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Learning and Motivation 37 (2006) 189–208
Learning and Motivation
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Not all same-different discriminations are created equal: Evidence contrary to a unidimensional account of same-different learning

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Received 9 February 2005; received in revised form 3 June 2005
Available online 1 September 2005

Abstract

In Experiment 1, we trained four pigeons to concurrently discriminate displays of 16 same icons (16S) from displays of 16 different icons (16D) as well as between displays of same icons (16S) from displays that contained 15 same icons and one different icon (15S:1D). The birds rapidly learned to discriminate 16S vs. 16D displays, but they failed to learn to discriminate 16S vs. 15S:1D displays. In Experiment 2, the same pigeons acquired the 16S vs. 15S:1D task after being required to locate and peck at the odd-item in the 15S:1D displays. Acquisition of the 16S vs. 15S:1D task had little effect on discriminative performance in the concurrent 16S:16D task, suggesting that a unidimensional entropy explanation for mastery of these two same-different tasks is not viable. During testing, the birds transferred discriminative performance in both tasks to displays composed of different visual stimuli. Such concurrent discrimination learning, performance, and transfer suggest that pigeons are flexible in the way they process the displays seen in these two same-different tasks.

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doi:10.1016/j.lmot.2005.06.002

Keywords: Catagorical learning; Same-diffferent discrimination; Entropy; Oddity; Concepts

Although humans (Young & Wasserman, 2001, 2002) and nonhuman primates (Fagot, Wasserman, & Young, 2001; Oden, Thompson, & Premack, 1988; Premack, 1976; Wasserman, Fagot, & Young, 2001) have been found to learn abstract stimulus relationships, researchers continue to explore and debate whether animals other than primates can acquire abstract rules (Bhatt, Wasserman, Reynolds, & Knauss, 1988; Cook, 2002a; Herrnstein, Loveland, & Cable, 1976; Santiago & Wright, 1984; von Fersen, Wynne, Delius, & Staddon, 1991; Wright, Cook, & Rivera, 1988; Wright, Santiago, Urcuioli, & Sands, 1983). One relational rule that has received much attention is the same-different (S/D) discrimination.

In 1995, Wasserman, Hugart, and Kirkpatrick-Steger (1995) and Cook, Cavoto, and Cavoto (1995) used two separate S/D training techniques to see if pigeons could discriminate the relations among the items in a display that was presented on a computer monitor. Wasserman and his associates required their pigeons to make two different responses to 7×7 cm displays composed of 16 small and complex, black-and-white Macintosh icons (1×1 cm) placed into 4×4 arrays; the 16 items comprising the displays were either all identical or all nonidentical. In contrast, Cook and his associates examined relational learning with an oddity-based discrimination task involving 3×2 arrays with six identical elements or 3×2 arrays formed with five common elements and one odd element (see also Blough, 1989; Lombardi, Fachinelli, & Delius, 1984; Zentall, Hogan, & Edwards, 1980, 1981 for other oddity studies). Different types of elements were used to create such oddity task displays including: colored geometric shapes; images of fish, humans, birds, and flowers; and, colored and gray-scaled photographs (Cook, 2002b; Cook, Katz, & Cavoto, 1997, 1999).

Despite clear differences in experimental methodology, these S/D projects conducted in the Wasserman and Cook laboratories yielded very similar results: (a) pigeons learn these S/D discriminations within approximately the same time span (30–45 sessions) and (b) they transfer discriminative responding to a wide variety of novel stimuli. One immediate interpretation of these results is that, despite the disparities in the stimuli and procedures used by the two laboratories, the pigeons may have learned to use similar types of relational information to master these two kinds of S/D discriminations.

To examine the features of the displays that controlled their birds' behavior, Young and Wasserman (1997) trained pigeons to discriminate same displays composed of 16 same icons from different displays composed of 16 different items. The birds were then tested with a number of "mixed" displays that varied in the number of nonidentical icons within each 16-item display. Although all of the mixed displays could have been categorically treated as "different," the pigeons tended to report mixed displays with relatively few nonidentical items as being "same" and to report mixed displays with relatively many nonidentical icons as being "different." Thus, the pigeons' propensity to report "same" or "different" was strongly and monotonically related the variability of the items in the display. Young and Wasserman (1997) suggested that entropy—a mathematical measure of display variability—is a single relational cue that could account for their pigeons' S/D discrimination behavior (for more details about the entropy concept, see Young & Wasserman, 2001). Entropy is calculated by determining the number of stimulus categories in a display. As the number of unique items (categories) in a display increases, the amount of display variability rises.

Given the results of Young and Wasserman (1997), perhaps entropy can also be used to explain other reports of successful relational S/D discrimination—such as those described by Cook (e.g., Cook et al., 1995, 1997)—as well as other oddity-based discriminations (Blough, 1989; Zentall et al., 1980, Zentall, Edwards, & Moore, 1981). Specifically, the pigeon may set a decision criterion along the entropy dimension, which then allows them to discriminate the oddity displays (low entropy) from the same displays (no entropy). When a presented display contains more entropy than that specified by its criterion (Cook & Wasserman, 2005), then the bird should report the display as being "different;" otherwise, the bird should report the display as being "same."

Critical to this unidimensional interpretation is that the birds studied in Wasserman et al. and Cook et al. likely used different criterion locations because of the smaller entropy difference in the oddity task displays. Consistent with this interpretation, Cook, Kelly, and Katz (2003) have recently reported that pigeons readily acquire such a S/D discrimination using successive 2-item displays. In contrast, Young, Wasserman, and Garner (1997) found that pigeons failed to discriminate two-item displays that contained either two identical icons or two nonidentical icons following extensive training to discriminate 16-item displays that contained icons that were all identical or all nonidentical. Perhaps, the large difference in display entropy between 16-item same and different displays encountered during training by the pigeons in Young et al. (1997) resulted in the birds adopting a relatively high decision criterion for reporting that a display was "different" (due to the large disparity in display entropy between same and different arrays). In other words, the failure of pigeons in Young et al. (1997) to discriminate the 2-item same and different displays may be described as a range effect: it may have been more difficult for the pigeons to make a difficult entropy discrimination (2-item, low entropy) after having been trained on an easy entropy discrimination (16-item, high entropy).

