigeons in the inconsistent group. The dotted reference line in each panel depicts chance responding.

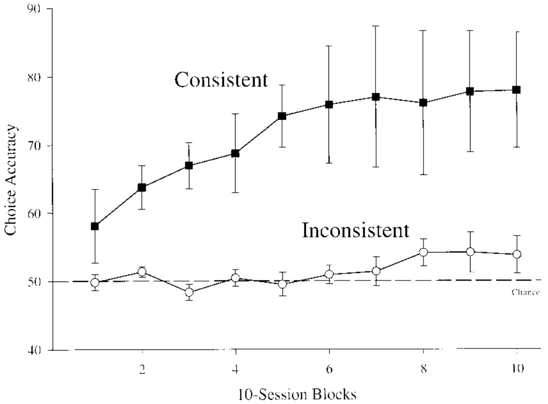

Fig. 3. Mean choice accuracy for the consistent and inconsistent groups over the 100 training sessions of Experiment 1 as averaged over the geometric, object, and photo display types. The dotted reference line in each panel depicts chance responding. Error bars show the *SEM* for each group.

ture and feature display types were seen as very similar to each other. As mentioned, this was evident in the immediate transfer to feature displays when they were consistently mapped with the texture displays and the production of strong interference when they were in conflict. Because the pigeons viewed these two display types as similar, the results for the inconsistent group may be compromised. This is because 2 of the 3 pigeons in this group received conflicting mappings of the texture and feature display types that also resulted in the deterioration of their previously learned texture-based same–different discrimination. Therefore, it is possible that their general failure to learn with the introduced display types may have been caused by confusion over how to deal with this conflict created with their existing learned discrimination. The 1 inconsistent pigeon that did receive a corresponding texture–feature mapping also showed the same inability to learn the entire discrimination, a result suggesting a more general interference effect caused by the inconsistent mappings rather than the specific disruption of already learned behavior. Nevertheless, trying to make the case on the results of a single pigeon motivated us to perform Experiment 2.

EXPERIMENT 2

Experiment 2 used the same logic and tactics as Experiment 1, but with a number of improvements. First, naive pigeons were used. This eliminated problems possibly caused by the extensive prior texture experience of the pigeons used in the first experiment. Second, the feature display type was not used, thereby eliminating any problems potentially caused by the similarity of this display type to the texture display type. Eliminating this display type also produced the benefit of having an even number of display-type assignments for Experiment 2 (texture, geometric, object, photo) in contrast to Experiment 1. In this experiment, 3 pigeons were tested in the consistent condition, and 3 pigeons were tested in the inconsistent condition. Following the completion of training, transfer tests with novel stimuli were conducted to assess the degree of concept formation attained by each group.

Method

Subjects and apparatus. Six naive male White Carneau pigeons were tested. They were maintained at 80% of their free-feeding weights in a colony room with a 12:12 hr light/dark cycle. During testing, the pigeons and had free access to water and grit in their home cages. The same stimuli and arrangements were used as in Experiment 1, except that the feature display type was not used.

Procedure. The initial autoshaping and training to peck the stimuli followed that described in Cook et al. (1997). Once the pigeons were regularly pecking at the displays, the procedure for each trial was the same as in Experiment 1. Each daily training session consisted of 160 trials. The one major change from Experiment 1 was that the feature display type was not tested; thus, each of the four remaining display types (texture, object, photo, geometric) were tested 40 times (20 same and 20 different trials) within each session. The testing order of the 160 randomly selected displays was also randomized within a each session. Three pigeons were tested in the consistent condition, and 3 pigeons were tested in the inconsistent condition. The right–left choice mappings are listed in Table 2 for each pigeon and display type.

Transfer tests. Following the completion of 100 sessions of training, all pigeons were tested with novel transfer stimuli of each display type. Transfer testing consisted of six sessions. Following a 30-trial warm-up period, 16 trans-

Table 2

Choice hopper assignments for display types in Experiment 2.

Pigeon	Stimulus class	Left	Right
Consistent group			
6B	Texture	Different	Same
	Geometric	Different	Same
	Object	Different	Same
	Photo	Different	Same
7D, 8L	Texture	Same	Different
	Geometric	Same	Different
	Object	Same	Different
	Photo	Same	Different
Inconsistent group			
9J	Texture	Different	Same
	Geometric	Same	Different
	Object	Same	Different
	Photo	Different	Same
10F	Texture	Same	Different
	Geometric	Same	Different
	Object	Different	Same
	Photo	Different	Same
11R	Texture	Different	Same
	Geometric	Same	Different
	Object	Different	Same
	Photo	Same	Different

