

Same/different discrimination learning with trial-unique stimuli

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A long-standing issue in same/different discrimination learning concerns the possible role of individual stimulus memory through repeated presentation. The aim of eliminating any effect of repetition prompted us to devise a new method for generating trial-unique stimuli. These stimuli were arrays of 16 *mosaics*, each containing 16 cells, which could be filled with 16 possible luminance levels. In Experiment 1, we successfully trained 4 pigeons with these trial-unique stimuli in a two-alternative forced choice same/different discrimination task to 80% correct-choice performance. We later conducted two tests that explored the nature of this discrimination and suggested that pigeons compared the mosaics in the arrays on the basis of their spatial configurations, not on the basis of lower level perceptual properties. In Experiment 2, college students responded similarly to the same sequence of training and testing. Our results suggest that pigeons and people may use similar mechanisms in relational discrimination learning.

How does one tell whether two or more stimuli are the same as or different from one another? Answering this question would greatly extend our understanding of abstract conceptual behavior in both humans and animals.

Critically, a same/different discrimination must be based on the abstract relations between or among items, not on the physical properties of the items. Over a century ago, C. Lloyd Morgan proposed that forming an abstract concept requires that we “neglect all that is variable and focus the attention on the uniform relation. [Then] we have reached a conception, and this conception is not concrete, particular, and individual, but abstract, general, and of universal application” (1894, p. 263). We explored the nature of abstract conceptualization by eliminating the participation of particulate, individual information in the mastery of a same/different discrimination.

Since Morgan, same/different discrimination behavior has been a special concern of comparative psychologists trying to understand abstract relational learning. Considerable empirical research has supported the possibility that pigeons, baboons, and humans are sensitive to interitem variability and that this sensitivity underlies same/different discrimination behavior (Wasserman, Young, & Cook, 2004).

Initial investigations into the control of behavior by variability used stimuli (black-and-white computer icons) that were more or less similar to one another along unknown dimensions. Young and Ellefson (2003) recently used stimuli that ranged along the color dimension to more carefully control variability, both within and between trials. We followed their lead by creating stimuli from 16 different brightness levels (Figure 1).

The key property of our stimuli was that they contained individual items (*mosaics*) that were generated randomly without replacement from a vast collection. If organisms were to learn a same/different discrimination with these trial-unique stimuli, such learning would have to be due to a general property underlying the relations between or among the stimuli rather than to some particular property of the individual stimuli. Critically, in our task, every discrimination training trial was also a generalization testing trial.

In previous studies, trial-unique procedures have been sought to study visual object categorization and same/different concept formation. The goal of such studies was for organisms to respond discriminatively in the absence of item-specific cues. For instance, Bhatt, Wasserman, Reynolds, and Knauss (1988) successfully taught pigeons to categorize 2,000 nonrepeating photos into four categories: cats, flowers, cars, and chairs. Other researchers claimed to have used “trial-unique” stimuli to study concept learning, but they either reused stimuli in different phases (Santiago & Wright, 1984) or repeated the stimuli from day to day (Wright, Cook, Rivera, Sands, & Delius, 1988).

It may seem that the control of behavior by item-specific cues in prior same/different discrimination studies was unlikely, given that many used large stimulus sets. Nevertheless, now that we appreciate even the pigeon’s prodigious capacity for remembering individual stimuli (Cook, Levison, Gillett, & Blaisdell, 2005), item-based accounts of same/different learning (Mackintosh, 2000) cannot be dismissed. Thus, there is good reason to devise a same/different discrimination task using trial-unique stimuli with highly controllable variability between or among items.

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In Experiment 1, we trained pigeons to discriminate 16-item, trial-unique *same* versus *different* displays. Two tests followed. The first, an isoluminance test, eliminated alternative explanations of pigeons' discrimination behavior based on lower level properties of the visual stimuli. Here, birds had to categorize displays created by an even more rigidly controlled stimulus generation algorithm, in which each of the 16 mosaics in each display shared the same individual features (Figure 1, isoluminant stimuli). Correct categorization under these conditions would suggest that either global brightness discrimination or lower

level visual processing alone cannot explain pigeons' discriminative behavior.