Despite its promise, some recent evidence is inconsistent with such a unidimensional account of S/D learning. Cook et al. (1997) trained pigeons to discriminate between same displays that contained six copies (3×2 array) of one element and different displays that contained one odd and five common elements. Following training, the number of common elements in the odd-item display was reduced, so that 2×2 (one odd and three common elements) and 3×1 (one odd and two common elements) organizations were presented during testing trials. The amount of entropy in these odd-item displays increased as the number of common elements was decreased (i.e., the number of items in one category was reduced). A unidimensional entropy model of S/D discrimination would predict that accuracy should improve on different trials during these tests because the entropy in the odd-item displays increased. Notably, correct responses fell on trials with these modified different displays, suggesting that display entropy alone cannot account for the pigeons' testing behavior in this study.

An alternative to the unidimensional entropy account is that the nature of the training experiences that the pigeons encountered during the S/D training procedures in these two laboratories caused the birds to process different attributes of the same and different displays. Training with 16-item displays containing all identical icons or all nonidentical icons, as conducted by Wasserman and his associates (Wasserman et al., 1995; Young & Wasserman, 1997; Young et al., 1997), may lead to pigeons' responding to a *quantitative* dimension of stimulus variability or entropy. In contrast, training with all identical and odd-item displays, as conducted by Cook and others (e.g., Blough, 1989; Cook et al., 1995, 1997; Zentall et al., 1980, 1981), may lead pigeons to learn about the more *qualitative* properties of sameness and differentness.

Experiment 1

We trained four pigeons to concurrently discriminate between 16-item same (16S) and different (16D) displays (16S vs. 16D task) as well as between 16-item same (16S) and odd-item (15S:1D) displays using the basic procedural framework from the Wasserman laboratory (Wasserman et al., 1995; Young & Wasserman, 1997, 2001; Young et al., 1997). Note that the difference in entropy between the16S vs. 16D task displays is substantially greater than the difference in entropy between the 16S vs. 15S:1D task displays. If a unidimensional entropy account of S/D discrimination is correct and the disparity in display entropy is the sole factor supporting these apparently different types of S/D discriminations, then previous research (e.g., Young et al., 1997) suggests that a range effect should be observed; pigeons should readily acquire the 16S vs. 16D task, but they should acquire the 16S vs. 15S:1D task more slowly or not at all. However, if the pigeons readily acquire both tasks, then this result would suggest that pigeons may learn very different things about the stimulus information required for mastering these two tasks despite each nominally being a S/D discrimination. Following training, we conducted several probe tests (described below) to see whether the pigeons had learned a generalized S/D relational rule.

Method

Animals

Four adult feral pigeons were individually housed and maintained at 85% of their free-feeding weights with controlled access to mixed grain following daily experimental sessions. All of the pigeons had free access to grit and water treated with a vitamin supplement. Each had served in other unrelated studies using different visual images and procedures than those described below.

Apparatus

Training and testing were conducted in four operant chambers previously described by Young and Wasserman (1997). The stimulus displays that were used during training and testing were presented in a central display area (7 × 7 cm) on a computer monitor that was located on the front wall of each chamber. Yellow, green, red, and blue choice keys were located 1.5 cm diagonally from the northwest, northeast, southwest, and southeast corners of the display area, respectively. A touchscreen (Elotouch, Fremont, CA) was used to record the locations of the responses that the birds made to the display and choice areas. A feeder dispensed 45-mg food pellet reinforcers (Research Diets, New Brunswick, NJ) into a small cup located on the floor next to the rear wall of the chamber.

Stimulus displays

Prior to the start of the experiment, 96 unique Macintosh icons were randomly sorted into three stimulus sets that each contained 32 unique items. One set of 32 icons was used to generate the displays for the 16S vs. 16D task (Fig. 1). Same displays (16S) were composed of 16 identical copies of a randomly selected icon, whereas different (16D) displays were composed of 16 nonidentical icons randomly selected on each trial from the total pool of 32 icons in the set. The 32 icons in the second set were used to generate the displays for the 16 S vs. 15S:1D task (Fig. 1). The 16S displays were composed as described above. The 15S:1D displays were constructed by randomly selecting two icons from the set; 15 copies were made of one icon and one copy was made of the second icon. The sets from which the displays for the two tasks were constructed were counterbalanced across birds. Transfer displays were constructed from the third set of 32 icons (transfer set) and used only during testing (see below).

For all types of displays, the spatial positions of the 16 icons in each type of array were based on a "jittering" algorithm, which generated displays that had irregular outlines and involved no horizontal or vertical alignments. The jittering procedure made the global features of the same and the different displays closely comparable and minimized the possible participation of global cues as a controlling feature of the pigeons' discrimination behavior (Young & Wasserman, 2001).

Training

Each pigeon was placed into the operant chamber and a training trial began when the start stimulus—a black cross on a white background—appeared in the display area. A peck to the display area removed the cross from the screen and a display from either the 16S vs.16D, or 16S vs. 15S:1D task was presented. The pigeon then was required to make a fixed number of observing responses to the stimulus at any location within the display area. The observing requirement was a response cost that was used to maintain discriminative performance at 80% correct choices for each task. Some birds were required to make more responses to achieve the criterion level of performance compared to others (mean fixed ratio = 30, range = 18–35).

Next, two of the four choice keys appeared along with the training display. If the stimulus presented during the trial was a 16S vs. 16D task display, then the red and green choice keys appeared beyond the northeast and southwest corners of the display area, respectively. A response to the red choice key when the 16S display

