

## Time-course of control by specific stimulus features and relational cues during same–different discrimination training

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We trained 7 pigeons to discriminate visual displays of 16 *same* items from displays of 16 *different* items. The specific stimulus features of the items and the relations among the items could serve as discriminative stimuli. Unlike in most studies of same–different discrimination behavior, we gave a small number of probe tests during each session of acquisition to measure the time-course of control by the learning of specific stimulus features and relational cues. Both the specific stimulus features and relational cues exerted reliable stimulus control, with the specific stimulus features exerting more control during the final three fourths of same–different learning. These findings replicate research suggesting that pigeons encode both the specific stimulus features and relational cues, and for the first time document the time-course of control by each kind of cue.

Herrnstein, Loveland, and Cable (1976) were among the first to study category learning by nonhuman animals. These researchers trained pigeons to classify 80 photographic slides into two categories defined by whether the photographs did or did not display a tree. The pigeons rapidly learned to classify these slides into tree and nontree categories. Note, however, that the pigeons could have used either the relations among the stimuli (tree vs. nontree) or the specific stimulus features of the individual photographs to accurately learn and transfer this discrimination. Because memorizing 80 slides seemed to be an inordinately difficult task for pigeons to master, an explanation based on the specific features of the stimuli appeared at first blush to be less plausible than a relational interpretation.

But first impressions can be deceiving. To test the possible role of individual stimulus memory during category learning, Vaughan and Greene (1984) trained pigeons to discriminate among color slides of outdoor scenes that were randomly assigned to the S+ and S– categories. Only the memory of each item in a set would permit accurate discrimination, because there was no consistent feature of the sets of items that the birds could use to form a relational rule. Nevertheless, the pigeons accurately discriminated among the 160 S+ and 160 S– slides after only a few exposures to each. More recent research by Cook, Blaisdell, Levison, and Gillette (2001) has revealed that pigeons can remember more than 1,000 such arbitrary visual items!

Because of the pigeon's prodigious memory for individual visual stimuli, researchers have endeavored to eliminate the specific features of stimuli as a discriminative feature in relational learning tasks by generating the same and different stimulus displays from a *single* set of stimuli. For example, if two stimuli, A and B, constitute a single stimulus set, then *same* displays would be composed of the left–right pairs AA and BB, and *different* displays would be composed of the left–right pairs AB and BA. The emphasis that this training method places on stimulus relations rather than on the specific stimulus features should encourage relational discrimination learning (Herrnstein, 1990). Indeed, prior research has found robust discrimination learning under just such conditions (e.g., Cook, Katz, & Cavoto, 1997; Santiago & Wright, 1984; Wasserman, Hugart, & Kirkpatrick-Steger, 1995; Young & Wasserman, 1997).

Pigeons' ability to encode the specific features of individual stimuli when relational cues are eliminated and to learn relational rules when the specific stimulus features are eliminated has led some theorists to conclude that discriminative behavior during relational learning may be controlled by either the memory of individual stimuli or the relations among the stimuli, but not by both sources of information (see Fetterman, 1996, for a review). This perspective may be unrealistic, considering that the things to be categorized in the natural environment need not always be found in both the *same* and *different* sets during learning.

Recently, Gibson and Wasserman (2003) trained pigeons to discriminate displays of 16 *same* items from displays of 16 *different* items when both the specific features of the items and the relations among the items could serve to distinguish the displays. The pigeons learned about both the specific stimulus features and stimulus relations when these two sources of information served as

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redundant, relevant cues. These findings are consistent with work suggesting that pigeons and monkeys attend to both specific and relational information during discrimination learning (Wasserman, Frank, & Young, 2002; Wright, Cook, & Kendrick, 1989).

Of additional importance, tests of cue competition following acquisition in the Gibson and Wasserman (2003) study suggested that the specific stimulus features might have exerted greater stimulus control than the relational cues did. Indeed, the fact that pigeons are capable of rapidly learning the specific features of hundreds of complex stimuli (Vaughan & Greene, 1984) suggests that pigeons may first learn about the specific features of the items and that the emergence of control by relational cues may occur later during same-different learning. Because Gibson and Wasserman (2003) tested for control by relational cues and the specific stimulus features after the birds had mastered the same-different discrimination—as is usual in the category learning literature—the time-course of control by each cue could not be directly evaluated.