fer test trials were randomly inserted among the remaining trials of a session. The 16 transfer trials in each session consisted of eight novel displays (four different displays [two color and two shape or gray scale] and four same displays) testing two of the four display types. Each transfer session tested a different pairing of the four display types. For the texture and geometric displays, three novel colors (pink, gray, and aquamarine) and shapes (star, plus sign, and two closely spaced diagonal dots) were tested. For the object displays, eight novel color or gray scale pictures (four birds, four flowers) were tested. For the photo displays, eight novel color or gray scale photo (two cats, two dogs, two birds, two flowers) were tested. Because of the numbers of stimuli used, each transfer trial used a novel combination of elements for each display type (i.e., they were all trial unique). The identical TD-FR response requirement was used with the transfer trials as with the baseline trials. All choice responses on transfer trials were neither reinforced nor punished and simply started the ITI for the next trial.

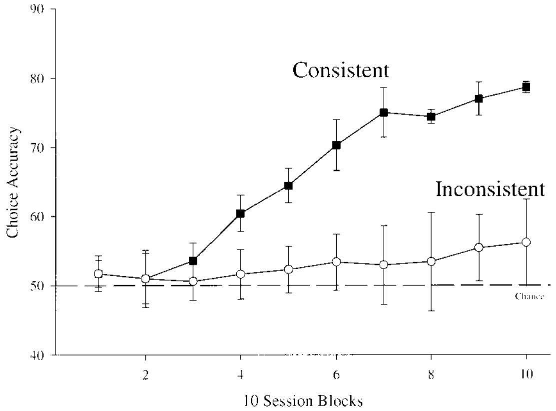

Fig. 4. Mean choice accuracy for the consistent and inconsistent groups over the 100 training sessions of Experiment 2 as averaged over the texture, geometric, object, and photo display types. The dotted reference line in each panel depicts chance responding. Error bars show the *SEM* for each group.

Results

Figure 4 shows the acquisition results in 10-session blocks for the two groups as a function of mean choice accuracy averaged over all four display types. Overall, the consistent group again significantly learned their discrimination faster and to a higher level of accuracy than the inconsistent group. This difference was confirmed by a mixed ANOVA comparing the two groups that revealed a significant Group × Block interaction, $F(1, 9) = 19.9$. The large difference in mean choice accuracy over the last 10 sessions of training (consistent = 79%, inconsistent = 56%) further confirms this difference between the groups.

Further comparisons within each group looked for differences in the rate of acquisition among the display types. Figure 5 shows the acquisition results for the individual pigeons, broken down by display type. For the consistent group, the pattern of results was similar to that observed by Cook et al. (1997). Learning of the same–different discrimination across the four display types seemed to proceed at the same rate, although learning with the texture display type was slightly and consistently faster for all 3 pigeons. A repeated measures ANOVA of accuracy for each display type confirmed this latter difference, revealing the presence of a significant Display Type × Block interaction, $F(27, 54) = 1.8$. A second ANOVA, in which the results of the