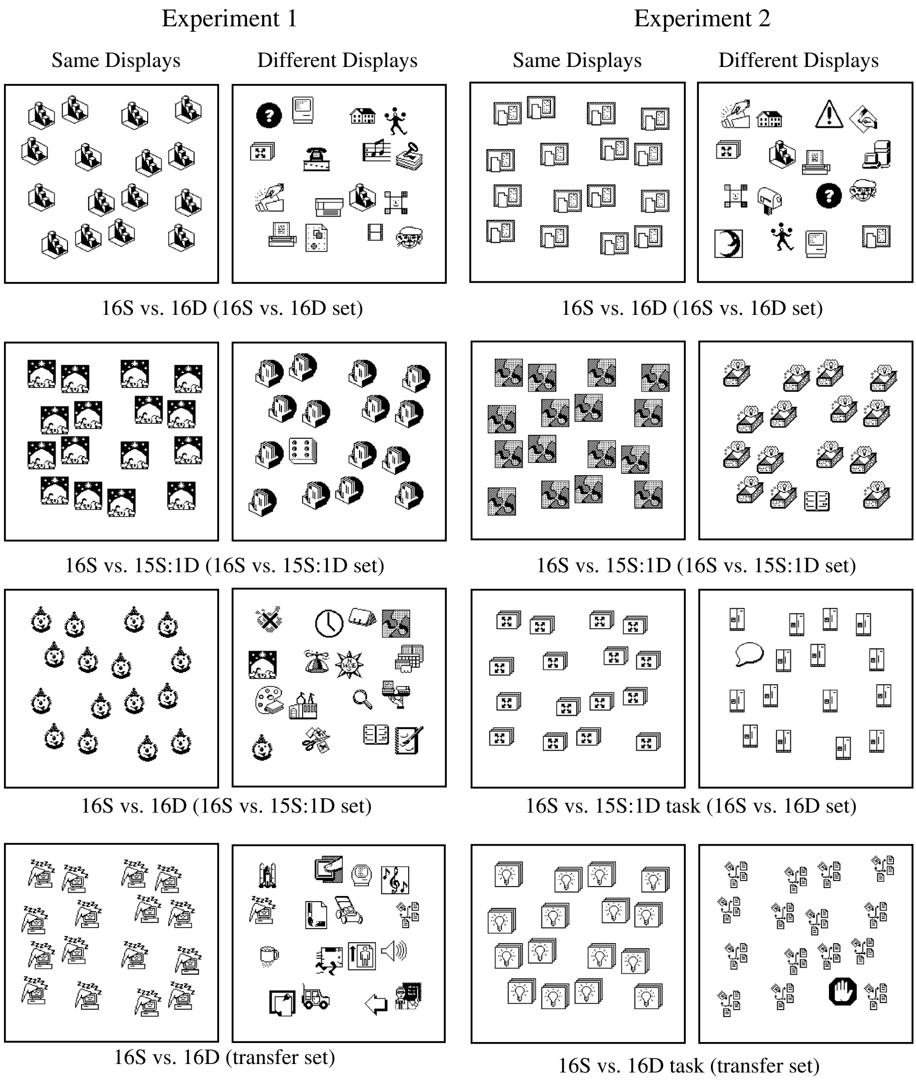


Fig. 1. The training (top two rows) and testing (bottom two rows) stimulus displays that were used during Experiments 1 (left two columns) and Experiment 2 (right two columns). Examples of same and different displays are organized into the leftmost column and rightmost column for each experiment, respectively. Each row shows an example of one pair of same and different displays that were used in each experiment. The label below each pair of same and different displays [e.g., 16S vs. 16D task (16S vs. 16D)] indicates the discriminative task that was presented and the set from which the icons were taken (16S vs. 16D, 16S vs. 15S:1D, or transfer) to construct those displays.

appeared and a response to the green choice key when a 16D display appeared were considered correct; such correct responses were followed by the delivery of a food pellet. The yellow and blue response keys appeared (northwest and southeast corners, respectively) following the final observing response if a 16S vs. 15S:1D task display was presented during the trial. A response to the yellow choice key when a 16S display appeared and a response to the blue choice key when a 15S:1D display appeared were considered correct; such correct responses were also followed by the delivery of a food pellet. The choice keys and stimulus display were removed from the screen following a correct response and an intertrial interval (ITI) with a mean duration of 10 s ensued prior to the start of the next trial.

Any incorrect choice response resulted in the houselight being turned off and the initiation of a time-out period with a mean duration of 20 s (the variable duration helped ensure that the bird attended to the screen during the course of the time-out); the choice keys were hidden and the display was inverted to a white-on-black state. The display was returned to its original black-on-white state following the time-out period and the trial was repeated until a correct response was made. Choices made on correction trials were not used in data analysis. The display-choice key relationships were counterbalanced across pigeons.

During each block of daily training sessions, the birds encountered eight presentations of each of the two different types of training displays for each task (Fig. 1). The spatial orders of the training displays were randomized within each block. Each daily session was composed of six blocks for a total of 192 trials. Training was scheduled to continue until the birds were making 80% correct responses to the displays in each of the 16S vs. 16D and 16S vs. 15S:1D tasks.

Testing

Each daily testing session was composed of six blocks. The first block of testing was a warm-up block, in which the birds encountered the same types of stimulus displays that they had experienced in training. During each of the five subsequent blocks, the birds encountered eight presentations of each of the two different types of training displays for each task, as well as a single presentation of each of four different types of 16S vs. 16D testing displays. These testing displays included: (a) 16S and 16D displays composed of icons from the 16S vs. 15S:1D set, and (b) 16S and 16D displays composed of icons from a novel transfer set (see Fig. 1). The order of the training and testing displays was randomized within each block. Due to the failure of the birds to acquire the 16S vs. 15S:1D task (see results below), we did not present the birds with 16S vs. 15S:1D displays composed of icons from the 16S vs. 16D or transfer sets during testing in Experiment 1.

The testing procedures were like those used during training except that, during testing trials, nondifferential food reinforcement was given and correction trials were not administered. Nondifferential reinforcement has been successfully used in other S/D studies when prolonged testing was administered (e.g., Young & Wasserman, 1997). The 16S vs. 16D task choice keys (green and red) were used with all of the testing displays during Experiment 1. Each session of testing was followed by at least 1 day of training; pigeons did not resume testing until their discriminative performance during these alternating training sessions again attained criterion. Testing continued until each bird had completed eight sessions of testing. Choices made during the warm-up block of a testing session were not used in criterion determination or in any analyses of discriminative performance.

Results

As can be seen in the top panel of Fig. 2, the pigeons rapidly learned to discriminate the 16S vs. 16D task displays, but they failed to discriminate the 16S vs. 15S:1D task displays. The pigeons averaged 80% correct responses on the 16S vs. 16D task after a mean of 4032 trials of training (range: 1536–5568). Training continued to see if the pigeons would eventually acquire the 16S vs. 15S:1D task discrimination. Even after 9600 trials (50 sessions) of training (by which time performance appeared to asymptotic for all conditions), the pigeons failed to discriminate the 16S vs. 15S:1D task displays. We conducted an Analysis of Variance (ANOVA) with display type (four display types across both tasks) and block as variables and percentage correct as the dependent measure. Alpha was set at .05 for all of the statistical tests. The analysis revealed a significant effect of block, $F(9,27)=49.30$, and an interaction between block and display type, $F(27,81)=49.30$; the effect of display type alone was not significant, $F(3,9)=2.49$. Planned comparisons indicated that the percentage of correct choice to the 16S vs.16D task displays were not statistically distinguishable, but that the scores for both were reliably higher than those for the 16S vs. 15S:1D displays (all ps < .05); the percentage correct scores to the 16S displays were numerically higher than those to the 15S:1D displays for the 16S vs. 15S:1D task, but this difference only approached significance, $F(1,9)=3.71$, $p=.07$.

