



## Object discrimination by pigeons: effects of object color and shape

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### Abstract

Can nonhuman animals attend to visual stimuli as whole, coherent objects? We investigated this question by adapting for use with pigeons a task in which human participants must report whether two visual attributes belong to the same object (*one-object* trial) or to different objects (*two-object* trial). We trained pigeons to discriminate a pair of differently colored shapes that had two targets either on a single object or on two different objects. Each target equally often appeared on the *one-object* and *two-object* stimuli; therefore, a specific target location could not serve as a discriminative cue. The pigeons learned to report whether the two target dots were located on a single object or on two different objects; follow-up tests demonstrated that this ability was not entirely based on memorization of the dot patterns and locations. Additional tests disclosed predominate stimulus control by the color, but not by the shape of the two objects. These findings suggest that human psychophysical methods are readily applicable to the study of object discrimination by nonhuman animals.

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### 1. Introduction

Much research suggests that the human visual system does not passively process all of the available information in a visual scene. Instead, humans seem to selectively attend to different features of the scene at different times. Depending on the situation, we may attend to a specific spatial location, to a specific object, or to a specific part of an object (Duncan, 1984; Vecera,

2000; Vecera et al., 2000; Zemel et al., 2002; Egly et al., 1994). The ability to flexibly process different aspects of a visual scene or object is generally referred to as visual attention (Palmer, 1999).

There are two forms of visual attention that most researchers identify: spatial (or location-based) attention and object-based attention (Egeth and Yantis, 1997). Evidence for location-based attention comes from a variety of experimental paradigms, among which Posner's classic technique appears to be one of the most widely used cuing tasks. In this task (Posner, 1980), observers were asked to detect the onset of a visual target that was preceded by a spatial cue. The cue was

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either *valid*, in which case it predicted the upcoming target's location (i.e., the cue and the target appeared in the same spatial position) or *invalid*, in which case the cue did not predict the upcoming target's location (i.e., the cue and the target appeared in different locations). Detection times were faster when targets were validly cued than when they were invalidly cued, suggesting that human observers attended to the specific location of the valid cue.

Spatial attention has variously been described as a “spotlight” (Posner, 1980), a “zoom lens” (Eriksen and Eriksen, 1974), or a “spatial gradient” (Downing and Pinker, 1985; LaBerge and Brown, 1989). Regardless of the metaphor, location-based theories of attention typically assume that attention is directed toward *un-grouped* locations in the visual field; that is, the spotlight (or zoom lens or spatial gradient) is not shaped by the stimuli falling within it. Rather, the spatial focus of attention has some assumed structure; for example, location-based attention may be circular in nature, with the organism being able to focus on larger or smaller scales in the case of the “zoom lens.” By using cuing and similar techniques, researchers have found that nonhuman animals (rhesus monkeys) too were able to attend to a spatially relevant location; moreover, the responses of single neurons in various regions of the extrastriate cortex were enhanced when the target occurred at a spatially cued location (Moran and Desimone, 1985; Sharma et al., 2003).

Several behavioral reports also suggest that pigeons are also able to focus on a specific region of visual field. The most direct evidence was reported by Shimp and Friedrich (1993); they used a modification of Posner's task in which pigeons were required to detect the onset of the target (red light appearing on either the right or the left key) within 5 s of its appearance. A pre-cue (white light) could appear on either the same key as the target (*valid* trial) or on the different key (*invalid* trial), just as in human experiments. Pigeons appeared to detect the target faster on valid trials than on invalid trials, demonstrating their ability to attend to the specific location that had been cued prior to the target's appearance.

Other experimental results provide suggestive evidence of spatial attention in pigeons. For example, pigeons can learn a delayed matching-to-sample task using the location of the sample as a cue (Wilkie and Summers, 1982), thereby demonstrating that they can

indeed focus on, process, and retain spatial information. Moreover, pigeons exhibit better memory for the location of the sample than for the color of the sample (Wilkie et al., 1985), suggesting that they may be biased to attend to spatial information. Other matching-to-sample experiments have shown that pigeons and rhesus monkeys attend to and code the location of the sample together with other sample-specific information, even when the experimental contingencies do not require them to do so (Iversen et al., 1986; Lionello and Urciuoli, 1998).

Still other experiments have found that pigeons exhibit no decrement in recognizing cartoons whose parts have been spatially scrambled (Cerella, 1980; Watanabe, 2000), suggesting that birds' visual recognition performance may be predominately controlled by the local features of an image. Such a result suggests that pigeons may attend to a restricted region in a visual field rather than to the object as a whole, although other evidence suggests otherwise (Kirkpatrick-Steger et al., 1996; Kirkpatrick-Steger et al., 1998; Wasserman et al., 1993).

In contrast to location-based accounts, object-based accounts of attention suggest that attention is directed to grouped “chunks” in the visual field that correspond to objects or shapes. All of the visual features of an attended object are processed concurrently; features that belong to other, unattended objects are processed little, if at all (Duncan, 1984; Vecera, 2000; Vecera and Farah, 1994). Evidence for object-based attention has come from several different tasks. For example, some studies have demonstrated that stimuli of the same color (i.e., stimuli that are grouped together by similarity) are selected simultaneously (Baylis and Driver, 1992). Other Gestalt grouping cues, such as connectedness and good continuation, allow stimuli to be grouped together and processed continuously as well (Baylis and Driver, 1992; Watson and Kramer, 1999).

Note that the term “object” in object-based attention studies typically refers to perceptual objects defined by Gestalt grouping cues. One influential view of object-based attention, the “grouped array” hypothesis (Vecera, 1994; Vecera and Farah, 1994), proposes that most object-based attention effects arise from the influence of grouping cues on spatial attention. Thus, object-based attention can be characterized as directing spatial attention to groups of locations that have been organized or chunked based on perceptual cues, in-

cluding surface similarity, connectedness, closure, and good continuation. The term “object” in the current paper need not imply late object-centered representations used for invariant object recognition (although there may be forms of object-based attention that select from such invariant object representations; see Vecera and Farah, 1994).

Are nonhuman animals also able to attend to visual stimuli as whole, coherent objects? Surprisingly, very little research has explicitly explored this question. Recent neurobiological evidence suggests that nonhuman animals may have neuronal mechanisms which operate on objects as entities rather than as mere “lists” of abstract features. In one representative study (Roelfsema et al., 1998), monkeys performed a task requiring them to attend to one irregular curve and to ignore another overlapping curve. Multi-unit recording in area V1 of the primary visual cortex disclosed that neurons with receptive fields containing segments of the attended curve simultaneously enhanced their responsiveness, whereas neurons with receptive fields containing segments of the distractor curve did not. Thus, neurons which detect different segments of the same, attended curve fired in unison even when the attended curve overlapped with the distractor curve, documenting the existence of a very early visual mechanism that seems to operate in accord with such Gestalt principles as connectivity and proximity.