In the present experiment, we adapted the methods of Gibson and Wasserman (2003) to train pigeons to discriminate displays of 16 *same* items from displays of 16 *different* items. Both the specific features of the items and the relations among the items could serve as discriminative features of the displays during training. Specifically, pecks to one button (e.g., red) were reinforced with food in the presence of identical visual items from Set A (*same* displays), whereas pecks to a second button (e.g., green) were reinforced in the presence of nonidentical visual items from Set B (*different* displays).

We monitored control by relational and the specific stimulus features “on-line” with a low density of specialized probe tests as the birds were acquiring the same-different discrimination. To assess the development of stimulus control by the relations among the icons, we tested the pigeons with displays of identical and nonidentical items from a third set (Set C) during each session. We also tested the pigeons with displays of identical items from Set B and nonidentical items from Set A during each session. These “reversed” displays pitted relational cues and cues provided by the specific stimulus features against each other. This “on-line” monitoring procedure is quite different from that commonly used by categorization researchers, and it allows the examination of possible differences in the time-course of stimulus control by relational and the specific stimulus features during same-different discrimination learning.

## METHOD

### Animals

Seven experimentally naive adult feral pigeons were studied. The birds were individually housed and maintained at 85% of their ad lib weight with controlled feedings of mixed grain. All birds had free access to water that contained a vitamin supplement.

### Apparatus

Training and testing were conducted in operant chambers described by Young and Wasserman (1997). Stimuli were presented in

a  $7 \times 7$  cm display area on a computer monitor positioned in the front wall of the chamber. Responses were recorded from red and green report buttons located to the lower left and lower right of the display area, respectively. A touchscreen (EloTouch, Fremont, CA) recorded the locations of responses that the birds made to the screen. A feeder located outside the chamber dispensed 45-mg food pellets (Research Diets, New Brunswick, NJ) into a food cup located on the floor next to the rear wall of the chamber.