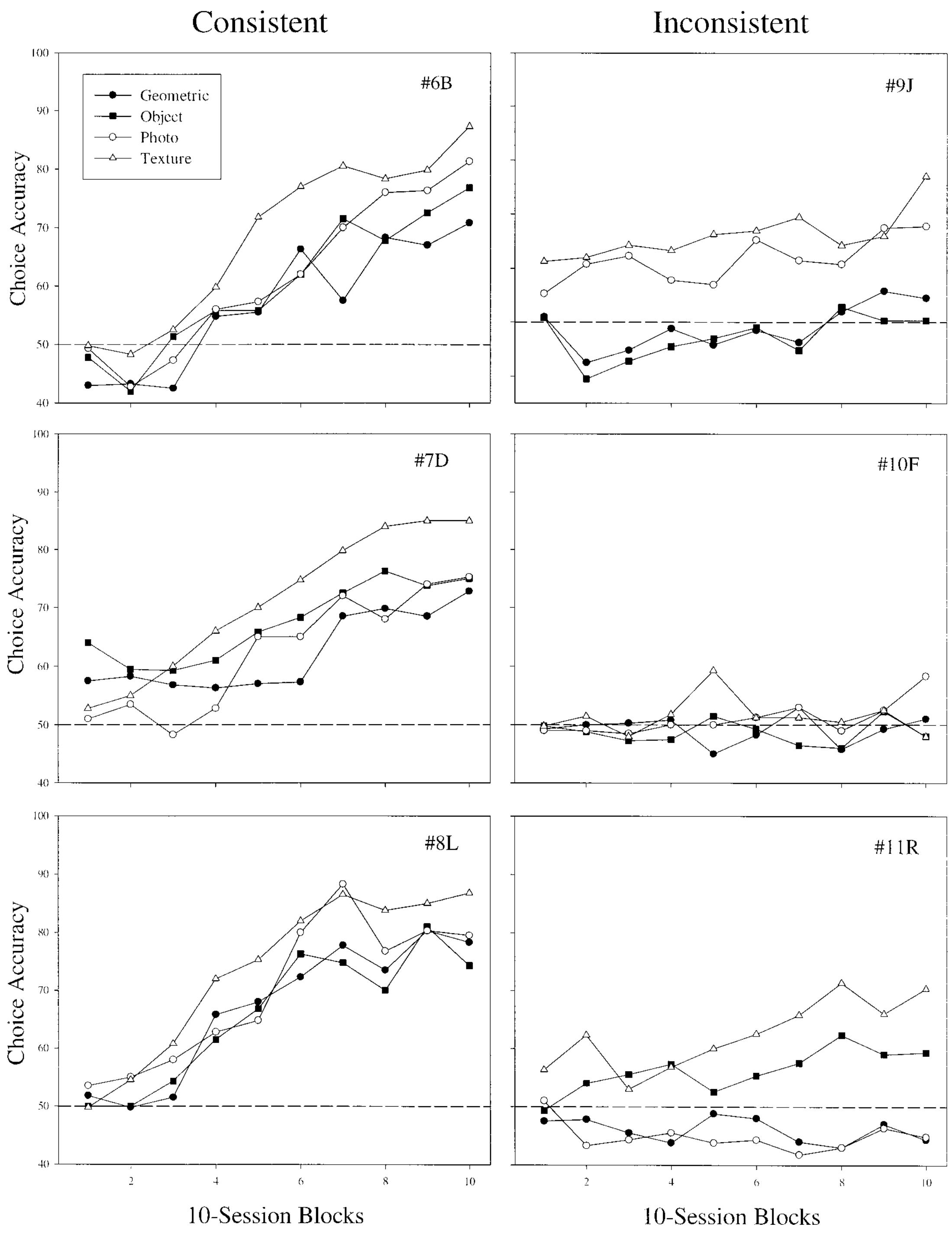

Fig. 5. Mean choice accuracy for texture, geometric, object, and photo display types over the 100 training sessions for each individual pigeon. The three left panels show these acquisition data for the 3 pigeons in the consistent group. The three right panels show the acquisition data for the 3 pigeons in the inconsistent group. The dotted reference line in each panel depicts chance responding.

texture displays were not included, revealed no significant interactions or main effect of display type among the geometric, object, and photo display types. Thus, choice accuracy improved at the same rate for these three latter display types, but this was slightly slower than the accuracy exhibited with the texture display type.

The effects of display type were more complex in the inconsistent group. Because each pigeon showed a different pattern of performance, the identical repeated measures ANOVA used above revealed only a significant effect of blocks, $F(1, 10) = 3.2$. Nevertheless, display type clearly had effects, except for Pigeon 10F, which exhibited no signs of learning at any point. Pigeon 9J showed consistent evidence of above-chance discrimination with the texture and photo display types but not with the two remaining types. Pigeon 11R showed evidence of above-chance discrimination with the texture and object display types but no learning with the two remaining display types. In keeping with the faster texture acquisition seen with the consistent group, it appears that discrimination of the texture display type was also easier for the inconsistent pigeons, because the 2 pigeons that learned something in this group did so with the texture displays. Interestingly for both of these pigeons, the display type that shared the same choice mapping as the texture displays also exhibited some evidence of learning. In neither of these cases, however, did learning ever proceed as quickly as it did with the consistent pigeons, nor did it reach the same high level of choice accuracy by the end of training.

To better understand the differential learning and transfer between the two groups, how they learned their respective discriminations was studied further by examining performance as a function of same and different displays. The results of this analysis are shown in Figure 6. For the consistent pigeons, the same two-phase pattern of same–different learning reported by Cook et al. (1997) was found. Accuracy first increased with the same displays followed over the next sessions by increased accuracy with different displays, with both types of displays eventually reaching similar levels of accuracy later in training. For the 2 inconsistent pigeons that showed evidence of learning, these patterns were different. The middle and bottom panels of Figure 6 displays same–different performance for each of these pigeons. Pigeon 9J chose accurately with same displays, but never successfully performed with the different displays, except perhaps at the end of training. Pigeon 11R chose accurately with different displays, but never successfully performed with the same displays. These contrasting patterns of same–different performance suggest that the consistent and inconsistent groups were learning different things over the course of acquiring their respective discriminations. The 3 pigeons in the consistent group seemed to learn the entirety of the discrimination and in the same way, whereas the 3 pigeons in the inconsistent group each behaved differently, with any learning limited to a subset of the display types and even further limited to just the same or different displays of those display types.