As noted above, in contrast to Cerella (1980) and Watanabe (2000), research in our own laboratory has consistently found that pigeons trained to recognize line drawings of objects show a significant decrement in recognizing modified drawings that do not preserve the correct spatial arrangement of the object’s components (Kirkpatrick-Steger et al., 1996; Kirkpatrick-Steger et al., 1998). In other words, we found that pigeons are sensitive to global, organizational properties of the objects (see also Kirkpatrick-Steger and Wasserman, 1996). Additionally, an experiment reported by Matsukawa et al. (2004) suggested that pigeons may attend to either local or global properties of an image depending on the task. When pigeons were taught to discriminate simple line drawings of cartoon faces on a white background, they were relatively insensitive to spatial scrambling and appeared to attend primarily to the eyes and eyebrows. When, however, the pigeons were trained to discriminate line drawings of cartoon faces on a variety of backgrounds scenes, their per-

formance with scrambled images reliably deteriorated, suggesting that the birds were attending to global, configural properties of the image. These data suggest that, at least under some circumstances, pigeons may attend to global rather than to local properties of objects; pigeons may thus be capable of using objects as units of attention. To obtain clear behavioral evidence of object-based attention was the prime aim of this study.

We decided to adapt for use with pigeons one of the many tasks that have been used in studies of object-based attention in humans. In this task, participants are instructed to report whether two visual attributes belong to the same object (*one-object* trial) or to different objects (*two-object* trial). For example, in the experiment conducted by Vecera and Farah (1997), participants saw two transparent, overlapping shapes that had two small Xs either on one shape or on both shapes. Importantly, the spatial distance between the Xs was equivalent on *one-object* trials and on *two-object* trials; thus, differential performance on these trials cannot be explained by people’s attending to different spatial areas of the display. Yet, the participants responded faster and more accurately when the two Xs were on the same object than when they were on two different objects—a common result in many object-based attention studies (Duncan, 1984; Egly et al., 1994; Vecera, 1994; Watson and Kramer, 1999).

To adapt this task for pigeons, we used a go/no-go method that should be quite sensitive to the birds’ visual discrimination performance: namely, differential reinforcement of high rate (DRH) versus differential reinforcement of low rate (DRL) schedules. This multiple schedule method associates one class of stimuli, for example, *one-object* displays, with a schedule in which reinforcement is delivered only if a response is made *within* a certain amount of time following the preceding response; this schedule encourages responding to *one-object* stimuli at a high rate—DRH. The second class of the stimuli, *two-object* displays, is associated with a schedule in which reinforcement is delivered only *after* a certain amount of time has elapsed since the preceding response; this schedule encourages responding to *two-object* stimuli at a low rate—DRL. Note that a more commonly used go/no-go procedure associates one class of stimuli with a Variable-Interval (VI) schedule, in which reinforcement is delivered after a variable amount of time has elapsed since the last response, and it associates another class of stimuli with experimental

extinction (EXT). Thus, the VI-EXT go/no-go procedure encourages the birds to cease responding (and, perhaps, attending) to one class of stimuli, whereas the DRH-DRL procedure maintains responding (and, we hoped, attending) to both classes of stimuli.

In an earlier report (Lazareva et al., in press), we showed that pigeons can accurately discriminate *one-object* from *two-object* stimuli. However, in that project we found that the birds relied on an unintended cue (the spatial location of a single target dot) to perform the task, instead of comparing the locations of the two target dots. To remedy this problem, we designed new discriminative stimuli that eliminated this accidental cue; we then trained pigeons to perform the *one-object* versus *two-object* discrimination with these stimuli. This new task was used in the present study.

## 2. Experiment 1

### 2.1. Method

#### 2.1.1. Subjects

The subjects were two feral pigeons (*Columba livia*) maintained at 85% of their free-feeding weights. Prior to this study, the pigeons had participated in several unrelated experiments that did not involve the multiple DRH-DRL schedule.

#### 2.1.2. Apparatus

The experiment used two operant conditioning chambers and two Macintosh computers that were detailed by Wasserman et al. (1995). One wall of each chamber contained a large opening with a frame attached to the outside that held a clear touch screen. An aluminum panel in front of the touch screen allowed the pigeons to access to circumscribed portions of a video monitor behind the touch screen. There were five openings or buttons in the panel: a 7-cm × 7-cm square central display area in which the stimuli appeared and four round areas (1.9-cm diameter) located 2.3 cm from each of the four corners of the central opening. Only the central opening was used. A food cup was centered on the rear wall level with the floor; a food dispenser delivered 45-mg food pellets through vinyl tube into the cup. A house light mounted on the rear wall of the chamber provided illumination during the session. The experimental procedure was programmed in HyperCard, Version 2.4 (Apple Computer, Inc., Cupertino, CA).

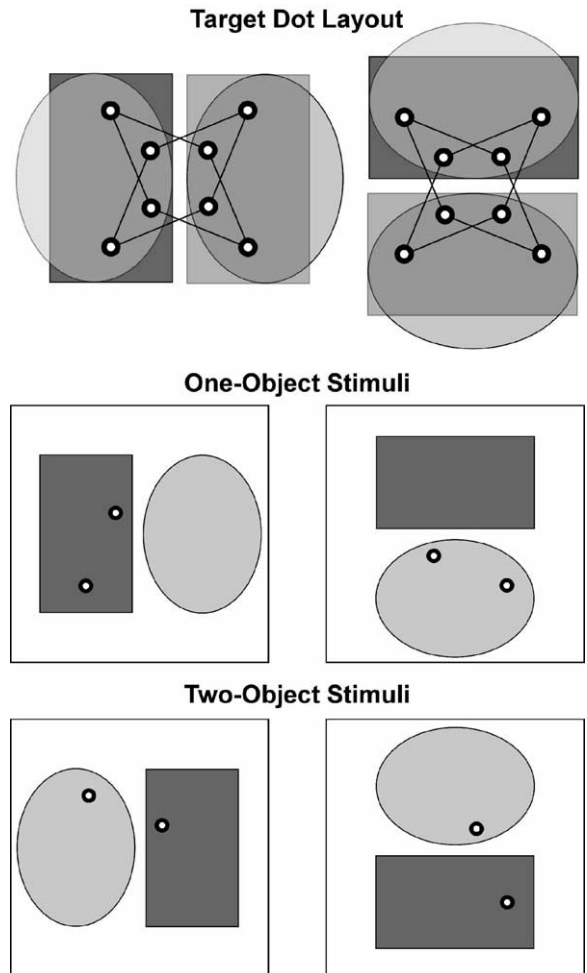


Fig. 1. Construction of the experimental stimuli. The upper row illustrates the geometrical constraints that were used to create the 32 training stimuli. Note that the isosceles triangles are shown for illustrative purposes only; they were not visible to the pigeons. The bottom rows show two examples of the *one-object* and *two-object* stimuli.