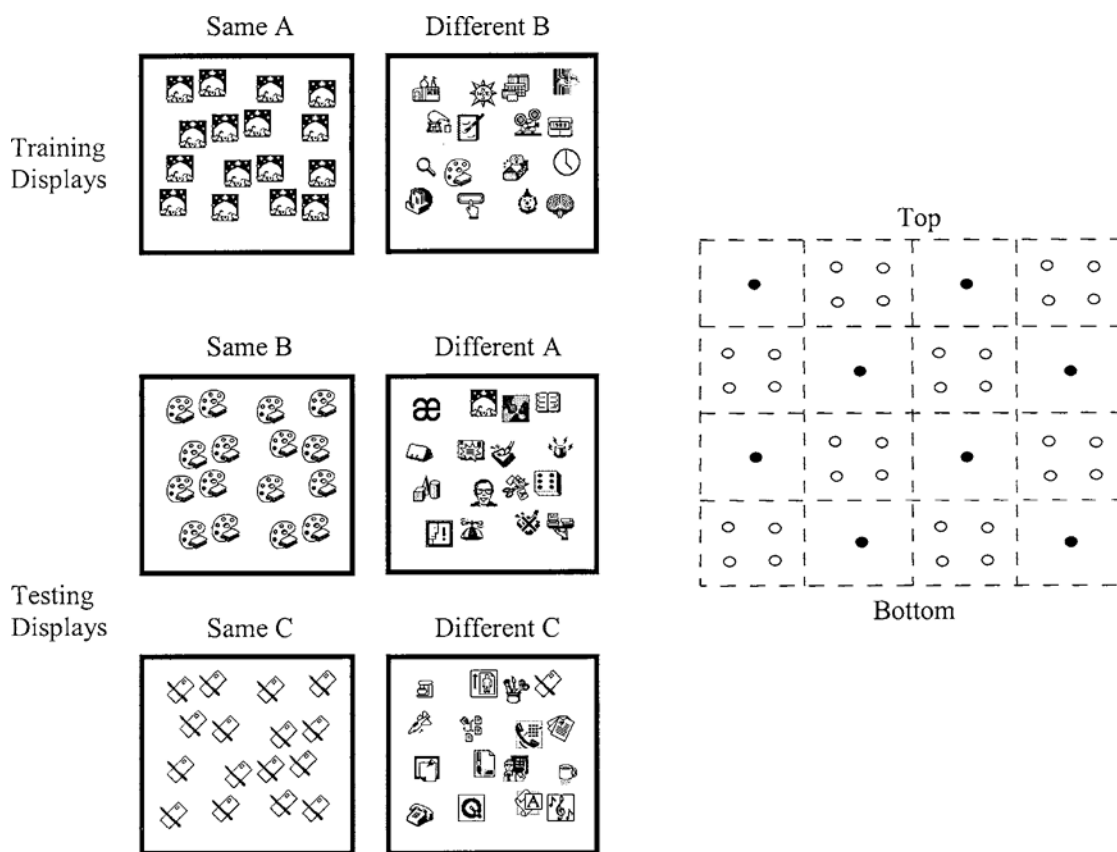
### Experimental Stimuli

Forty-eight highly distinguishable Macintosh icons were randomly sorted into one of three sets—A, B, and C—each containing 16 icons. On each trial, the birds were presented with either a *same* or a *different* display. Sixteen identical copies of a randomly selected icon from a given set were used to generate *same* displays, whereas *different* displays contained all 16 nonidentical icons in a set. *Same* and *different* training displays were always composed of icons from Set A and Set B (Figure 1). One group of birds ( $n = 4$ ) encountered *same* arrays composed of icons from Set A and *different* arrays composed of icons from Set B, whereas a second group of birds ( $n = 3$ ) encountered *same* arrays composed of icons from Set B and *different* arrays composed of icons from Set A. During a session, the birds encountered four types of testing displays (Figure 1): (1) same-reversed—*same* displays composed of icons from the other set (e.g., if trained with Set A, then tested with Set B); (2) different-reversed—*different* displays composed of icons from the other set (e.g., if trained with Set B, then tested with Set A); (3) same-transfer—*same* displays composed of icons from the transfer set (Set C); and (4) different-transfer—*different* displays composed of icons from the transfer set (Set C). The 16 icons in each of the training and testing arrays were positioned in the display area according to an algorithm that generated displays that were decidedly “jittered” (Young & Wasserman, 2001) and had irregular outlines and icon alignments (Figure 1). The positional algorithm made the global shape of the *same* and the *different* displays highly similar to one another and eliminated the spatial organization of the displays as an effective discriminative stimulus. Much additional research has suggested that spatial frequency does not readily account for same-different learning using these displays (e.g., Young & Wasserman, 1997, 2001).

### Procedure

Each daily session was composed of 112 trials. Two *same* and 2 *different* warm-up training trials were given at the beginning of the session and were followed by three consecutive blocks of 36 trials. During each of the three blocks, the birds were presented with 16 *same* and 16 *different* training displays as well as with 1 display from each of the four different types of testing displays: same-transfer, different-transfer, same-reversed, and different-reversed. The order of the training and testing displays was randomized within each block.

A trial began when a black-cross orienting stimulus appeared on a white background in the display area. A single peck by the bird anywhere in the display area advanced the trial. Next, a *same* or a *different* array appeared as a black-on-white picture in the display area for a fixed interval (FI) of 15 sec. A single peck to the display area after the FI reversed the display to a white-on-black picture (to signal the availability of the choice buttons), and the red and green choice areas below the display were then illuminated. The choice buttons (red or green) and the display relationships (same or different) were balanced within each group. A peck to the red button on *same* trials or to the green button on *different* trials was considered correct for approximately half of the birds in each group, whereas the opposite relationship held true for the other birds in each group. A correct choice during the training trials resulted in a food pellet's being delivered, the termination of the trial and the display, and the response buttons' being cleared from the screen. Following an incorrect choice during a training trial, the house light was darkened



**Figure 1.** (Left) Examples of the 16-icon *same* and *different* training and testing displays. The icon set that was used to generate the items in the *same* or *different* array is listed above each display. (Right) The 16 icons in the *same* and *different* displays were positioned on the screen using the grid indicated in this diagram. In the cells marked with a filled circle, the icon was placed into the center of the cell; in the cells marked with open circles, the icon was randomly placed into one of the four corners of the cell. This spatial distribution process resulted in arrays of icons in which neither the *same* arrays nor the *different* arrays were at all orderly; in no case could two icons fall into either vertical or horizontal alignment with one another.

and the icons were removed from the screen. The picture was returned to its original black-on-white state, and the trial was repeated until a correct response was made. An intertrial interval with a mean of 10 sec (range 5–15 sec) followed the termination of each trial. The events were identical on the testing trials, except that nondifferential reinforcement—that is, the delivery of food regardless of the pigeon's choice—was given and correction trials were not administered. This nondifferential reinforcement procedure has been used successfully in other same–different studies (e.g., Young & Wasserman, 1997) when prolonged testing was administered to avoid problems accompanying experimental extinction.