Testing with the 16S vs. 16D and 16S vs. 15S:1D displays began following training even though the pigeons had failed to acquire the 16S vs. 15S:1D discrimination. The rationale for this testing was to see if the birds would transfer their learning about familiar 16S vs. 16D task displays to novel 16S vs. 16D task displays composed of icons from other sets.

Fig. 2 (bottom) shows choice accuracy to the training and testing displays during the testing sessions in Experiment 1. The left two bars show that the pigeons continued to discriminate at a high level between the 16S vs. 16D training displays (88% correct), but not between the 16S vs. 15S:1D training displays (50% correct). Binomial tests (two-tailed) confirmed these observations, disclosing that discriminative performance was reliably above chance to the 16S vs. 16D training displays, $z(1)=38.6$, but not to the 16S vs. 15S:1D training displays, $z(1)<1$. The right two bars show accuracy on the two types of transfer tests. As we have found in other experiments (Wasserman et al., 1995; Young & Wasserman, 1997), the percentage of correct choices to the 16S vs. 16D displays composed of icons from a novel set (75%) was lower than that observed to the 16S vs. 16D training displays, but it was still reliably above chance, $z(1)=8.55$. Surprisingly, the birds' accuracy was at chance level (50%) when the 16S vs. 16D displays were composed of icons from the 16S vs. 15S:1D set, $z(1)=1.84$.

We conducted a one-way repeated-measures ANOVA with display type as a repeated factor and the percentage of correct choices as the dependent measure. The analysis revealed a reliable effect of display type, $F(3,9)=64.46$. Planned least-

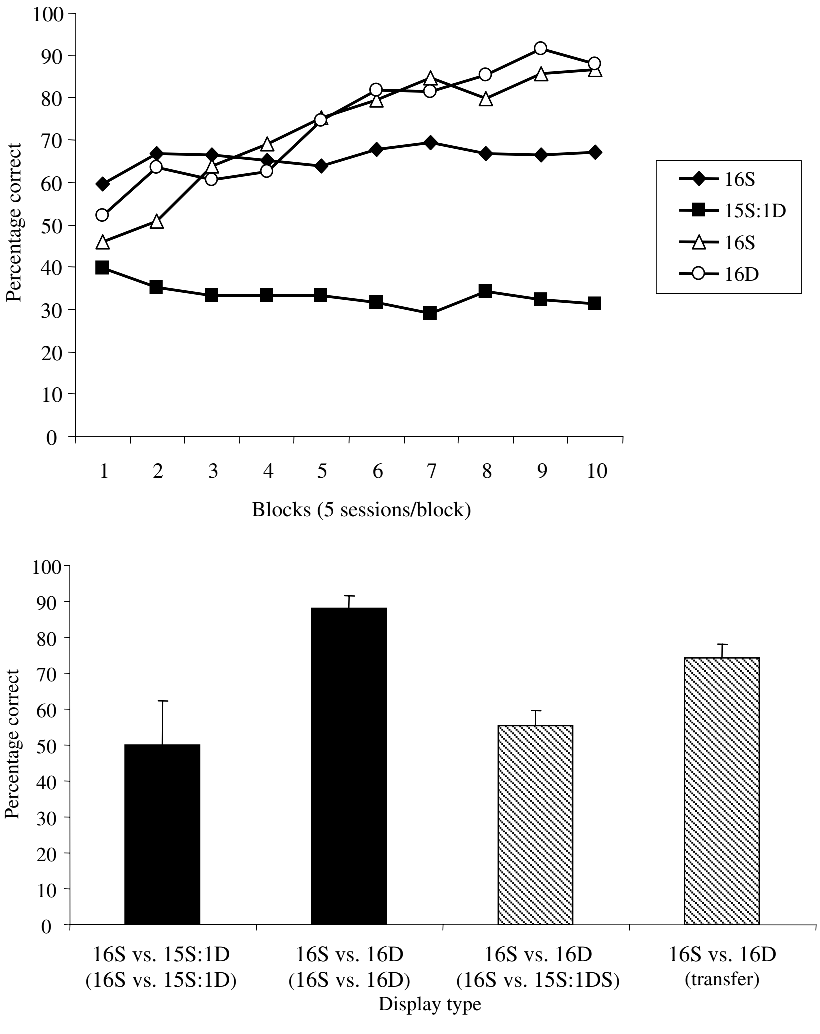


Fig. 2. (Top) Percentage of correct choices to the 16S vs. 16D and 16S vs. 15S:1D task displays across the first 50 sessions of acquisition. Performance with the 16S vs. 16D task displays is indicated by the unfilled markers, whereas the filled markers indicate performance with the 16S vs. 15S:1D displays. (Bottom) Percentage of correct choices to the 16S vs. 15S:1D and 16S vs. 16D task training displays (two solid filled columns), as well as the 16S vs. 16D testing displays (two diagonally filled columns) averaged across the eight sessions of testing during Experiment 1. The labels in parentheses below the columns indicate the set of icons that was used to construct the display.

squared means contrast comparisons indicated that the pigeons more accurately discriminated the 16S vs. 16D task training displays than the 16S vs. 16D task testing displays composed of items from the 16S vs. 15S:1D set, $F(1,9) = 89.86$, or the 16S vs. 16D task displays composed of icons from the transfer set, $F(1,9) = 8.93$. The birds were also reliably more accurate in discriminating the 16S vs. 16D task testing displays composed of items from the transfer set than they were discriminating the 16S vs. 16D task testing displays constructed of items from the 16S vs. 15S:1D set, $F(1,9) = 42.13$.

Discussion

The results of Experiment 1 were clear: pigeons readily learned the 16S vs. 16D task, as has been reported in previous studies (Wasserman et al., 1995; Young & Wasserman, 1997; Young et al., 1997). Yet, the same birds failed to learn the 16S vs. 15S:1D task, even when they were given extended training.

We then tested the generality of our pigeons' learning of the 16S vs. 16D task. The birds generalized the 16S vs. 16D discrimination to displays involving novel icons, suggesting that the birds had learned some form of conceptual rule. But, this rule appeared not to be so general as to include 16S vs. 16D displays created from the icons used in the 16S vs. 15S:1D task. The pigeons appear to have learned and remembered something about the items from this unsolved 16S vs. 15S:1D task that prevented successful discrimination transfer when those items were later organized into 16S vs. 16D displays.