#### 2.1.3. Stimuli

Fig. 1 (upper part) illustrates the constraints on stimulus construction. Each stimulus display comprised either a red oval and a green rectangle (Bird 25Y) or a green oval and a red rectangle (Bird 12Y). The rectangle was 5.27 cm high and 3.09 cm wide and the oval was 5.28 cm high and 3.93 cm wide; therefore, both the rectangle and the oval had an equal area, 16.28 cm<sup>2</sup>. The oval and the rectangle were placed in either left-right or in top-bottom orientations.

Four isosceles triangles with two long sides of 2.68 cm were positioned so that the apexes of all four triangles were evenly spaced on top of the oval and the rectangle. The eight possible targets (black dots, 0.49 cm in diameter, with a white center 0.21 cm in diameter) were placed at the corners of all four triangles. Only those pairs of targets that were connected with the lines drawn in the top portion of Fig. 1 were allowed, ensuring an equal distance (2.68 cm) between all target pairs; therefore, eight displays with the targets on the same object and eight displays with the targets on different objects were possible.

By randomizing the left-right and top-bottom positions of the objects, we generated a total of 32 training stimuli: 16 with two dots on one of the objects (*one-object* stimuli) and 16 with one dot on each of the two (*two-object* stimuli) objects. Four examples of these stimuli are shown in the bottom portion of Fig. 1. Each target was equally often presented on the *one-object* and *two-object* stimuli; therefore, a specific target location could not serve as a discriminative cue. The stimuli were placed on a white, 3.4-cm × 3.4-cm background so that the gap between the objects was always positioned in the middle of the square. The minimal distance between the objects was equal to 0.37 cm. All of the stimuli were created in Canvas™ Standard Edition, Version 7.0 (Deneba Software, Inc.) and were saved as PICT files with 144 dpi resolution.

#### 2.1.4. Procedure

**2.1.4.1. Pretraining.** Following weight reduction, the pigeons began pretraining, in which they were required to peck at the center button for food reinforcement.

**2.1.4.2. Training.** The pigeons were trained to discriminate the pictorial stimuli using DRH and DRL schedules of reinforcement. The sequence of events in a training trial is shown in Fig. 2. At the start of a trial, the pigeons were shown a black cross in the center of a white display screen. Following one peck anywhere on the white display, the training stimulus appeared for a fixed interval of 10 s. Pecks during this 10-s interval were recorded and used as the dependent measure. After the 10 s elapsed, the birds had to complete either the DRH or the DRL schedule requirement. On a DRH trial (first row of Fig. 2), the birds usually had to peck twice within 7 or 11 s; on a DRL trial (second row of Fig. 2), the birds usually had to peck 7 or 11 s apart. The duration of the DRH-DRL requirement was occasionally varied from 5 to 11 s during training to make indiscriminate responding more punishing. However, by the time that testing began, Bird 25R was always given the 7-s DRH-DRL schedule and Bird 12Y was always given the 11-s DRH-DRL schedule. For Bird 25R, *one-object* stimuli were associated with the DRL schedule and *two-object* stimuli were associated with the DRH schedule; Bird 12Y was exposed to the opposite contingencies. After the pigeons completed the DRH-DRL schedule requirement, food was delivered and the intertrial interval ensued, randomly ranging from 5 to 10 s. During training, each session comprised 128 trials composed of four blocks of 32 trials, so that each training stimulus was shown four times in a single session.

Pigeons tend to peck at a high rate if the DRH procedure is regularly paired with one class of stimuli, whereas they tend to peck at a low rate if the DRL procedure

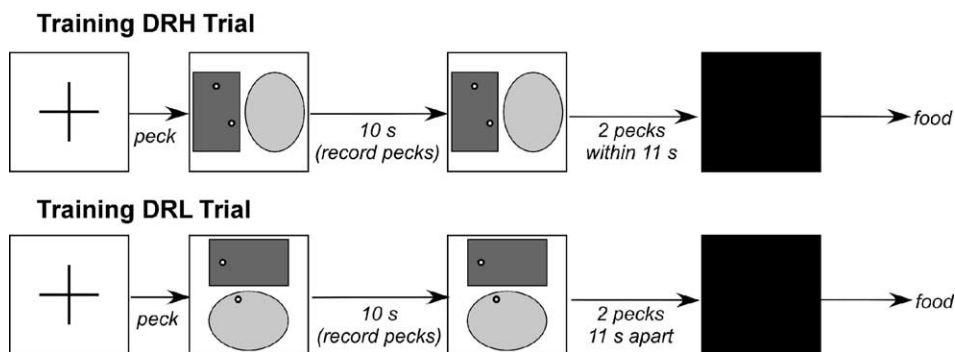


Fig. 2. The sequence of events in a DRH training trial and a DRL training trial for Bird 12Y. For Bird 25R, the *one-object* stimuli were associated with a 7-s DRL schedule and the *two-object* stimuli were associated with 7-s DRL schedule.