During testing trials when the item sets were reversed for the *same* and *different* displays, the pigeons might respond as they had during training; they would continue to do so if the relationships among the stimuli were controlling behavior, even though the pools of icons used to generate the *same* and *different* displays were switched. For example, if a pigeon had been trained to peck the red button after a *same* display (generated from icons in Set A) and to peck the green button after a *different* display (generated from icons in Set B), it should continue to behave in the same manner during the reversed tests (when the *same* displays were composed of items from Set B and the *different* displays were composed of items from Set A, in this example). Although reinforcement was given regardless of whether the pigeons selected the green or the red button on testing trials, the

birds' responses during testing were analyzed in accord with their relational contingencies for later statistical analyses. So, in this example, the pigeon would be scored as making a correct response during testing with reversed displays for pecking the red key after a *same* display (composed of items from Set B) and for pecking the green key after a *different* display (composed of items from Set A).

Alternatively, if the specific stimulus features of the icons and their association with a particular stimulus display (*same* or *different*) competes with and “overshadows” relational control when relational and the specific stimulus features are placed in conflict during reversed testing, then the same bird should peck the green key after a *same* display (again composed of items from Set B) and the red key after a *different* display (again composed of items from Set A). Such responding would be scored as incorrect, and the mean percent choice score for the reversed trials would decline.

To summarize, if relational cues control behavior when the specific stimulus features and relational cues are pitted against each other, then our measure of discriminative performance (percent correct choices based on relational control) should be high and above chance (50%). However, percent correct choice performance should fall below chance during these conflict tests if the specific stimulus features overshadow relational cues.

Variations of the conflict test—where two cues are pitted against each other—have had a long history of use in psychological science

for dissociating the relative contributions of stimuli controlling behavior (e.g., blocking, overshadowing). Note that in our case, the pigeons could use a combination of relational cues and the specific stimulus features across multiple reversed tests (use the specific stimulus features on one trial and relational cues on another trial); but, such a strategy would effectively drive mean discriminative performance (percent correct scores) to chance levels. Likewise, if conflict itself has a generally disruptive effect, then choice again should not differ from chance. Only the consistent use of relational cues or the specific stimulus features during these tests would result in above chance or below chance performance, respectively, providing a decisive measure of control by each cue.

Finally, if the pigeons learn about the relationships among the stimuli in the display when the specific stimulus features are also a discriminative feature of the task during training, then discriminative responding should extend to *same* and *different* displays composed of transfer icons (Set C)—a common test of conceptual transfer in experiments examining categorical learning. Alternatively, if the specific stimulus features are the sole feature controlling the pigeons' discrimination learning, there should be no transfer of discrimination performance (percent correct scores) to the (Set C) displays.

### Measures and Analyses

For each daily session, we determined the number of times that the birds responded correctly to each type of display that was presented (training, transfer, or reversed) as well as the number of times that each type of display was presented. Each score was summed across blocks of four sessions. A percent correct choice score was determined to characterize performance for each type of display by dividing the number of responses that a bird made to a display by the total number of times that particular type of display was presented. Binomial tests were used to see whether the number of correct responses obtained during each block reliably exceeded chance (50%) for the training (chance = 192 correct responses) and testing (chance = 12 correct responses) trials.

A difference score was also determined for each display type by calculating the absolute difference between the percent correct choice score obtained for a display type and the percent correct score expected by chance (50%). The difference scores were summed across blocks of four sessions and used in a repeated measures analysis of variance (ANOVA) with display type (training, transfer, or reversed) and blocks as variables and the difference score as the dependent measure. Alpha was set at .05 for the determination of reliable statistical effects.

## RESULTS

Percent correct choice to the training displays improved rapidly and regularly across the 12 blocks of discrimination training shown in the upper portion of Figure 2. Percent correct choice scores were reliably above chance by Block 2 ( $z = 16.07$ ) and remained reliably above chance during the following 10 blocks. There were slower and less regular changes in choice responding to the transfer and reversed testing displays. Percent choice to the transfer displays was first reliably above chance in Block 3 ( $z = 2.24$ ), whereas percent choice to the reversed displays was reliably below chance during the same block ( $z = 2.24$ ).