The second, a planar-rotation test, suggested that pigeons' discrimination behavior was configuration based rather than feature based. Here, pigeons had to categorize displays that either contained a mixture of four different mosaics (Figure 1, mixture) or contained one mosaic in four different orientations: 0°, 90°, 180°, or 270°. Young and Wasserman (2001b) found an intermediate level of "different" responding to mixture displays in which four different computer icons were each repeated four times;

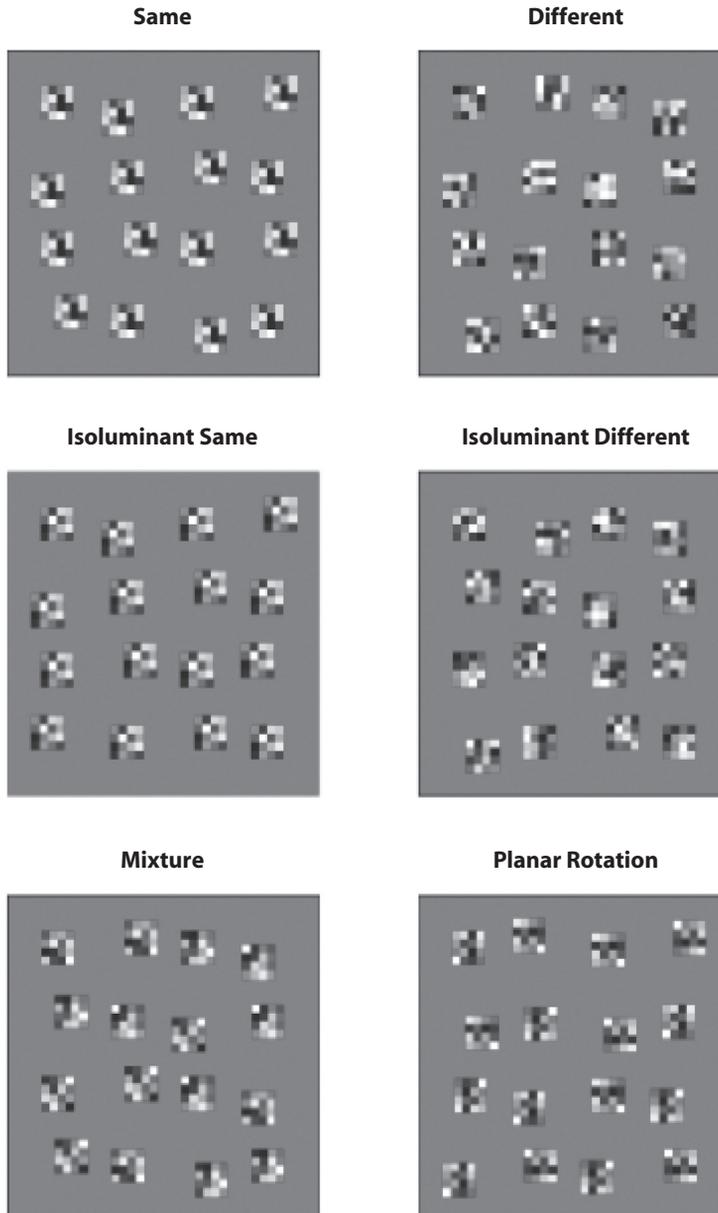


Figure 1. Examples of individual displays that could have been shown to pigeons in Experiment 1 and people in Experiment 2. Training stimuli, under the headings Same and Different, comprised 16 mosaics placed into a 4×4 staggered array. Isoluminant Same, Isoluminant Different, Mixture, and Planar Rotation designations were specific to particular tests, as detailed in the text.

but, when the same icon was presented in four different planar orientations (0°, 90°, 180°, and 270° of rotation) with each rotation presented four times, Young and Wasserman (2001b) obtained a reliably higher level of “same” responding. This disparity suggests a unitization or object-based account of pigeons’ discrimination based on a rotationally invariant representation. We repeated the rotation test using trial-unique stimuli to see whether pigeons would unitize the present mosaics.

In Experiment 2, we gave the same acquisition and testing tasks to college students. Because of the abstract nature of the mosaics, it was unlikely that our human participants would verbally encode the stimuli, perhaps increasing their sensitivity to the same underlying variables that control the behavior of animals in discrimination learning tasks (Wills & Mackintosh, 1998; Wright, Santiago, Sands, Kendrick, & Cook, 1985).

EXPERIMENT 1

Method

Subjects

Four feral pigeons (*Columba livia*) with unrelated experimental experience were kept at 85% of their free-feeding weights.