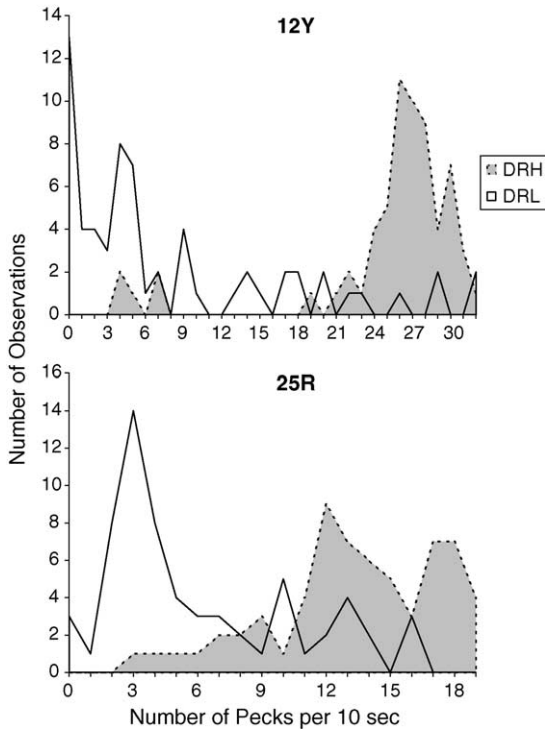


Fig. 3. Distribution of pecks on DRH and DRL trials in the last criterion training session.

cedure is regularly paired with another class of stimuli. A large difference in peck rate to the DRH-paired and DRL-paired stimuli would thus indicate a bird's successful discrimination of the *one-object* from the *two-object* training stimuli. We hoped that the pigeons would meet a criterion of no overlap between the mean rates of responding to each of the 16 DRH stimuli and to each of the 16 DRL stimuli on *two* consecutive sessions. But, only one bird (25R) met this criterion in a timely manner; therefore, the criterion was lowered for the second bird (12Y): no overlap in a *single* training session.

## 2.2. Results and discussion

Discrimination training took 28 days for Bird 25R and 73 days for Bird 12Y. Fig. 3 shows frequency distributions of the number of pecks on the 64 DRH trials and the 64 DRL trials in the final training session. Recall that the birds were exposed to each training stimulus four times in a single session and that the discrimina-

Table 1

Distributions of number of pecks per 10-s interval on DRH and DRL trials during the last criterion training session

	Mean	Mode	Standard deviation
Bird 12Y			
DRH	25.2	26.0	6.3
DRL	8.0	0.0	8.9
Bird 25R			
DRH	13.4	12.0	3.9
DRL	6.1	3.0	4.0

tion criterion required no overlap between the mean rates of responses to each of the 16 DRH stimuli and to each of the 16 DRL stimuli. Thus, even though there was no overlap in the *mean* rates of response to the 16 DRH stimuli and to the 16 DRL stimuli, there was some overlap in the rates of response on the 64 *individual* DRH trials and on the 64 *individual* DRL trials. Nonetheless, the DRH trials clearly supported much higher rates of pecking than did the DRL trials.

Table 1 shows the means, the standard deviations, and the modes of the distributions of pecking on DRH and DRL trials for both birds. For each pigeon, the mean number of pecks to the DRH stimuli was separated from the mean number of pecks to the DRL stimuli by at least 1.5 standard deviations, indicating that both birds strongly discriminated the *one-object* stimuli from the *two-object* stimuli.

To simplify our comparisons of training and testing performance, we used the following procedure. In each session, the first DRH training stimulus was paired with the first DRL training stimulus. Then, the percentage of pecks to the DRH stimulus divided by the sum of pecks to both the DRH stimulus and the DRL stimulus was calculated and multiplied by 100, yielding a discrimination score that could range from 0.0% to 100.0%. The procedure then was repeated until all of the succeeding DRH training stimuli were paired with all of the succeeding DRL training stimuli, resulting in 64 discrimination scores per session. These discrimination scores were then subjected to arcsine transformation and used in all subsequent statistical analyses.

Recall that successful discrimination is indicated by a high rate of response to the DRH stimuli and a low rate of response to the DRL stimuli (cf. Fig. 3). Thus, discrimination scores higher than 50% indicate that the birds pecked more often on DRH trials than on DRL trials (successful discrimination); 50% scores indicate

that the birds pecked equally often on DRH and DRL trials (no discrimination); and, discrimination scores lower than 50% indicate that the birds pecked more often on DRL trials than on DRH trials (discrimination reversal). For example, the data shown in Fig. 3 yielded discrimination scores of 79.3% for Bird 12Y and 70.7% for Bird 25R, establishing that the pigeons were accurately discriminating the training stimuli.

The current results thus clearly indicate that pigeons are able to report whether two target dots are located on a single object or on two different objects. However, our stimuli involved a fixed and small number of dot patterns (four patterns for *one-object* stimuli and four patterns for *two-object* stimuli); these patterns might have been memorized by the pigeons. Therefore, the pigeons' ability to discriminate features on one object from features on two objects might not be based on perceptual grouping processes that segregate the two objects from one another; instead, the results could be based on the pigeons' memory of the dot locations. This possibility was tested in the next experiment.

### 3. Experiment 2

In the current series of Dot tests, we explored whether the pigeons' ability to discriminate the *one-*

*object* training stimuli from the *two-object* training stimuli depended on the exact locations of the target dots. We had earlier found that, when the spatial location of only one of the two target dots indicated whether the display belonged to the *one-object* stimuli or to the *two-object* stimuli, pigeons memorized this cue and used it to discriminate the pictorial stimuli (Lazareva et al., in press). Although in the present experiment each target dot appeared equally often in the both *one-* and *two-object* stimuli, the specific combinations of dots were unique for the *one-object* stimuli and for the *two-object* stimuli and might have been memorized by the pigeons. We tested this possibility in the *New Dot Combination* and the *New Dot Location* tests.

#### 3.1. Method

##### 3.1.1. Subjects

The same two birds were studied; they were housed and maintained as in Experiment 1.

##### 3.2. Apparatus and stimuli

The same apparatus and training stimuli were used as in Experiment 1. To construct the new testing stimuli, we modified the training stimuli as shown in Fig. 4. The left panel of Fig. 4 shows the design of the *New Dot*

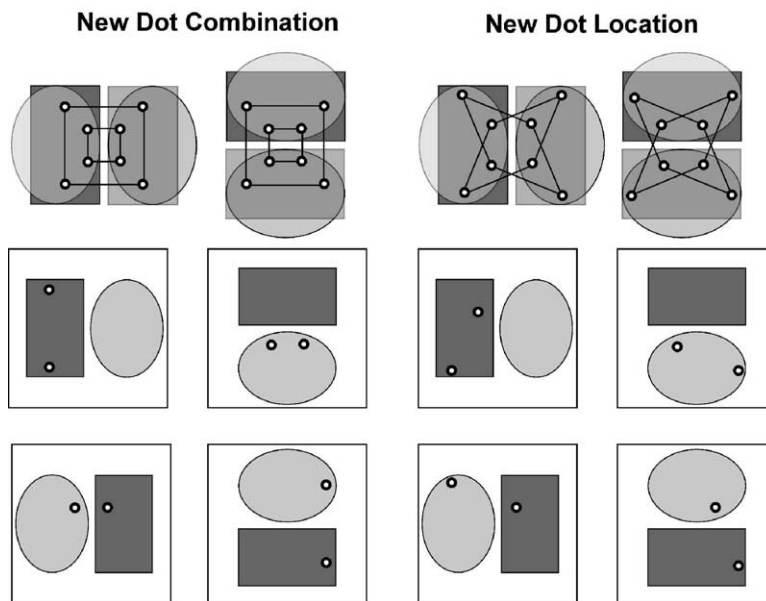


Fig. 4. Examples of the testing stimuli in the *New Dot Combination* test and the *New Dot Location* test.