Consistent with the generally rising difference scores to the training, transfer, and reversed displays shown in the lower portion of Figure 2, the ANOVA revealed a reliable overall effect of blocks [ $F(11,66) = 15.48$ ]. The pigeons generally exhibited higher difference scores to the training displays than to either the transfer or the re-

versed displays. In agreement with this observation, the ANOVA indicated a significant effect of the display condition across all blocks [ $F(2,12) = 37.06$ ]. Planned least squared means contrasts indicated that the pigeons exhibited reliably higher difference scores to the training displays than to either the transfer [ $F(1,12) = 70.28$ ] or the reversed displays [ $F(1,6) = 34.67$ ]. Also, the difference scores were reliably larger following presentations of the reversed displays than following presentations of the transfer displays [ $F(1,12) = 6.23$ ].

Beyond these overall results, the ANOVA revealed a reliable interaction between the display and block variables [ $F(22,132) = 4.31$ ]. One component of this interplay was between the transfer and reversed displays. Difference scores for the reversed and transfer displays were similar during the first three blocks (all  $ps > .05$ ); however, difference scores rose faster and to higher levels for the reversed displays than for the transfer displays during later blocks. Follow-up least squared means comparisons confirmed that the difference scores for the reversed displays were higher than those for the corresponding transfer displays on Blocks 4 [ $F(1,132) = 7.05$ ], 5 [ $F(1,132) = 7.69$ ], 6 [ $F(1,132) = 4.45$ ], and 7 [ $F(1,132) = 11.55$ ], as well as on Blocks 10 [ $F(1,132) = 9.52$ ], 11 [ $F(1,132) = 8.35$ ], and 12 [ $F(1,132) = 3.81$ ].

## DISCUSSION

We trained pigeons to discriminate displays of 16 *same* items from displays of 16 *different* items; both the specific stimulus features and the relations among the items could be used as discriminative stimuli for task mastery (Figure 1). Gibson and Wasserman (2003) reported faster discrimination learning when both relational cues and the specific stimulus features were available ( $M = 1,536$  trials) than when only relational cues were available (cf. Young & Wasserman, 1997;  $M = 4,450$  trials). In agreement with the results of Gibson and Wasserman (2003), the speed of discrimination learning in the present experiment was quite fast, averaging 1,952 trials for pigeons to reach a criterion of 85% correct choice. The faster learning observed in Gibson and Wasserman (2003) and in the present experiment suggests that the combination of relational cues and the specific stimulus features may enhance discrimination learning in comparison with when only relational cues are available during training.

In our earlier study (Gibson & Wasserman, 2003), both relational cues and specific stimulus features exerted reliable control over choice behavior; the same was true in the present experiment. During the reversed trials, the specific stimulus features were primarily used when the specific stimulus features and relational cues were pitted against each other. The level of control by the specific stimulus features in the present experiment was high and consistent with that observed previously (Gibson & Wasserman, 2003). Likewise, categorical responding also transferred at a modest level to *same* and *different* displays composed of icons from a set of items that