The acquisition data are certainly explainable by a unidimensional entropy-based account: that is, the pigeons found it quite easy to discriminate the low variability 16S displays from the high variability 16D displays during the 16S vs. 16D task and to generalize that discrimination to novel stimuli, but they found it very hard to discriminate the two kinds of low variability displays that characterized the 16S vs. 15S:1D task stimuli. Thus, the pigeons' failure to learn the 16S vs. 15S:1D task is not surprising, especially if the context of the 16S vs. 16D task makes the "entropy" dimension especially salient to the birds.

Nevertheless, other studies have found that pigeons can discriminate odd-item displays (Blough, 1989; Cook et al., 1995, 1997; Lombardi et al., 1984; Zentall et al., 1980, 1981) involving as few as two items (e.g., Cook et al., 2003). The difference in entropy between the same and odd-item displays used in those studies is comparable to that between the 16S vs. 15S:1D displays in the current project. Perhaps other differences in the methods involved in previous studies of odd-item discrimination, in particular those used by Cook and his associates (Cook et al., 1995, 1997), and in the current study may be responsible for these empirical discrepancies. Experiment 2 was conducted to examine this possibility.

Experiment 2

The odd-item displays that have been used in previous studies have generally contained fewer total items and occupied more space on the computer screen than the 15S:1D displays that we used in the present study. Thus, one possibility to consider is that our pigeons may have failed to attend to the odd-item in the present 15S:1D displays because each odd-item was much smaller and competed with a much larger number of surrounding distractors. This possibility seemed unlikely because the odd-item appeared quite salient among the remaining 15 items, at least to the human eye (see Fig. 1). However, Cook et al. (1995) have explicitly trained their pigeons to locate and to peck directly at the odd-item of each display to guarantee that the pigeons detected it. So, in Experiment 2, we required the pigeons to peck directly at the odd-item in a 15S:1D display prior to receiving the choice keys.

The unified entropy account of S/D discrimination predicts that systematic changes in the 16S vs. 16D task should occur if the pigeons were to learn the 16S vs. 15S:1D task. As the birds learn to discriminate the relatively small disparity in entropy between 16S and 15S:1D displays, the decision criterion (or the ability to detect differences in entropy between displays) shared with the 16S vs. 16D task should systematically shift to encompass all of the values of the low (16S vs. 15S:1D task) and high (16S vs. 16D task) displays. Specifically, after learning the 16S vs. 15S:1D task, the pigeons should make many more mistakes in the 16S vs. 16D task on same trials (16S displays should appear to be more similar to 15S:1D displays than to 16D displays) and many fewer errors on different trials (16D displays should appear even more different than 16S displays) as a function of this criterion shift.

On the other hand, if the locating the odd-item is critical to learning and results in a different type of S/D responding, then there should be minimal influence on the extant 16S vs. 16D task. Such an outcome would suggest that, although the 16S vs. 16D and 16S vs. 15S:1D tasks are both S/D procedures, the birds may respond to qualitatively different stimulus features of each task.

Method

Animals

The same four pigeons that served in Experiment 1 served in Experiment 2.

Training

The procedures and stimulus displays that were used for training in Experiment 2 were identical to those used in Experiment 1, with one critical exception: in Experiment 2, the pigeons had to execute a fixed number of observing responses directly at the odd-item in a 15S:1D display. This observing response procedure is consistent with those methods that have previously produced robust S/D discrimination learning using odd-item displays (Cook et al., 1995, 1997).

The *total* number of observing responses that the pigeon made on each 15S:1D trial (including those that did not hit the odd-item) was recorded and averaged across all 16S vs. 15S:1D trials in a session. To equate the number of pecks that the birds made to both of the 16S and 15S:1D displays, the total number of observing responses that a pigeon made on the previous 15S:1D trial was set as the number of observing responses that the bird had to make on the next 16S trial for the 16S vs. 15S:1D task. The mean number of responses made during all 15S:1D trials was used instead if the number of 16S trials for the 16S vs. 15S:1D task exceeded the number of 15S:1D trials the bird had currently encountered in the session. The mean number of responses made during all 15S:1D trials from the previous experimental session was used instead if an 15S:1D trial had yet to be preceded by an 16S trial for the 16S vs. 15S:1D task in a given session. The other procedures used in Experiment 2 were identical to those described for Experiment 1. Training continued for 50 sessions when performance reached asymptote.

Testing

The first 8 days of testing proceeded as described in previously for Experiment 1. During each daily session, the birds were given the training displays intermixed with a small number of 16S vs. 16D type testing displays: (a) 16S and 16D displays composed of icons from the 16S vs. 15S:1D set and (b) 16S vs. 16D displays composed of icons from the transfer set (Fig. 1).

During testing Days 9–16, two groups of 16S vs. 15S:1D task displays were used. The first group of testing displays included 16S vs. 15S:1D displays that were composed of items from the 16S vs. 16D set. The second group of 16S vs. 15S:1D testing displays were composed of icons from the transfer set. The procedures for these tests were identical to those described for the tests with the 16S vs. 16D displays in Experiment 1.

Results

In contrast to Experiment 1, the pigeons now effectively learned to discriminate the 16S vs. 15S:1D displays (Fig. 3). Furthermore, the improvement in discriminating the 16S vs. 15S:1D task displays did not come at the expense of 16S vs. 16D task performance. Following training in Experiment 1, the pigeons were making 87% correct responses to 16S displays and 88% correct responses to 16D displays during the 16S vs. 16D task (Fig. 2: Block 10). During the first block of training in Experiment 2, discriminative responding to the 16S displays dropped a bit (79% correct responses), while responding to the 16D displays remained essentially unchanged (85% correct responses).

The data for the training and testing displays during testing are consistent with these observations. The birds made a high percentage of correct responses to the 16S vs. 16D (84%) and the 16S vs. 15S:1D (82%) task training displays (Fig. 4, top) during testing. Binomial tests indicated that the percentage of choices made to the 16S vs. 15S:1D task, $z(1)=34.13$, and the 16S vs. 15S:1D task, $z(1)=32.43$, training displays were each reliably above chance and very similar to one another.