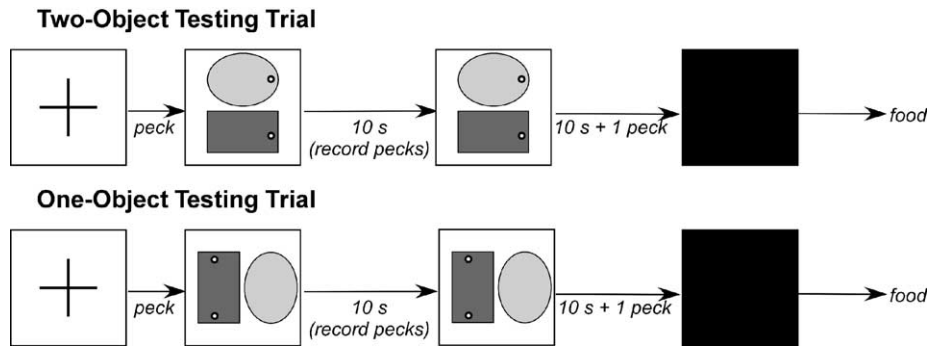


Fig. 5. The sequence of events in a *two-object* testing trial and a *one-object* testing trial.

*Combination test* (cf. Fig. 1); only those combinations of targets that were connected with lines in Fig. 4 were allowed. Thus, in this test, each of the targets occupied the same spatial locations as on the training stimuli, but the particular combinations of targets were different. The inner squares show the four combinations in which the target dots were separated by 1.5 cm (Near test stimuli, total of 16 images); the outer squares show the four combinations in which the target dots were separated by 3.4 cm (Far test stimuli, total of 16 images).

The right panel of Fig. 4 shows the design of the *New Dot Location* test. In this test, we increased the distance between the dots from 2.68 cm in the training stimuli to 3.33 cm—a distance similar to that between the targets in the Far test stimuli. Unlike the Far test stimuli, however, each target dot in these images was moved from its original location to a new location.

### 3.2.1. Procedure

We used the same training procedure as described in Experiment 1. Before testing, the pigeons were required to meet the criterion of no overlap in the mean response rates to the *one-object* and *two-object* stimuli in either two training sessions (25R) or one training session (12Y). So, if the *one-object* stimuli were associated with the DRH schedule and the *two-object* stimuli were associated with the DRL schedule, then, in order to achieve criterion, the highest mean peck rate to any of *one-object* stimuli had to be lower than the lowest mean peck rate to any of the *two-object* stimuli. At least one training session was conducted after each testing session, and both birds were required to again meet the discrimination criterion in that single session before the next testing session could be given.

The sequence of events in a testing trial is shown in Fig. 5. Both *one-object* and *two-object* trials used the same testing procedure. First, the pigeon had to start the trial by pecking at the white display screen with the black cross in the middle. Then, the testing stimulus appeared for a fixed interval of 10 s. Pecks during this 10-s interval were recorded and used as the dependent measure. After this recording period elapsed, an additional 10-s interval was implemented; pecks during this interval were not recorded and could not advance the trial. Following the second 10-s interval, the pigeon had to peck the testing stimulus once; after that, food was delivered and the intertrial interval ensued. We conducted testing trials in this manner to make them as close to training trials as possible without arranging differential contingencies of reinforcement on *one-object* and *two-object* trials.

Each testing session consisted of four blocks of 32 training trials and eight testing trials (160 trials total), so that the pigeons received four presentations of each training stimulus and one presentation of each testing stimulus. The *New Dot Combination* test included four testing sessions separated by at least one training session. Thus, the birds completed 64 Far test trials and 64 Near test trials, and they were exposed to each testing stimulus twice. The *New Dot Location* test lasted 2 days, so that the birds were again exposed to each testing stimulus twice.

## 4. Results and discussion

Recall that, although any specific dot location could appear on both *one-object* and *two-object* trials, the



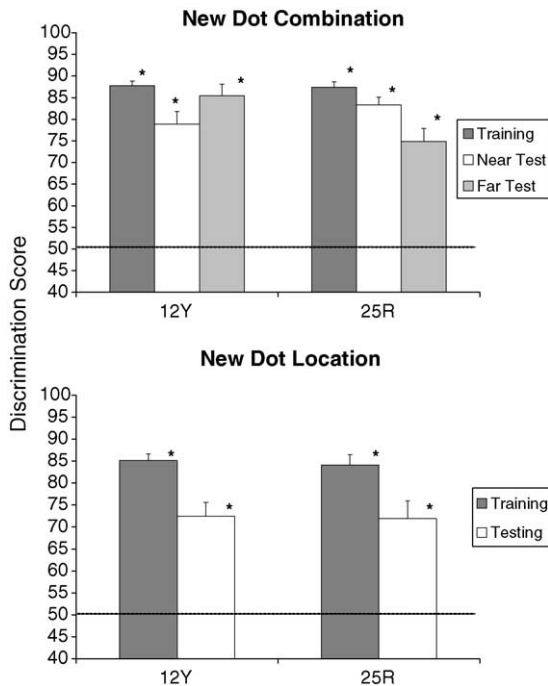


Fig. 6. Percent of correct responses to training and testing stimuli in the *New Dot Combination* test and the *New Dot Location* test. Asterisks indicate a significant difference from chance.

two-dot combinations were unique for each trial type (cf. Fig. 1). It is thus conceivable that the birds could have learned the specific dot combinations that were associated with *one-object* and *two-object* trials. So, we presented testing images that involved new dot combinations (Fig. 4, left panel) and new dot locations (Fig. 4, right panel).