The results of the transfer tests were consistent with these acquisition results. The consistent group showed good transfer to the novel same–different stimuli, but the inconsistent group failed to transfer to these stimuli. For the consistent group, mean accuracy with the transfer stimuli averaged across all four displays types was 71.7%, and choice accuracy with the familiar baseline trials was 79.5%. For the inconsistent group, mean choice accuracy with the transfer stimuli was 50.8%, and mean choice accuracy on the baseline trials was 60.7%. Individual single-mean t tests for each pigeon across the six test sessions revealed that mean transfer performances for all 3 consistent pigeons were significantly above 50% across the six test sessions, $ts(5) > 2.57$; Pigeon 6B = 69.7%; 7D = 67.3%; 8L = 75.8%, but mean transfer performance was not significantly above chance for any of the 3 inconsistent pigeons, $ts(5) < 1$; Pigeon 9J = 56.2%; 10F = 51.2%; 11R = 45.1%. Specific examination of transfer performance for those display types that supported some degree of above-chance performance in the 2 inconsistent pigeons also failed to show any consistent evidence of transfer (9J texture = 50%, photo = 62.5%; 11R texture = 38.2%, object = 54%).

Discussion

Once again, a large performance difference was found between the two groups, but

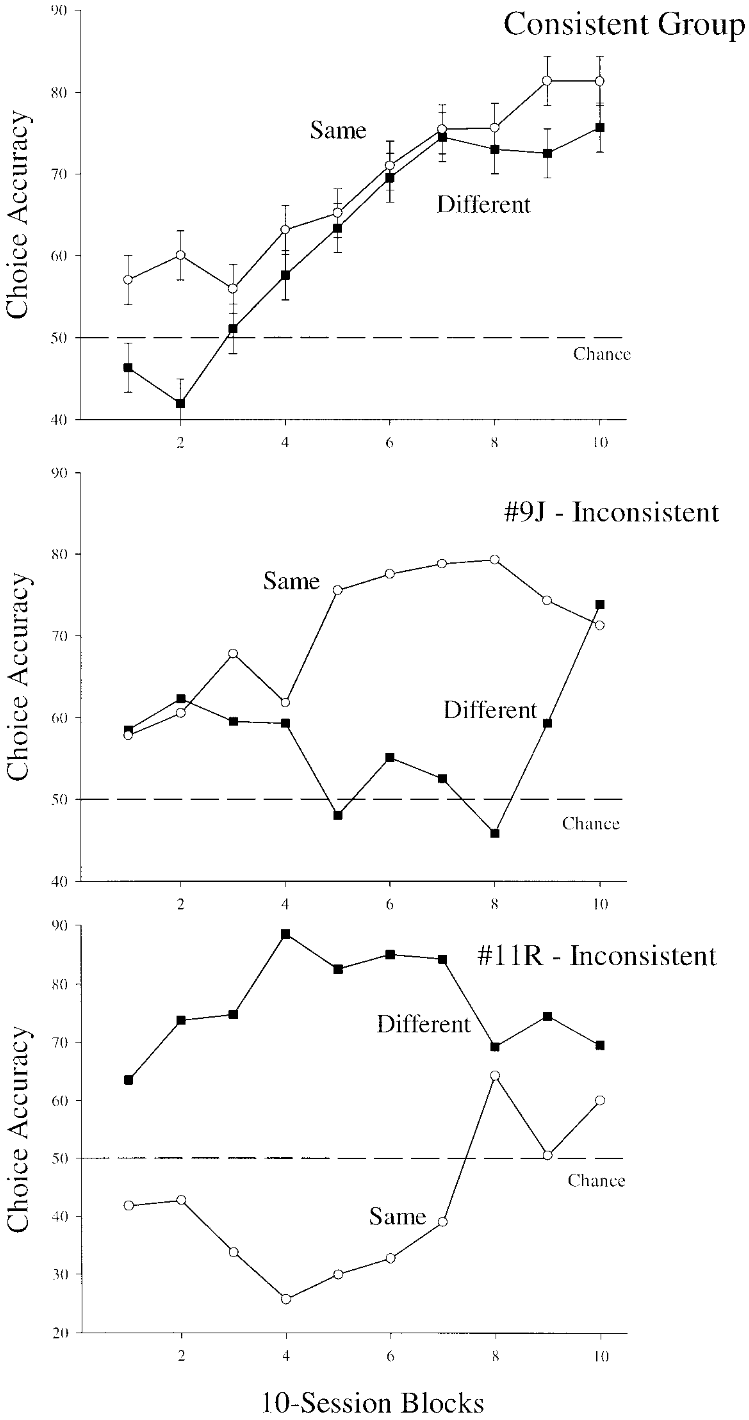

Fig. 6. The top panel shows mean choice accuracy for same and different trials collapsed over all four display types for the 3 pigeons in the consistent group. Error bars show the *SEM* for the group. The middle panel shows mean choice accuracy for same and different trials averaged over the texture and photo types for Pigeon 9J of the inconsistent group. The bottom panel shows mean choice accuracy for same and different trials averaged over the texture and photo types for Pigeon 11R of the inconsistent group. The dotted reference line in each panel depicts chance responding.