Testing with 16S vs. 16D displays

The birds also transferred (Fig. 4, top) their discrimination of the 16S vs. 16D task discrimination to displays composed of icons from both the 16S vs. 15S:1D set (63%) and the transfer set (62%). Indeed, performance to the 16S vs. 16D task displays composed of icons from the 16S vs. 15S:1D set, $z(1)=4.75$, and to the 16S vs. 16D

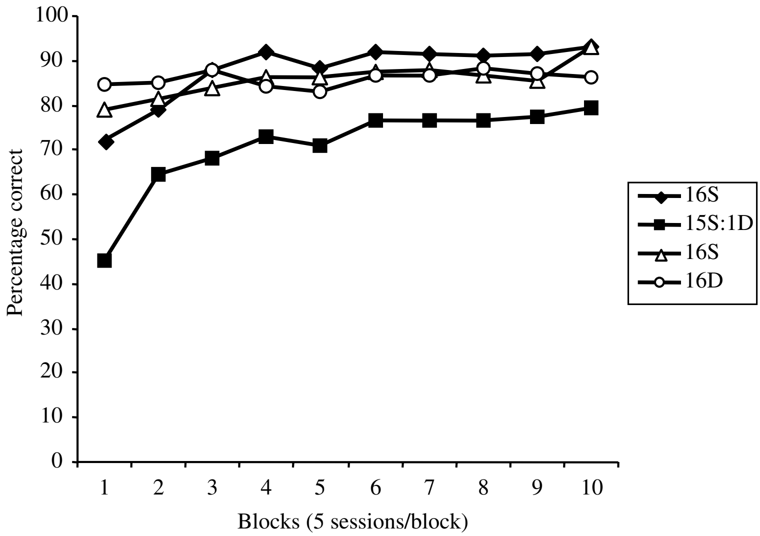


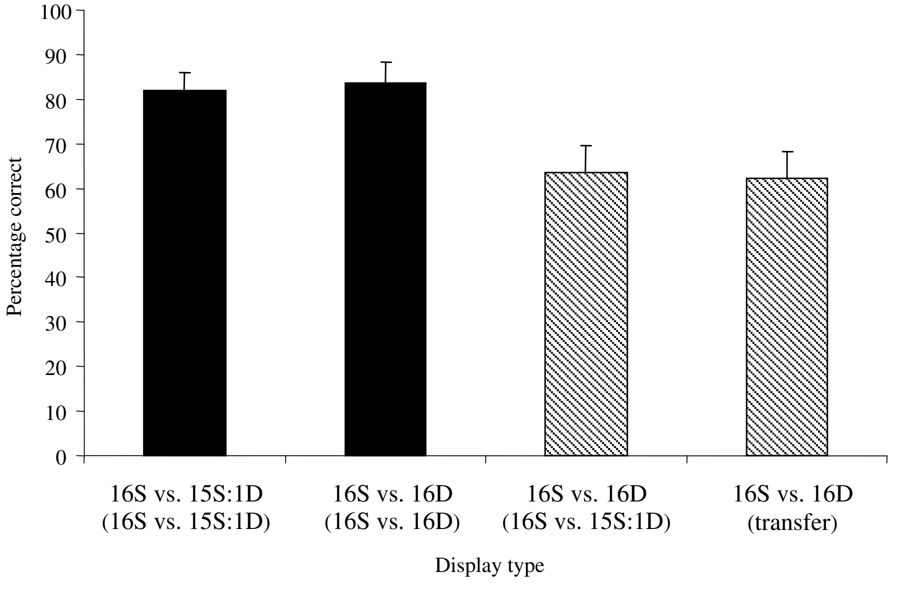
Fig. 3. Percentage of correct choices to the 16S vs. 16D and 16S vs. 15S:1D task displays across the first 20 sessions of acquisition in Experiment 2.

task displays composed of transfer icons, $z(1) = 4.30$, were each reliably above chance (although each was lower than responding to the 16S vs. 16D task training displays).

A one-way ANOVA, with display type as a repeated factor and the percentage of correct responses as the dependent measure, was conducted to compare performance to the four different types of displays. The analysis revealed a reliable effect of display type, $F(3,9) = 6.52$. Planned least-squared means contrast comparisons indicated that there was no difference in discriminative performance to the 16S vs. 16D task training or 16S vs. 15S:1D task training displays, $F(1,9) < 1$. The pigeons did make a higher percentage of correct choices to the 16S vs. 16D task training displays than to either the 16S vs. 16D task displays composed of icons from the 16S vs. 15S:1D set, $F(1,9) = 9.98$, or from the transfer set, $F(1,9) = 10.99$. Likewise, the percentage of correct choices to the 16S vs. 15S:1D task training displays were also higher than choices to the 16S vs. 16D task displays composed of icons from the 16S vs. 15S:1D set, $F(1,9) = 8.56$, or from the transfer set, $F(1,9) = 9.49$. The percentage of correct choices that the pigeons made to each of the two types of testing displays did not differ, $F(1,9) < 1$.

Testing with 16S vs. 15S:1D displays

The pigeons made a high percentage of correct responses to the 16S vs. 16D task (81%) and the 16S vs. 15S:1D task (76%) training displays during testing sessions (Fig. 4, bottom); binomial tests indicated that the percentage of correct choices to the 16S vs. 16D task, $z(1) = 31.27$, and the 16S vs. 15S:1D task, $z(1) = 25.37$, training displays continued to be reliably above chance. The pigeons also transferred 16S vs. 15S:1D responding to 16S vs. 15S:1D displays composed of icons from the 16S vs.