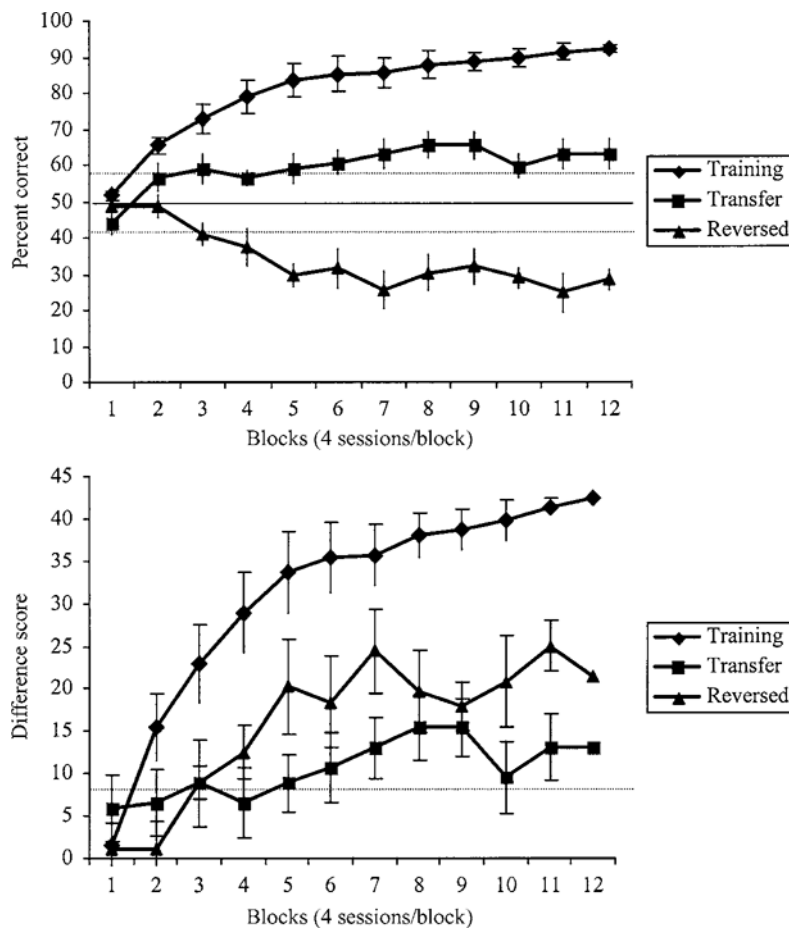


Figure 2. (Top) Mean percent correct choices by pigeons to the training, transfer, and reversed displays across the 12 (four-session) blocks of acquisition. The plot for the transfer condition indicates the strength of control by relational cues, whereas the plot for the reversed condition indicates the strength of control by either relational cues (values greater than 50%) or specific stimulus features (values less than 50%). The bold line indicates chance levels of discriminative performance for all conditions, whereas the fine dotted lines indicate above chance and below chance levels of choice for the transfer and reversed conditions. (Bottom) Mean difference scores to the training, transfer, and reversed displays across acquisition. The fine dotted line demarcates difference scores that differ reliably (either above or below) from chance (see the Method section) for the transfer and reversed conditions; this difference criterion = the absolute difference between the above (58.33%) or below (41.77%) chance criteria for the percent correct scores – 50% (chance performance) = 8.33%.

was not differentially reinforced during training. The level of transfer during these tests was consistent with that reported in similar studies in which the specific stimulus features could not be used as a discriminative stimulus (e.g., Wasserman et al., 1995).

Our findings suggest that the specific stimulus features of the items in a display and the relations among them can independently control pigeons' discriminative behavior. As well, control by either set of cues *alone* (specific stimulus features for reversed testing or relational cues for transfer testing) failed to approach the level of discriminative performance observed on the training displays. Although the use of nondifferential reinforcement during testing trials may have affected performance dur-

ing the tests (see below), the pattern of results from both reversed and transfer tests suggest that both sources of stimulus information concurrently controlled the pigeons' behavior on the training trials (cf. Fetterman, 1996).

Another finding in Gibson and Wasserman (2003) was that the specific stimulus features exerted somewhat stronger control over behavior than did the relational cues during testing. Two lines of evidence suggest that this pattern was also true during the majority of training in the present experiment. First, during reversed testing, the specific stimulus features and relational properties of the displays were placed in conflict with one another; the birds could discriminate either. Our results suggested that the birds consistently and reliably (in 8 of 12 blocks)

discriminated the specific stimulus features of the icons rather than the relations among them during these conflict tests. Such overshadowing of relational cues by the specific stimulus features could not be based on the absence of relational learning; responding to the transfer displays (and hence relational control) also exceeded chance during the same blocks. Second, the difference scores for the reversed tests (indexing the magnitude of the preference for the specific stimulus features over relational cues) were not only reliably greater than chance during most blocks, but they were also reliably greater than the difference scores obtained after presentations of the transfer displays, when only relational cues could be used.

It is of particular interest that the overshadowing of relational cues by the specific stimulus features (difference score = 21%) during conflict testing in the study by Gibson and Wasserman (2003) was recorded only after pigeons had mastered the same–different discrimination to a high level (85% correct). At a comparable point in acquisition in the present study (e.g., Block 7), our pigeons also exhibited stronger control by the specific stimulus features (difference score = 24%). These parallel results suggest that from the outset of discrimination learning in both studies, the specific stimulus features might have exerted greater control than the relational cues did. Indeed, given the work of Vaughan and Greene (1984), the pigeons' learning of the specific stimulus features in the present experiment might have emerged earlier and their learning about stimulus relations might have occurred much later—if at all.