without the complications of Experiment 1. Overall, the consistent group learned faster and to a higher level of accuracy than did the inconsistent group. Furthermore, their acquisition proceeded at the same rate for three of the four displays, with the texture displays being learned somewhat more easily. Finally, this group showed good evidence of discrimination transfer when tested with novel stimuli, which is indicative of concept formation as the basis for their performance. In contrast, the inconsistent group showed considerable difficulty in learning their discrimination. One pigeon completely failed to learn anything over the 100 sessions of training. Two of the inconsistent pigeons did show some moderate degree of learning, but only with a subset of the display types. Further their pattern of responding to the same and different displays of these ''learned'' display types suggested that even this partial discrimination was limited to only one or the other stimulus organization. This incomplete learning of even the basic discrimination by the inconsistent group was responsible for their overall failure to show transfer to the novel stimuli.

These results provide further evidence that pigeons learned and transferred a visual same–different discrimination as instantiated by numerous, highly polymorphic types of stimulus displays. Further, they suggest that while doing so the pigeons learned a single discriminative rule that divides all of these stimuli into two broader classes, rather than by using a number of separate and independent rules or feature-based solutions. This is also reflected in the fact that the consistent pigeons learned their discrimination at the same rate across the majority of the display types. It is not clear why the texture displays were learned somewhat faster. One possibility is that the exclusion of the feature displays that required global processing of the display's relations permitted some of the local properties of the texture displays to become more salient than those in Cook et al. (1997). For instance, the close proximity of the dimensionally simple color or shape elements at the target–distraction boundary of this display type may have made their same–different relations easier to detect in comparison to the complex mixture of variable colors and shapes that existed in the object and photo stimuli. It has been suggested in other contexts that such textural boundaries or edges are salient features for the pigeons' early visual system (Cook, 1992, 1993), and the absence of the more variable feature displays may have helped to attract processing to these useful features.

With difficulty, some members of the inconsistent group did exhibit a degree of learning. Their discrimination was different, however, from that of the consistent group. Whereas the consistent group seemed to have learned a single broadly applied solution, these pigeons mustered only a partial and limited solution to only a subset of the stimuli. Their slower and partial acquisition of the discrimination, failure to transfer to novel stimuli, and contrasting patterns of responding to the same and different displays all support the conclusion that the fundamental nature of learning in the inconsistent group was different from that of the consistent group and seemed not to have a conceptual foundation.

EXPERIMENT 3

The above results suggest that the consistent pigeons treated the same and different trials of each contrasting display type as equivalent instances of these two common underlying concepts. That is, despite the considerable differences and variability among the displays, the pigeons recognized the fundamental sameness of the repeated elements in the same displays and the contrasting presence of a polymorphic difference in the different displays. The logic of these experiments, however, hinges on the pigeons' ability to distinguish among the four display types used here. If they cannot distinguish among the display types, as appears to have happened with the texture and feature displays in Experiment 1, then the apparently common recognition of the same and different organizations across display types would not be surprising, nor would the interference caused by the inconsistent mapping condition. If these latter pigeons could not have discriminated among the display types, then they could never have learned the required discrimination. Although the display types were designed to be different from one another (and were so to humans comparably tested in the inconsistent condition), this key assumption nevertheless requires empirical support. That 2 of the 3 inconsistent pigeons showed some evidence of learning suggests that at least some of the display types were discriminable from each other, but this is limited and indirect evidence at best. As a stronger and more direct test of this assumption, we collected experimental evidence about the capacity of pigeons to discriminate among the display types used in Experiments 1 and 2.

Method

Subjects and apparatus. Four experienced male White Carneau pigeons were tested in Experiment 3. These pigeons had previously had same–different training similar to that described for the consistent group, and were familiar with each of the display elements and types used here (this previous training is described by Cook et al., 1997, 1999). They were maintained at 80% of their free-feeding weights in a colony room with a 12:12 hr light/dark cycle. During testing, the pigeons had free access to water and grit in their home cages.

The apparatus was similar to that used to test the pigeons in the previous experiments. The most significant difference was that pecking responses were collected using a different brand of touch screen (15-in. Carroll Touch infrared touch screen) that presented a slightly larger area of the display and was less recessed relative to the plane of the front panel. In this experiment, all food reinforcement was delivered from a center hopper located 10 cm below the bottom edge of the touch screen. The bottom of the feeder's opening was flush with the floor.