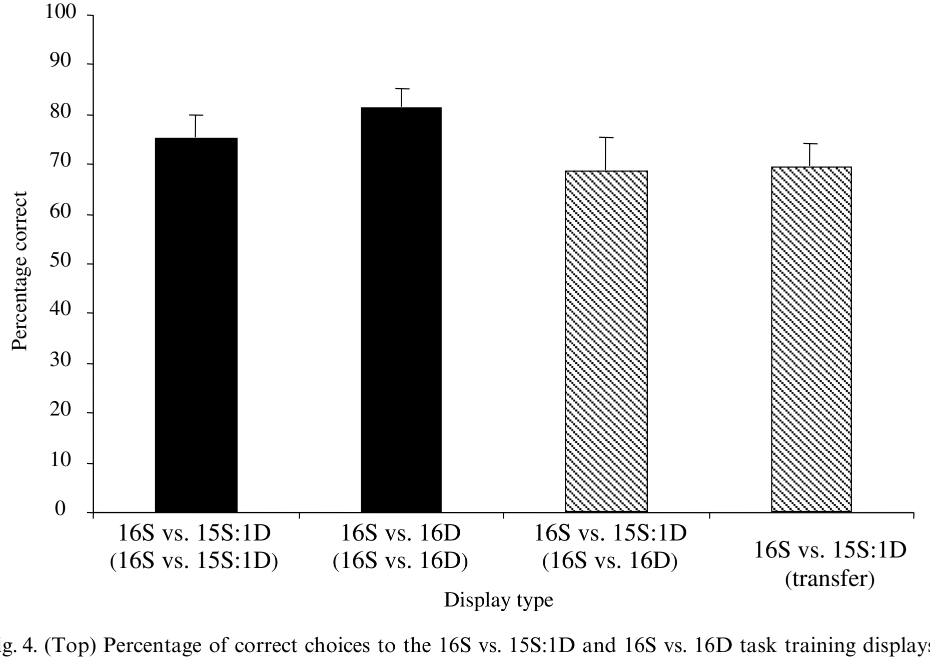


Fig. 4. (Top) Percentage of correct choices to the 16S vs. 15S:1D and 16S vs. 16D task training displays (two solid filled columns), as well as the 16S vs. 16D testing displays (two diagonally filled columns) averaged across the eight sessions of testing during Experiment 2. The labels in parenthesis below the columns indicate the set of icons that was used to construct the display. (Bottom) Percentage of correct choices to the 16S vs. 15S:1D and 16S vs. 16D task training displays (two solid filled columns), as well as the 16S vs. 15S:1D testing displays(two diagonally filled columns) averaged across the eight sessions of testing during Experiment 2.

16D set (69%) and from the transfer set (70%). The percentage of correct choices to the 16S vs. 15S:1D task displays composed of icons from the 16S vs. 16D set, $z(1) = 6.48$, and the transfer set, $z(1) = 6.85$, were reliably above chance.

A one-way ANOVA, with display type as a repeated factor and percentage of correct choices as the dependent measure, was again conducted to compare performance to the different types of training and testing displays across sessions of testing. The analysis revealed a reliable effect of display type, $F(3,9) = 6.86$. Planned least-squared means contrast comparisons indicated that there were no differences in discriminative responding to the 16S vs. 16D task training or 16S vs. 15S:1D task training displays, $F(1,9) = 3.65$. The percentage of correct choices to the 16S vs. 15S:1D task training displays did not differ significantly from the percentage of correct responses to either the 16S vs. 15S:1D task displays composed of items from the 16S vs. 16D set, $F(1,9) = 4.28$, or to the 16S vs. 15S:1D displays composed of icons from the transfer set, $F(1,9) = 3.35$.

Finally, the percentage of correct choices to the 16S vs. 16D task training displays was significantly higher than the percentage of correct responses to either the 16S vs. 15S:1D task displays composed of items from the 16S vs. 16D set, $F(1,9) = 15.84$, or to the 16S vs. 15S:1D displays composed of icons from the transfer set, $F(1,9) = 14.00$. The percentage of correct choices to either of the 16S vs. 15S:1D testing displays did not differ from each other, $F(1,9) < 1$.

Discussion

In contrast to the results of Experiment 1, the pigeons in Experiment 2 now learned to discriminate 16S vs. 15S:1D displays following observing response training. The ability of our pigeons to discriminate 16S vs. 15S:1D displays is consistent with the results of other odd-item discrimination research using pigeons (Blough, 1989; Cook et al., 1995, 1997; Cook et al., 2003; Lombardi et al., 1984; Zentall et al., 1980, 1981). Prior to the present set of experiments, pigeons had not been trained on an odd-item discrimination using displays and procedures commonly arranged by Wasserman and his associates (e.g., Wasserman et al., 1995; Young & Wasserman, 1997). The results are also unique in that the odd-item discrimination was acquired following extensive exposure to the 16S vs. 16D task, in which low variability 16S displays were successfully discriminated from high variability 16D displays. This finding suggests that the acquisition of the 16S vs. 15S:1D task was not due to a change in a single criterion for detecting display entropy (unidimensional account), but rather due to the birds' deployment of a qualitatively different mean of discriminating same- from odd-item displays (see General Discussion).

The 16S vs. 15S:1D task was acquired very quickly following the initiation of the observing response requirement. This finding suggests that the acquisition of the 16S vs. 15S:1D task was due to the peck requirement procedure rather than simply to delayed acquisition of the 16S vs. 15S:1D task. Indeed, Cook et al. (1995) similarly reported very quick acquisition of an oddity task following the use of the peck requirement procedure after previous attempts at oddity learning without this procedure had failed. Thus, the failure of the same birds to learn the 16S vs. 15S:1D discrimination in Experiment 1 is probably due to their lack of attention to the odd-item in the 15S:1D displays. Requiring the pigeons to peck directly at the odd-item, as in Cook et al. (1995), forced the birds to process that critical portion of the display, helping them to acquire the 16S vs. 15S:1D discrimination.

The birds in Experiment 2 were again tested for transfer of the 16S vs.16D task discrimination to 16S vs. 16D task displays composed of icons from the transfer set and from the 16S vs. 15S:1D set. Now, when 16S vs. 16D displays were created from icons in the 16S vs. 15S:1D set, the pigeons did reliably discriminate the former displays from the latter. Clearly, 16S vs. 16D report responses could also be made to displays created from icons in the 16S vs. 15S:1D set. The birds continued to discriminate 16S vs. 16D displays composed of icons from the transfer set, although the level of discriminative performance to these stimuli was a bit lower than it had been in Experiment 1.

One concern may be that the birds learned the 16S vs. 15S:1D task using a response-based cue rather than the stimulus information provided in the displays. Specifically, the birds might have learned to peck one choice key after making a series of spatially restricted responses to the 15S:1D displays and to peck a second choice key after making spatially unrestricted responses to the 16S displays. This would seem an unlikely explanation for several reasons. First, the birds could only discriminate the 16S vs. 16D displays during Experiment 1 based on the display properties, not on response properties. It seems unlikely that they would use the display properties for one task and the response properties for another in Experiment 2. Indeed, it is difficult to imagine how the birds would continue to discriminate the 16S vs. 16D displays at such a high level if they had learned to use the response properties for the 16S vs. 15S:1D discrimination in Experiment 2, since the responses to the later would be comparable (presumably both dispersed spatially). Perhaps, the pigeons learned to use the information in the displays to mediate the use of display- or response-based information to make these two discriminations (Urcuioli & Honig, 1980); but, in this case, they would have had to attend to both types of displays and their relation properties. This type of explanation seems more complex and again would likely result in a dramatic performance drop on the 16S vs. 16D task at the beginning of Experiment 2 (which we did not see). Finally, Cook et al. (1995) conducted several response-based analyses on data collected using the directed response procedure and found that response-based considerations were not viable explanations to the birds' performance in on comparable categorical tasks.