Apparatus

The pigeons were trained in four conditioning boxes (Gibson, Wasserman, Frei, & Miller, 2004). The stimuli were presented on an LCD monitor behind a resistive touch screen. A food dispenser delivered 45-mg pellets into a cup on the rear wall. A houselight provided illumination during sessions.

Stimuli

Training. Each trial stimulus was a 9.5×9.5 cm display in the center of the screen. Each display contained 16 (1×1 cm) mosaics roughly organized in a 4×4 fashion, with each mosaic being a neat 4×4 matrix and with each cell (0.25×0.25 cm) randomly filled with 1 of 16 brightness levels. These 16 levels were equidistant along a monochromatic spectrum.

Two kinds of displays were shown: *same* displays, in which each of the 16 mosaics was constructed from the same luminance matrix, and *different* displays, in which each of the 16 mosaics was constructed from a different luminance matrix. Throughout all experiments, a record was kept of each matrix used and a hashing algorithm guaranteed that no luminance matrix was repeated.

On each trial, 16 mosaics were placed on a red square background and arranged so that the stimuli in each row and column were staggered randomly, thereby eliminating any simple perceptual strategy, such as orderliness, for solving the task (Young & Wasserman, 2001b).

Testing: Isoluminant stimuli. To control for disparities in luminance variability between *same* and *different* displays, we conducted a test in which each mosaic had the same luminance. This goal was

accomplished by showing each of the 16 brightness levels in each mosaic (Figure 1, isoluminant same, isoluminant different).

Testing: Mixture stimuli. Two further types of testing displays were introduced. To allow for direct comparison with the isoluminant stimuli and to control variability during testing, these displays were also constructed with the constraints imposed on isoluminant trials. The first was a 4–4–4–4 *mixture display*, in which four different mosaics each appeared four times (Figure 1, mixture). This mixture was chosen as a benchmark, because it represents the psychological midpoint for pigeons in terms of reported display variability (Young & Wasserman, 1997). The second was a *planar rotation display* (Figure 1, planar rotation), in which one mosaic was presented four times in each of four planar rotations (0°, 90°, 180°, and 270°).

Procedure

Training. Each trial started with the presentation of a white square (7×7 cm) with a central black cross. Following one peck, a training display was presented until the bird completed a fixed number of pecks (different for each bird and ranging from 30 to 40). The bird had to discriminate between *same* and *different* displays by pecking one of two 2.5×2.5 cm buttons (a circle and a triangle) to the left and right of the display (locations counterbalanced across birds). Incorrect choices were punished with a dark time-out (ranging from 30 to 35 sec), followed by 1 or more correction trials. Correct choices produced one or two food pellets. Following a correct choice, an 8-sec intertrial interval preceded the next stimulus. Daily sessions comprised 150 (75 *same*, 75 *different*) randomly ordered training trials. The training phase ended when the birds reached a criterion of 80% correct on both *same* and *different* trials. Testing criteria for each bird varied slightly to collect data in a timely manner. Bird 11Y was tested at 90% correct, Bird 81W at 75%, and Birds 88B and 36R at 70%. Testing sessions were separated by at least 1 day of training.

Isoluminance testing. Testing sessions were structured like training sessions, except that all choices to testing stimuli were followed by nondifferential food reinforcement. Testing sessions with isoluminant stimuli comprised a warm-up block of 78 training trials, followed by a testing block of 60 training trials, 6 isoluminant *same* trials, and 6 isoluminant *different* trials. Testing sessions contained 150 trials; they were conducted only if the bird met criterion on the prior day’s training trials. A total of 10 isoluminance testing sessions were given to each bird.

Planar rotation testing. These testing sessions comprised a warm-up block of 78 training trials, followed by a testing block of 48 training trials, 6 isoluminant *same* trials, 6 isoluminant *different* trials, 6 4–4–4–4 mixture trials, and 6 planar rotation trials. Testing sessions contained 150 trials, conducted only if the bird met criterion on the previous day’s training trials. A total of eight testing sessions were given to each bird.