Procedure. The 4 pigeons were tested using a three-alternative conditional discrimination procedure. Only the photo, geometric, and object display types were tested. Using the same training elements as in Experiment 2, 16 object elements (eight color and eight gray scale drawings of birds and flowers) were assigned as the samples for one choice alternative, 16 photo elements (eight color and eight gray scale photos of dogs and buildings) were assigned to a second choice alternative, and all 64 geometric elements (the pairwise combination of eight colors and shapes) were assigned to the third choice alternative. On each trial, one of these elements was selected at random to be the sample. It was presented until a pigeon made 10 pecks to it, at which point it was turned off and the three choice alternatives were turned on. The pigeon's task was to categorize which of the three display types the sample was a member of by selecting the associated test stimulus. The display-type sample appeared in the center of the display 18 cm from the bottom edge of the touch screen. The three choice alternatives (blue, white, and red squares; 4 cm by 4 cm) appeared in fixed locations relative to the sample. The center choice stimulus appeared 8 cm (center to center) directly below the sample's location, and the right and left alternatives were 8.5 cm (center to center) to either the right or left of the sample. Correct choices were reinforced with 2.5-s access to mixed grain. Incorrect choices received a dark timeout of 5 s. Each session consisted of 96 trials (32 photo, 32 object, and 32 geometric samples). Trials were separated by a 4-s ITI. A correction procedure was used from the beginning of training, but only the first trial was used for the purposes of scoring performance.

Transfer tests. Following acquisition training, the pigeons were tested with new elements from each display type. Four different tests were conducted over 10 days for each pigeon. Each test session consisted of 12 nonreinforced test trials (four object, four photo, and four geometric stimuli) that were randomly mixed into the 96 baseline trials. All test stimuli were trial unique and were tested only once. All choices resulted in no consequences and instead led immediately to the ITI of the next scheduled trial.

Results and Discussion

The pigeons learned the task easily. It took a mean of only six sessions for the 4 pigeons (5, 5, 6, and 8 sessions each) to reach a choice accuracy of greater than 80% for a session (chance = 33%). Performance with the different display types was also good. By the 10th session, mean choice accuracy with object (93.0%), photo (90.8%), and geometric (88.4%) types was high, indicating that these classes of items were easy for the pigeons to distinguish. This display-type discrimination also supported significantly above-chance transfer when tested with new examples from each of the three display types (67.1%); *t*(3) = 18.2. Additional analyses examined which display types might be confused with each other at the time of the test, but these revealed little in the way of systematic bias. This suggests that the display types were approximately equally discriminable.

The ease of learning this display-type categorization task and the resulting high accuracy and ready transfer to new samples of each display type all indicate that the elements of the object, photo, and geometric display types were readily discriminated. This outcome suggests that the common recognition of relational sameness and difference across the displays does not derive from a general failure or inability to discriminate among the separate display types, but comes from a higher order determination of the relations among the component elements. Besides its implications for the present results, these results add extra weight to those previously reported by Cook et al. (1999). They found significant above-chance same–different discrimination transfer to novel presentations of the photo display type following training with the other four display types. This finding is important because all previous demonstrations of same–different transfer always tested novel items selected only from within the same display type used during training. The above display-type discrimination directly confirms that the photo display type was truly discriminable from the other display types, adding more weight to the general conclusion that pigeons can apply their solution to this type of multiple-class same–different task to items derived from both within and outside the range of their training.

GENERAL DISCUSSION

The major implication of these findings is that a single discriminative rule is employed when pigeons learn this type of multiple-class same–different choice discrimination. These experiments show that it was much easier for these pigeons to learn one consistent rule for classifying large numbers of same and different stimuli than to learn multiple independent rules. Further, learning this single rule also supported transfer to novel stimuli, indicating that conceptual-like behavior is involved. These results are consistent with our previous evidence suggesting that pigeons may be capable of learning a generalized relational concept when trained to classify large numbers of multielement same and different displays of different types.

Figure 7 provides a diagram of a framework to describe the stimulus and decision structures used by the pigeons in solving the present same–different task. It is a direct extension of the signal-detection framework proposed by Cook and Wixted (1997) in their analyses of texture-based same–different discriminations, but is modified to include information gleaned from more recent experiments. In this framework, the horizontal axis depicts the relational variable of stimulus difference, with displays containing larger element differences shown to the right and more uniform displays and same displays depicted towards the left. The vertical axis shows the different display types. Because each is empirically discriminable from the other, the four display types are depicted as independent distributions (although not included in the diagram, the feature display type's distribution would overlap that of the texture display type, given the results of Experiment 1). The distributions on the left capture the clustered internal representations of the various same displays, and the distributions on the right capture the clustered internal representations of the various different displays. The placement of the display types with respect to one another is not intended to show their relative similarity, a point on which there is little direct evidence at the moment. Their positioning is designed to show that discriminability relative to each other is greater than that separating the same and different organizations, as indicated by how easy it was for the pigeons to learn the display-type discrimination described in Experiment 3 relative to the slower acquisition of the same–different task tested in Experiments 1 and 2. The two texture-related distributions are placed somewhat further apart, because the current experiments suggest that the determination of stimulus difference and uniformity is slightly easier for this display type. The different distributions are depicted as wider than the same distributions because they seem to possess more inherent variability. This was first suggested by the signal-de-