However, unlike in most same–different discrimination studies, in the present experiment the precise time-course of control by the specific stimulus features of the items and the relations among the items could be tracked as the pigeons learned the same–different discrimination. The results from the transfer tests suggest that stimulus control by the relations among the items in a display actually began to acquire behavioral control at about the same time as or slightly sooner than learning about the specific stimulus features. Only after the fourth block of training did the specific stimulus features begin to overshadow relational cues (Figure 2). Thus, learning about the specific stimulus features of the items in a display and about the relations among them occurred concurrently; stronger control by relational cues followed reliable learning about both (Figure 2).

One concern that might be raised about the present experimental design is that repeated testing with nondifferential reinforcement in each daily session might have eliminated reliable control by either kind of discriminative stimulus: specific stimulus features or item relations. This concern does not appear to be warranted, however, because control by the specific stimulus features and item relations could be detected early in acquisition and control by both properties grew even stronger during later training blocks. As well, the percent choice scores to the training and testing displays at the end of acquisition were highly consistent with those reported in other studies that have measured

relational control after an extended period of training (Wasserman et al., 1995; Young & Wasserman, 1997).

A second possible concern is that the obtained difference scores to the transfer and reversed displays were each lower than those to the training displays (Figure 2, bottom). Differential reinforcement was given to the birds during the tests to prevent the birds from learning the correct responses to the testing arrays, and to control for the effect of reinforcement across the two types of tests. It is possible, however, that learning may have occurred during the small number of tests that were given, and that this subsequently affected performance. The difference in performance between the training and testing trials may also have been due to stimulus generalization decrement for both types of testing displays. Such lower levels of performance are, in fact, common to novel testing displays in studies of categorical learning with procedures similar to those used here (e.g., Wasserman et al., 1995). However, even though there was a drop in performance to the novel testing displays composed of novel icons, there was reliable transfer over the last three quarters of testing. As well, the drop in performance to the reversed displays cannot have been due to the novelty of the testing icons, because these items were given and were strongly discriminated on training trials. The arrangement of the specific icons in the reversed displays was also initially novel, but any such effect may have waned relatively rapidly, since the pigeons had extensive exposure to unique *same* and *different* arrangements during the training trials. Thus, any drop in performance here was likely due to individual item learning.

Although the results of the present study have revealed that the specific stimulus features exerted more control over choice behavior later in acquisition, the pattern of control by these cues may differ, depending on the stimulus parameters. Wasserman et al. (2002) have found that increasing the number of items in the stimulus sets used to generate the *same* and *different* displays decreased control by the specific stimulus features and increased control by relational cues. If the number of icons in each set had been increased in the present experiment, there might have been even more substantial and prolonged control by relational cues. As well, the availability of multiple cues raises the prospect of momentary tradeoffs as to which aspects of a compound stimulus control behavior. Gottselig, Wasserman, and Young (2001) trained pigeons to discriminate stimuli that varied along four dimensions: brightness, size, shape, and orientation. During training, the birds came to attend to additional dimensions of the stimuli. As they did so, these newly introduced dimensions reduced pigeons' attention to previously learned dimensions, much as the pigeons here showed a slight and transient downturn in control by stimulus relations from Blocks 3 to 4 as control by the specific stimulus features sharply rose around the same period.

In closing, C. Lloyd Morgan (1894) speculated over a century ago that, "not until the particular fades from view,

and the relationship, as common to all the particular instances, becomes focal do we reach the conception properly so-called” (p. 264). Morgan’s point was that as category learning occurs, organisms tend to shift their attention from specific features of stimuli to properties that define the relationships among the stimuli. Our present procedures allowed us to assess the control exerted by both specific and general aspects of stimuli during the course of category learning. In contrast to Morgan’s suggestion of a shift in attention from specific to general cues, our results suggest that (1) control by relational cues can occur at the same time as does learning about more specific stimulus features, and (2) the specific features of stimuli can exert more control than relational cues do, following extended same–different training. Our “on-line” method appears to have broad application for tracking changes in stimulus control by multiple stimulus features during conceptualization.

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