Results

Acquisition

Pigeons successfully learned the discrimination to a single-session criterion of 80% correct on both *same* and

Table 1
Acquisition and Testing Performance for the 4 Pigeons in Experiment 1

Bird	Acquisition: Sessions to Criterion	Isoluminance Test: % Correct Responses				Rotation Test: % “Different” Responses	
		“Same”	“Different”	Isoluminant “Same”	Isoluminant “Different”	Rotation	Mixture
11Y	73	79.06	84.45	78.33	83.33	13.33	40.00
36R	93	78.57	77.67	60.00	73.33	16.67	41.67
81W	149	94.21	89.56	93.33	93.33	41.67	50.00
88B	152	88.58	84.47	76.67	90.00	43.44	58.33

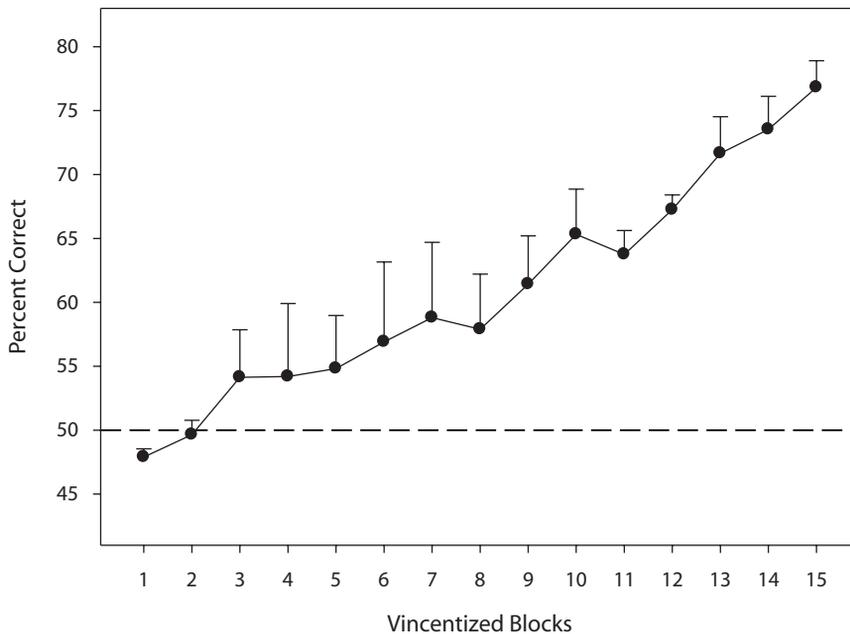


Figure 2. Acquisition as a function of Vincentized blocks, each representing 1/15th of the total number of sessions to reach 80% correct responding in a single session on both *same* and *different* trials. Error bars represent the standard errors of the means.

different trials (Table 1). To analyze the acquisition data, we constructed Vincent learning curves by grouping sessions into 15 blocks of 4 sessions (11Y), 6 sessions (36R), 9 sessions (81W), or 10 sessions (88B), and then placing any remaining sessions into Block 8 (Kling & Riggs, 1971). Figure 2 depicts the mean learning curve, which rose in a highly systematic fashion. An ANOVA (session \times trial type [S/D] \times bird as a random factor) confirmed a significant main effect of session [$F(14,42) = 7.69$] (all tests set alpha at $p < .05$). These data clearly document that pigeons can learn a same/different discrimination in which no mosaics are repeated, thereby attesting to this animal's abstract learning ability. There was no significant effect of trial type [$F(1,42) = 1.96, p > .25$] and no trial type \times session interaction [$F(14,42) < 1$], indicating that birds acquired the *same* and *different* discriminations at similar rates.

Isoluminance Testing

Throughout the isoluminance test, pigeons sustained high levels of accuracy on the original discrimination, in which the cells of the mosaics were filled randomly with 16 different brightness levels; birds averaged 85% correct on *same* trials and 84% correct on *different* trials. On isoluminant testing trials, in which each individual mosaic comprised each of the 16 brightness levels, birds' mean scores remained high, with accuracy on *same* trials declining slightly to 77% correct and with accuracy on *different* trials remaining unchanged at 85% correct (Figure 3, top left; Table 1). An ANOVA (trial type [S/D] \times testing condition \times bird as a random factor) did not disclose any significant differences in testing conditions, trial-type conditions, or the interaction of the variables. These results indicate that pigeons' same/different discrimination

was not based on the overall brightness of the individual mosaics.