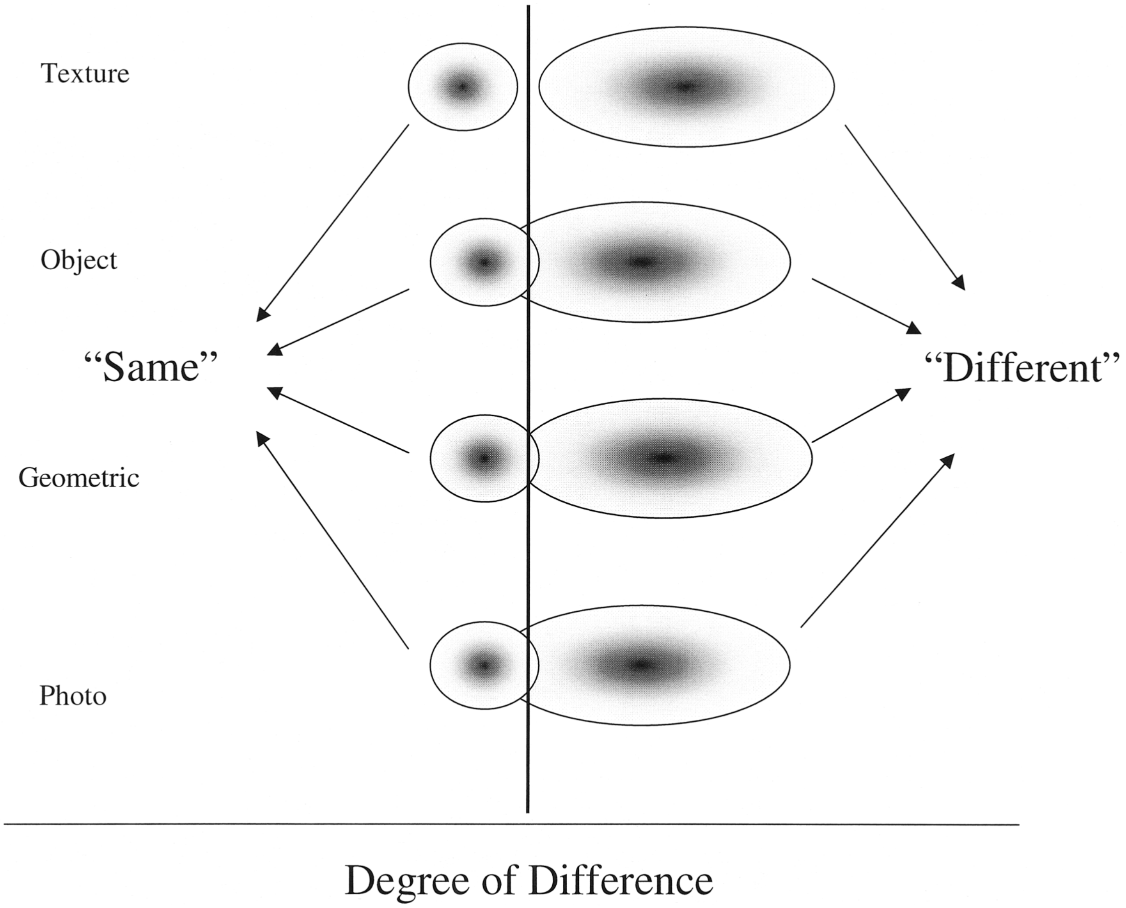

Fig. 7. Proposed theoretical structure for the stimulus and decision framework used by pigeons in their solution of this type of multiple-class same–different discrimination.

tection modeling performed by Cook and Wixted (1997) that found that the best fitting variance estimates for different displays were about three times that for same displays. Consistent with this, Young and Wasserman (in press) recently found that uniform displays may be more distinctive than ones characterized by degrees of difference (see also Honig & Matheson, 1995). In addition, the faster learning of the same displays observed in the current studies also suggests that same and different displays vary in their relative distinctiveness. Finally, given this framework, the current results suggest that only a single decision rule is placed within this stimulus space. This decision bound effectively separates the same and different stimuli created by the different display types. This engagement of a single rule is suggested by the strong inconsistent interference effect found in both studies and the similar rates of acquisition observed across display types.