General discussion

We conducted the present pair of experiments to see if pigeons can concurrently master two kinds of S/D discrimination tasks and later generalize these discriminations to displays created from other sets of visual stimuli. Heretofore, different pigeons had learned to discriminate all same vs. all different displays and same vs.

odd-item displays in separate laboratories using distinctly different kinds of visual stimuli in what essentially constituted a between-group design. The results of this first within-subject comparison between the tasks confirmed that pigeons can concurrently master both S/D tasks as well as generalize these discriminations to other visual stimuli.

The current pair of experiments also allowed us to examine alternative accounts of how pigeons learn these two kinds of S/D discriminations. One possibility—suggested by the work of Young and Wasserman (1997)—is that pigeons use the amount of entropy in a display to guide their choice as to whether a display contains all different elements or all same elements. Two sources of evidence suggest that a unified entropy-based account of S/D discrimination learning is not a viable explanation of our pigeons' performance on these two S/D tasks. First, previous research has indicated that, when pigeons are required to discriminate same displays from different displays that have a large amount of entropy (as in the current 16S vs. 16D task), they are unable to subsequently discriminate same from different displays that have a very small difference in display entropy (as with the 16S vs. 15S:1D contrast). Young and Wasserman (1997) found that 16-item mixed displays that contain one copy of four nonidentical icons and 12 copies of another single icon and that entail a level of entropy even greater than that of the 15S:1D displays in the current project, tend to be reported as "same" following training with the 16S vs. 16D displays. Likewise, after 16S vs. 16D training, pigeons fail to discriminate same from different displays composed of just two items (Young et al., 1997), where the entropy disparity is also small. This range effect is likely to be due the fact that the criterion for reporting that a display is different is set higher following training with displays that have a relatively large difference in entropy; thus, low entropy displays, like the 15S:1D displays used in the current experiment, are typically reported as being "same" rather than "different." Nevertheless, in Experiment 2 of the current study, this pattern of response was not the case, suggesting that the pigeons may have successfully learned to discriminate the 16S vs. 15S:1D displays according to some stimulus feature other than entropy.

Second, an entropy-based account would also suggest that performance to 16S vs. 16D displays should have substantially shifted in opposite directions during Experiment 2, as the birds acquired the 16S vs. 15S:1D task. Specifically, as the pigeons learned to discriminate the small entropy disparity between 16S vs. 15S:1D displays during Experiment 2, the criterion or threshold for detecting changes in display entropy should also have shifted, causing more "hits" to 16D displays and more "false alarms" to 16S displays during the 16S vs. 16D task. However, this prediction was not confirmed, as the percentage of correct choices to the 16S vs. 16D displays remained stable or slightly improved during acquisition of the 16S vs. 15S:1D task. This finding suggests that pigeons may have viewed the 16S vs. 16D and 16S vs. 15S:1D tasks in two different ways rather than one.

If pigeons are not using display entropy to solve the 16S vs. 15S:1D task, then how do they successfully acquire this discrimination? The results of the current experiments suggest that pigeons may be flexible in the way they process different features of S/D displays and how they use this information to develop categorical rules

(Cook & Wasserman, 2005). Notice that the organization of the same displays is identical for both the 16S vs. 16D and 16S vs. 15S:1D tasks; these displays thus provide a common point of reference for both S/D discriminations. In contrast, the organizations of the 16D and15S:1D displays are dissimilar; they likely resulted in the birds attending to different features of these displays while acquiring each S/D task.

It has recently been suggested (Cook & Wasserman, 2005) that there are two ways in which pigeons may solve the 16S vs. 15S:1D task. The first possibility is that pigeons form a *categorical* rule after training with 16S vs. 15S:1D displays. Indeed, many of Cook's studies have suggested that pigeons may learn the generalized twin concepts of sameness and differentness following training with odd-item displays. For example, Cook et al. (1997) reported that S/D discrimination training with an oddity task proceeded at the same rate for pigeons presented with each of four different types of odd-item displays: displays based on differences in (a) texture, (b) a feature, (c) a geometric shape, or (d) an object. A generalized categorical account of such learning that encompassed all of the different types of odd-item displays that the pigeons encountered would appear to be a highly parsimonious explanation.

Another possibility is that the pigeons used the unidimensional property of display oddity (defined as the minority number of elements in a display) to make such discriminations. The oddity alternative, like the entropy account, differs from a generalized S/D concept in that oddity is a discriminative dimension that is continuous in nature. Several studies have reported an increase in "different" responding when the number of common elements in an oddity display is increased (e.g., Cook, 1992). Such a benefit cannot easily be accounted for by a generalized categorical rule.

Regardless of which features of the 16S vs. 15S:1D displays are controlling discriminative performance during the 16S vs. 15S:1D task, it is clear that a multi-process account of S/D learning is needed to explain the performance of pigeons with the 16S vs. 16D and 16S vs. 15S:1D tasks reported here; a uni-process such as entropy seems to be inadequate.

As yet, we cannot rule out the possibility that the use of a different pair of response keys for each task may have biased the birds toward attending to different features of the displays to solve each task, thereby biasing the data against the unidimensional account. Based on the results of several experiments conducted in the Wasserman laboratory, we believed that entropy is an especially strong cue that may have overshadowed learning the 16S vs. 15S:1D task, particularly if we had used one set of keys for both tasks. The current results, however, disclose that pigeons can learn both tasks simultaneously, which is previously undocumented, and that entropy alone does not appear to be a reasonable explanation for the learning of both tasks.

Overall, these results attest to the pigeon's ability to concurrently learn two apparently distinctive S/D discriminations. Interestingly, these different discriminations are relatively transparent to the identity of the icons comprising them, as shown by the pigeons' discrimination transfer to novel icons and to icons learned in the other task. The displays and procedures that we used in the current set of experiments provide a firm methodological foundation for further comparing rival accounts of S/D learning based on different mechanisms of stimulus control. We believe the standardization of the methodologies reported here will soon allow us to explore these issues in greater detail.

Acknowledgment

This research was supported by Research Grant IBN 99-04569 from the National Science Foundation.

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