Planar Rotation Testing

The bottom left of Figure 3 depicts the percentage of "different" responses made to the various displays during planar rotation testing. The lowest percentage of "different" responses was made on isoluminant *same* trials (22%) and the highest percentage of "different" responses was made on isoluminant *different* trials (84%). Birds' "different" responding on trials in which the same mosaic was shown four times at each of four planar rotations (planar rotation trials) was slightly higher (28%) than on *same* trials. Mixture trials composed of four different mosaics repeated four times each (4-4-4-4 mixture trials) supported a higher level (49%) of "different" responding. An ANOVA (trial type \times bird as a random factor) revealed a significant main effect of trial type [$F(3,9) = 24.54$]. Because we were interested in any disparities among the testing conditions, we conducted Tukey tests. These tests disclosed no difference between *same* and rotation trials; each of these trials differed from mixture and *different* trials; as well, mixture and *different* trials differed from one another (Figure 3, bottom left; Table 1).

Discussion

All 4 birds mastered the same/different discrimination with trial-unique stimuli to 80% correct on both *same* and *different* trials. Acquisition occurred under conditions in which each training trial was also a transfer trial. Thus, no recurring perceptual cue or stimulus memory can account for our pigeons' discriminative performance. Later tests argued against lower level perceptual accounts of our pigeons' same/different discrimination behavior. These re-