Overall, the broad nature of the discrimination behavior observed in these experiments seems to require some form of abstraction that allows the grouping of the variable same and different displays into distinct sets. A key question at this point concerns the nature of this abstraction, or to place it within the framework outlined in Figure 7: What is the identity of the dimension along which the single discriminative rule is placed? The answer that has been consistently proposed for several reasons is that the pigeons respond to the degree of difference among the component elements. Other alternatives have been suggested, however. For instance, Mackintosh (2000) has suggested that simple visual features might be sufficient. Although this suggestion was originally made in the context of reviewing Cook et al.'s (1995) texture-based work, it seems much harder to identify the simple features that reliably distinguish the polymorphic same and different displays tested here. One could suggest that perhaps the pigeons are responding to the presence and absence of some form of generalized spatial anomaly in the displays. That is, there is a global visual disturbance created in the different displays by the odd element placed within the otherwise repeating mosaic of features in the remaining parts of the displays. Although no direct evidence in the present experiments can rule out this alternative, I have recently been successful in training pigeons to make same–different judgments with successively presented stimuli (Cook, in press), suggesting that this type of spatial factor is not the key to learning such tasks.

Another possibility centers around differences in the number and relative familiarity of the same and different displays. Macphail and Reilly (1989) have demonstrated that pigeons are sensitive to the relative novelty of complex pictures and use this information to successfully discriminate among slides presented for the second time within a session (S−) from the first (S+). Because of the large difference in the number of same and different displays in these experiments, relative familiarity might similarly mediate the current discrimination. From this perspective then, the critical difference between displays is not one of stimulus mixture, but is driven instead by the animal's remembering specific combinations of elements. This is an unlikely explanation for our results for several reasons. It predicts, for example, that as specific different displays become increasingly familiar, accuracy should decline. But we have found little or no decline in performance with repetitions of the specific displays (Cook et al., 1995). More conclusively, it is ruled out by the positive transfer results of Experiment 2 and those reported in Cook et al. (1997, 1999). Because all same and different transfer displays are equally unfamiliar to the pigeons, any type of familiarity-based hypothesis cannot account for the successful transfer of the discrimination to these stimuli.

Yet another dimension that has been suggested to account for same–different-like performance is based on the concept of entropy (Young & Wasserman, 1997, 2001), a metric that captures the amount of variability in a display. In several different experiments, Young and Wasserman successfully accounted for the performance of pigeons in their version of the same–different task based on combinations of numerous small Macintosh® icons. Although this measure could play a role in the present studies, it is not considered to be the most important factor. We have found that following the type of training used in this study, variations in the number of elements in our displays results in choice behavior that is incompatible with an entropy account (Cook et al., 1997). Further, the computed entropy of the geometric, photo, and object different displays tested in the present experiments is within the range of entropy values that, in Young and Wasserman's experiments, have repeatedly failed to produce strong different responding in their procedures. Given that pigeons readily did so in the present context suggests that a different type of learning is involved in the two procedures.

Whatever the nature of this abstraction, the spatially distinct common response outputs (i.e., the choice hoppers) used in this study may play some role in the pigeons' choice behavior. It is known that, in other contexts, differential outcomes can facilitate the learning of conditional discriminations (Trapold, 1970) by the formation of outcome expectancies (e.g., Edwards, Jagielo, Zentall, & Hogan, 1982; Peterson, 1984; Urcuioli & DeMarse, 1996). It is possible that the spatially separate hopper outcomes likewise may help the pigeons to recognize more quickly the many-to-one commonality of the same and different stimulus organizations. But presence of such differential outcomes seems not to be a necessary condition for the formation of such abstractions. In a previous same–different study using more traditional differential outcomes (safflower and mixed grains), there was no evidence that outcome quality was being encoded or used by the pigeons in learning the task (Cook et al., 1995). Further, the same–different experiments of Young and Wasserman (1997, 2001) used a common reinforcer for both types of display organizations Lastly, pigeons can learn a successive variation of the same–different task in which the items appear sequentially (Cook, in press), but which employs only a single central hopper for all reinforcement. These latter findings suggest that the type of hopper arrangement used here is at best facultative in its role of mediating the learning of these kinds of same–different discriminations.

Although the exact identity of the dimension critical to the pigeons in same–different tasks remains to be determined by future research, the current experiments contribute to this search by providing evidence of the pivotal idea that only a single type of decision is involved when pigeons learn this type of multiple-class same–different discrimination. Such results continue the steady progress in building a convincing case from different types of converging evidence that pigeons can conceptualize generalized stimulus relations among stimuli.

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