We first focus on the results of the *New Dot Combination* test (Fig. 6, upper panel). Here, and in all later tests, the pigeons continued to discriminate the training stimuli at highly reliable levels, attesting to the robustness of the *one-object* versus *two-object* discrimination. Both pigeons discriminated the *one-object* and *two-object* testing images significantly above chance [two-tailed  $t$ -test,  $t(31) \geq 8.45$ ,  $p < 0.01$ ]. Although the two birds exhibited slightly different patterns of performance in the Far and Near tests, the main effect of Bird [ $F(1, 5) = 0.69$ ,  $p = 0.41$ ] and the Bird  $\times$  Trial Type interaction [ $F(2, 2) = 2.75$ ,  $p = 0.06$ ] failed to reach significance—perhaps because of the small number of subjects and, hence, the lack of sufficient statis-

tical power. The main effect of Trial Type was significant [ $F(2, 5) = 17.46$ ,  $p < 0.05$ ]; a Tukey follow-up test found that mean performance on the Near and Far tests did not differ significantly, but that performance on both tests was significantly lower than on training trials.

We next focus on the results of the *Novel Dot Location* test (Fig. 6, lower panel). Again, both pigeons discriminated the testing images at levels that were significantly above chance [two-tailed  $t$ -test,  $t(31) \geq 5.41$ ,  $p < 0.05$ ]. ANOVA found a significant main effect of Trial Type [ $F(1, 3) = 24.82$ ,  $p > 0.05$ ], but no significant effect of Bird and no Bird  $\times$  Trial Type interaction [ $F < 1$ ], indicating that, for both birds, training performance was significantly higher than testing performance.

Although the changes in dot locations did lead to a reliable drop in discrimination performance, both birds discriminated the new testing images at a noteworthy level (71% correct or higher). Thus, it is unlikely that the pigeons' performance on the object discrimination task was based exclusively on memorizing the precise patterns of the target dots or their specific spatial locations.

## 5. Experiment 3

In all of our stimulus displays, the two objects differed by both color (red or green) and shape (oval or rectangle); the pigeons could rely on either color, shape, or both, to segregate the two objects from one another. Therefore, we designed a series of Color–Shape tests to examine which property of the stimulus objects, color or shape, is more important for the birds' discriminating whether the two targets were located on one or both of the objects.

### 5.1. Method

#### 5.1.1. Subjects

The same two birds were studied; they were housed and maintained as in Experiments 1 and 2.

#### 5.1.2. Apparatus and stimuli

The same apparatus and training stimuli were used as in Experiments 1 and 2. To construct the testing stimuli, we modified the training stimuli as shown in Fig. 7.

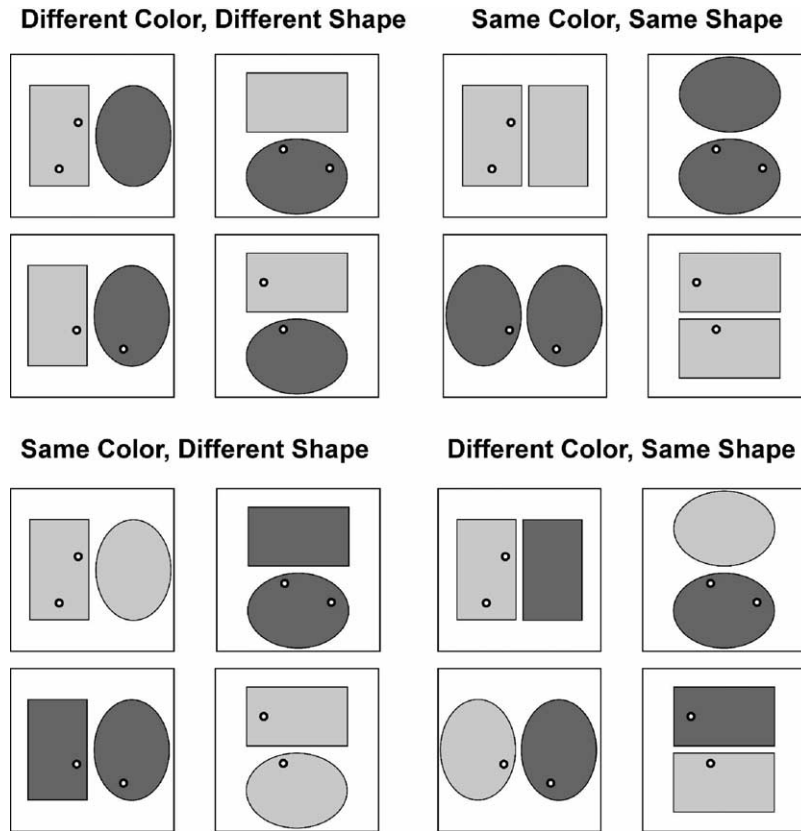


Fig. 7. Examples of the testing stimuli in the series of Color-Shape tests.

We created four sets of novel testing stimuli. For the *Different Color, Different Shape* test, we switched the colors of the two objects (Fig. 7, upper left panel): if, for a given pigeon, the training displays comprised a red oval and a green rectangle, then the testing displays comprised a green oval and a red rectangle (and vice versa for the other pigeon). Thus, the objects in this test again differed in both color and shape. In the *Same Color, Same Shape* test, each testing image comprised either two ovals of the same color or two rectangles of the same color (total of 32 test stimuli), so that the testing objects differed in neither color nor shape (Fig. 7, upper right panel). In the *Same Color, Different Shape* test, the novel images comprised an oval and a rectangle of the same color (both red or both green; for a total of 64 images), so that the testing objects differed in shape, but not in color (Fig. 7, lower left panel). Finally, in the *Different Color, Same Shape* test, each

novel image comprised either two ovals or two rectangles of different colors (for a total of 64 images; Fig. 7, lower right panel).

### 5.1.3. Procedure

The same training and testing procedures were used here as in Experiments 1 and 2. Each testing session contained four blocks of 32 training trials and eight testing trials (160 trials total), so that the pigeons received four presentations of each training stimulus and 1 presentation of each testing stimulus. The *Different Color, Different Shape* tests and *Same Color, Same Shape* tests ran for two sessions, so that the pigeons experienced each testing stimulus twice. Because of the larger number of testing stimuli, the *Same Color, Different Shape* tests and the *Different Color, Same Shape* tests ran for four sessions, so that the birds were again exposed to each testing stimulus twice.