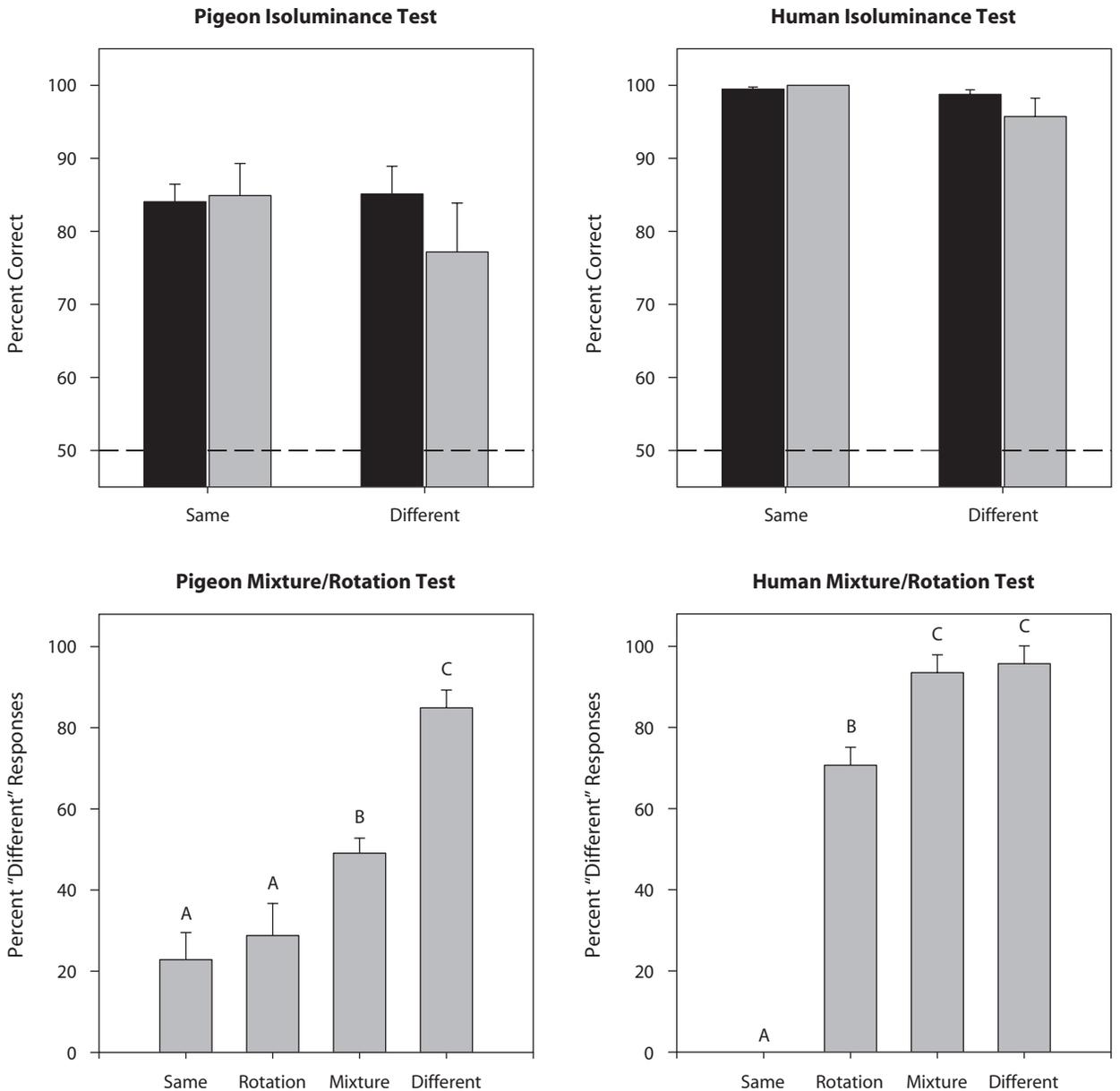


Figure 3. Top: Data from the isoluminance test for both pigeons in Experiment 1 (left panel) and people in Experiment 2 (right panel). Training stimuli (black bars) and testing stimuli (gray bars) did not differ significantly for either species. The dashed line represents chance responding. Bottom: Pigeons (left panel) perceived trials with one mosaic rotated four discrete ways as being equivalent to a *same* trial, but unequal to a mixture trial. Humans (right panel) were more inclined to label all nonidentical displays "different," but they still showed a similar effect of rotation when results were compared with results for mixture trials. Different letters indicate statistically different comparisons. Error bars represent the standard errors of the means.

results suggest that pigeons can use abstract stimulus relations to solve a same/different task.

In the planar rotation test, our pigeons responded to isoluminant displays in which the same mosaic was rotated in four different orientations as if they were *same* trials; by contrast, isoluminant displays comprising four copies of four different mosaics were equally likely to be reported as same or different. These results suggest a mosaic-based interpretation, in which pigeons encode each mosaic's pattern or

configuration in a rotation-invariant manner (Young & Wasserman, 2001b). Perhaps relevant here is that pigeons may discriminate rotated stimuli better than do humans (Hollard & Delius, 1982).

EXPERIMENT 2

Possible disparities between people and pigeons in visual perception prompted us to replicate Experiment 1

with humans. These disparities, such as differential sensitivity to variability and the role of verbal mediation in forming a stimulus representation, may be explored better through the use of the methodology in Experiment 1. This methodology allowed us to study same/different discrimination learning in humans with trial-unique stimuli that could not be encoded verbally.

Method

Participants

We studied 22 undergraduates in introductory psychology at the University of Iowa. All had normal or corrected-to-normal vision, and each received course credit for serving.

Apparatus and Procedure

Training. As many as 4 participants at a time were seated in front of their own computer and were asked to wear headphones. After participants were given general instructions, they were given a written paragraph detailing the experiment. They were asked to classify each display by choosing one of two responses (orange or blue key, counterbalanced across students), which appeared to the right and left of the display. At no point were the words *same* and *different* used, nor was any indication given that these would be the features of the displays to which participants should respond.

Participants first received a 100-trial training block comprising 50 *same* and 50 *different* trials with the stimuli constructed as in Experiment 1. Participants were reinforced differentially for their responses. Correct responses were followed by a consonant chime and a 10-point increment in a score counter on the display. Incorrect responses were followed by an unpleasant buzzer, a 10-sec time-out, and a "Try Again" screen; correction trials were given until the correct response was chosen.

Participants then moved without a break to testing, which consisted of 120 trials, 80 of which were training trials. Of the 40 testing trials, 20 were isoluminant trials (10 *same* and 10 *different*) and 20 were rotation test trials (10 planar rotation, 10 mixture). All testing trials involved nondifferential reinforcement.

Most participants learned the task, but only those who performed the task with high accuracy (>80% correct to both *same* and *different* trials) during the last block of training and on training trials during testing were included for analysis; 8 participants were excluded.

Results

Acquisition

Participants who met the inclusion criteria averaged 94% correct on *same* trials and 95% correct on *different* trials.

Isoluminance Testing

Throughout the isoluminance test, participants sustained high levels of accuracy on the original discrimination, in which the cells of the mosaics were filled randomly with 16 different brightness levels; participants averaged 99% correct on *same* trials and 98% correct on *different* trials. On isoluminant testing trials, in which each individual mosaic was composed of each of the 16 brightness levels, participants' scores remained high, with mean accuracy on isoluminant *same* trials at 100% correct and with mean accuracy on isoluminant *different* trials at 96% correct (Figure 3, top panel). An ANOVA (trial type [S/D] × testing condition × participant as a random factor) did not reveal significant differences among testing conditions, trial-type conditions, or the interaction of the

variables. These results closely accord with those of the pigeons in Experiment 1.

Planar Rotation Testing

Like pigeons, humans were more inclined to report "same" on isoluminant rotation trials (71% "different" reports) than on isoluminant mixture trials (94% "different" reports). Unlike pigeons, however, humans responded to isoluminant mixture trials as if they were isoluminant *different* trials. An ANOVA (trial type × participant as a random factor) yielded a significant effect of trial type [$F(3,13) = 102.28$]. Tukey tests disclosed no difference between isoluminant mixture and isoluminant *different* trials, but each of these trials differed from isoluminant rotation and isoluminant *same* trials, which also differed from each other (Figure 3, bottom right).

GENERAL DISCUSSION

Both pigeons and people learned a same/different discrimination involving trial-unique, multiple-mosaic displays. The behavior of both species was unaffected by an experimental manipulation (luminance equilibration) that tightly controlled the overall (display) and regional (mosaic) brightness levels of the experimental stimuli, thereby discounting lower level perceptual explanations of task mastery. Such explanations are also rendered improbable because the mosaics in each display were spatially staggered, thereby preventing vertical and horizontal alignment of the mosaics on either *same* or *different* trials. Both species further evidenced a robust tendency to classify planar rotation displays as more same-like than mixture displays. These similar results of the two different species under comparable conditions suggest that their behavior may have been mediated by common mechanisms.

An interesting between-species disparity occurred on planar rotation and mosaic mixture tests; reports of "same" and "different" to testing displays were located at different points along the same-different scale. Nonetheless, both pigeons and people rated mixture displays about 22% higher (more different) than rotation displays. Thus, although humans were more inclined to report any display of nonidentical mosaics as "different," they still exhibited the same rotation-mixture disparity as did pigeons. Higher "different" reports to nonidentical testing stimuli by people than by pigeons may result from humans' adopting a more stringent decision criterion, perhaps because of verbal mediation (Fagot, Wasserman, & Young, 2001; Young & Wasserman, 2002).

These and other results are consistent with both pigeons and people conceptualizing the sameness and differentness of the mosaics in the displays. Such conceptualization could not, of course, proceed if the mosaics were not discriminable from one another; if they were not, then all of the displays—*same* or *different*—should be classified as "same." As well, successful discrimination must have generalized to new mosaics; otherwise, across-trial discrimination learning with trial-unique displays would have been impossible.

The isoluminance test provides an effective way to control for at least two sources of variability that may have provided discriminative information. Within-display variability is controlled by equating the luminance of each mosaic. Nevertheless, when each mosaic was composed of the same features, discrimination was unaffected. The more subtle possibility of between-display variability was also addressed with this experimental manipulation. Because of random sampling of 1 mosaic (*same* trials) or 16 mosaics (*different* trials), extremely bright or dim displays were more likely on *same* trials than on *different* trials. Because isoluminant arrays were constructed from equally bright mosaics, between-display variability was also eliminated as a discriminative cue. Although the isoluminance manipulation did not address all brightness accounts, it did prove that certain salient aspects of variability cannot account for our experimental results.

Results from the planar rotation test further suggest that sameness and differentness are detected without the mediation of a display-wide spatial frequency discrimination. Because the pigeons reported “same” to rotation arrays, it is unlikely that the display-wide texture of each array played a key part in discrimination. On the other hand, theories that focus on the unitization and relational comparison of the mosaics generate more successful predictions.

Accounts that focus on the abstract relations in visual arrays—operationalized as the variability between or among items—have been quite successful in explaining behavior in this task. The interitem variability of an array has been captured nicely by entropy, a mathematical notion that has produced promising fits to both pigeon and human behavior (Young & Wasserman, 2001a). Yet entropy assumes a standardized coding of sameness or differentness of each item in an array; hence, entropy cannot account for the behavioral effects of different degrees of interitem disparity (Young, Ellefson, & Wasserman, 2003). Until recently, this kind of manipulation of visual items had been untested, because it is impossible to assess the degree of similarity of pictorial items that do not vary along specified dimensions. This scaling problem is compounded because, for humans, many pictorial items have a long training history that could influence their perceived similarity. Our new methodology addresses both of these problems.

AUTHOR NOTE

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