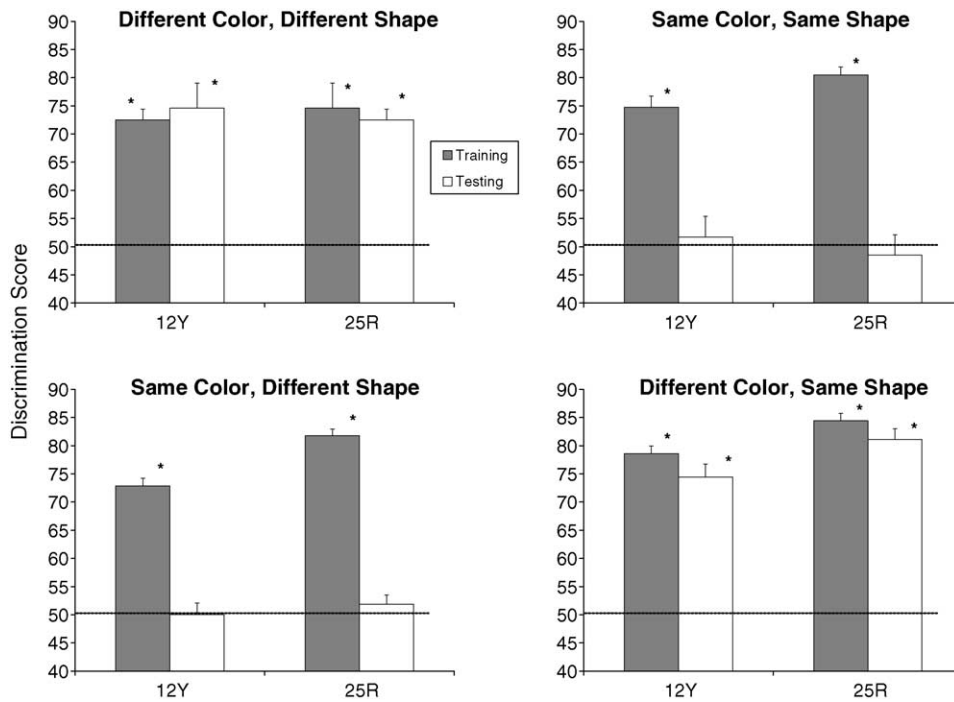


Fig. 8. Percent of correct responses to the training and testing stimuli in the series of Color–Shape tests. Asterisks indicate a significant difference from chance.

## 6. Results and discussion

Fig. 8 shows that both pigeons exhibited significant discrimination of the testing stimuli only in the *Different Color, Different Shape* tests [two-tailed  $t$ -test,  $t(31) \geq 5.51$ ,  $p \leq 0.01$ ] and the *Different Color, Same Shape* tests [two-tailed  $t$ -test,  $t(63) \geq 10.41$ ,  $p \leq 0.01$ ]. In other words, both objects had to be of different colors for the discrimination to occur; whether the two objects had the same shape or different shapes was irrelevant.

These conclusions were supported by an ANOVA (Test  $\times$  Trial Type  $\times$  Bird), which found a significant Test  $\times$  Trial Type interaction [ $F(3, 3) = 25.11$ ,  $p < 0.001$ ]. Planned comparisons indicated that performance to the testing stimuli was significantly lower than performance to the training stimuli in the *Same Color, Same Shape* tests and in the *Same Color, Different Shape* tests; but, no significant difference was found between training and testing performance in the other two tests. The ANOVA also revealed higher overall discrimination performance by Bird 25R than Bird 12Y [significant main effect of Bird,  $F(1, 15) = 4.97$ ,

$p < 0.05$ ], but no significant interactions [all  $F$ 's  $\leq 0.72$ ] suggesting that both birds responded similarly in this series of tests.

The results of this series of tests suggested that the colors of the objects played a key role in the pigeons' discrimination performance. This finding corresponds to early reports on attention in pigeons. Several studies found the color of a color–shape compound stimulus to be dominant in gaining stimulus control, although birds did attend to the shape of the stimulus as well (Wilkie and Masson, 1976; Farthing and Hearst, 1970; Kendall and Mills, 1979). The results of the Color–Shape series of tests do not allow us to determine whether the pigeons paid any attention to the shape of the stimuli; the next series of generalization tests did.

## 7. Experiment 4

In this series of Generalization tests, we examined our pigeons' ability to transfer their visual discrimination of *one-object* stimuli from *two-object* stimuli

to novel pictorial representations. The *New Color* and *Grayscale* tests explored whether the pigeons would effectively discriminate familiar-shaped stimuli in unfamiliar colors or in gray shadings, respectively. The *New Shape* test explored whether the pigeons would effectively discriminate familiar-colored stimuli in unfamiliar shapes. Note that the previous Color–Shape tests revealed strong stimulus control of behavior by the colors of the shapes. Thus, we might expect a large drop in discrimination performance to both the *New Color* and the *Grayscale* test images. On the other hand, the previous Color–Shape tests disclosed no control at all by the shape of the object. So, one might surmise that the pigeons were not attending to the shapes of the training images; the birds might therefore exhibit perfect transfer to the *New Shape* images.

## 7.1. Method

### 7.1.1. Subjects

The same two birds were studied; they were housed and maintained as in Experiments 1, 2, and 3.

### 7.1.2. Apparatus and stimuli

The same apparatus and training stimuli were used as in Experiments 1, 2, and 3. To construct the testing stimuli, we modified the training stimuli as shown in Fig. 9. In the *New Color* test, each testing stimulus comprised a yellow oval and a violet rectangle (Fig. 9, left panel). In the *Grayscale* test (not shown in Fig. 9), we changed the colors of the objects to different gray shadings (20% and 60%). Finally, in the *New*

*Shape* test, we replaced the oval and the rectangle with a jagged, straight outline shape and a smooth, curved outline shape (Fig. 9, right panel), each of which had the same total area (16.28 cm<sup>2</sup>) as the objects used in training.

### 7.1.3. Procedure

The same training procedures, testing procedures, and criterion as in Experiments 1, 2, and 3 were used. Each testing session consisted of four blocks of 32 training trials and eight testing trials (160 trials total), so that the pigeons received four presentations of each training stimulus and 1 presentation of each testing stimulus. Each test was conducted for two sessions, so that the birds were presented with each testing stimulus twice.

## 7.2. Results and discussion

Here, we presented testing displays that contained: the same oval and rectangular shapes, but in two novel colors; the same oval and rectangular shapes, but in two novel gray shadings; and, two novel shapes in the familiar red and green colors. As shown in Fig. 10, the pigeons discriminated neither the novel color nor gray shaded displays, consistent with our previous results attesting to the high salience of object color. Nevertheless, when new shapes in the familiar colors were shown, both birds evidenced sizeable drops in testing performance, with the pigeons' discrimination scores still reliably exceeding chance levels [two-tailed *t*-test,  $t(31) \geq 2.93, p < 0.01$ ].

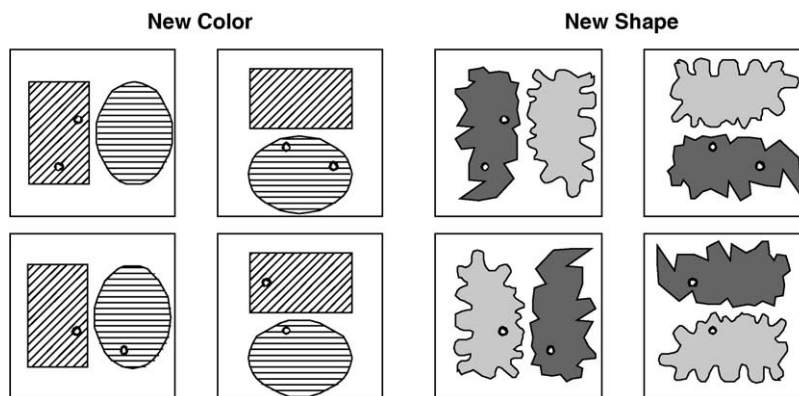


Fig. 9. Examples of the testing stimuli in the *New Color* test and the *New Shape* test. Different grid patterns in the *New Color* test stand for yellow and violet colors.

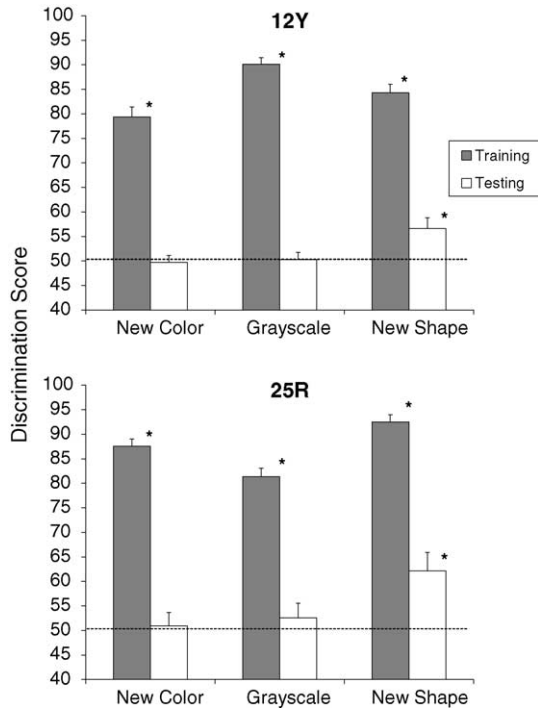


Fig. 10. Percent of correct responses to the training and testing stimuli in the *New Color*, *Grayscale*, and *New Shape* tests. Asterisks indicate a significant difference from chance.

ANOVA disclosed a significant main effect of Trial Type [ $F(1, 11) = 416.91, p < 0.001$ ], but no significant Trial Type  $\times$  Test interaction [ $F < 1$ ], suggesting that, in all three tests, discriminative performance on testing trials was significantly lower than on training trials. ANOVA also revealed a significant Bird  $\times$  Test interaction [ $F(1, 2) = 4.59, p < 0.01$ ], but no significant Bird  $\times$  Trial Type interaction [ $F < 1$ ], perhaps owing to different patterns of overall accuracy in the three tests by the two pigeons.

Thus, these data confirm the higher salience of color than shape in controlling the pigeons' discrimination behavior. Nevertheless, shape did control the birds' behavior—a result that is consistent with earlier reports of pigeons' discrimination of compound visual stimuli (Wilkie and Masson, 1976; Kendall and Mills, 1979).

### 7.3. General discussion

In Experiment 1, we found that pigeons were able to learn the *one-object* versus *two-object* discrimination,

documenting their ability to segregate the two forms from the background and to report whether the two target dots were on the same single object or on two different objects. Experiment 2 found that this ability was not based exclusively on the pigeons' memorizing the spatial locations or patterns of the target dots, although the birds did attend to those cues to a small extent. We further found in Experiment 3 that the ability of the pigeons to segregate the two forms from the background depended critically on the colors of those forms. If the two forms were of the same color, then the pigeons were not able to discriminate *one-object* from *two-object* displays, even though the shapes of the forms were different. If, however, the forms were of different colors, then excellent discrimination was observed, even though the forms were of the same shape. Finally, we found in Experiment 4 that pigeons did retain some information about the shapes of the training objects, as indicated by a significant drop in the birds' discrimination performance with two novel shapes in the familiar red and green colors.

Pigeons are not unique in treating the color of an object as its most salient property. In similar tasks, adult humans were found to attend to the surface properties of objects as well. For example, in one experiment (Watson and Kramer, 1999), people were shown a picture of two wrenches and were asked to report whether two target properties, a bent end and an open end, appeared on the same object or on two different objects. People were faster to produce *one-object* reports than *two-object* reports—a classic object-based attention result. However, when the handle of the wrench had its surface pattern different from the pattern of the ends, people produced both reports at a similar speed and the *one-object* benefit disappeared.

The importance of local information such as homogenous regions of color or texture was reported in several other experiments as well (e.g., Van Selst and Jolicoeur, 1995). Some theorists have even argued that homogenous surface properties such as color, lightness, or texture should be considered as a grouping principle similar to proximity or closure: all other things being equal, closed regions of homogenous chromatic color or texture tend to be perceived as single units (Palmer and Rock, 1994). It is important to reiterate that the objects of selection in this case need not be structural, invariant representations that are formed at high levels of visual processing, but rather perceptual grouping

cues that organize space into different regions at earlier stages of visual processing and that help to direct the attention of organisms to specific regions in the visual field.

The DRH-DRL technique that we used in this study proved to be quite successful in teaching pigeons to discriminate *one-object* from *two-object* displays. However, this technique has one significant drawback. Because the DRH-DRL technique associates these two classes of stimuli with different rates of response, it does not allow for a critical comparison of performance to *one-object* and *two-object* displays that can be achieved with other forced-choice procedures. As mentioned above, one of the prime results in human object-based attention studies is faster (and more accurate) responding on *one-object* trials compared to *two-object* trials. No such reaction time result is possible with the DRH-DRL technique.

Although we cannot similarly compare *one-object* and *two-object* responses in the current study, there is still much still to be learned by using the DRH-DRL technique: most importantly, what properties of the objects control the pigeons' discrimination performance? Close inspection of our stimulus displays (Fig. 1), suggests that the birds might compare the colors of local areas in the immediate vicinity of two target dots, instead of attending to the two objects as wholes. Ongoing experiments in our laboratory are now exploring this and other cues that may control birds' performance in an attempt to determine whether pigeons are capable of attending to objects as integral units.

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