Visual Cognition

The pigeon's discrimination of shape and location information

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Two groups of pigeons (*n* = 4) were trained with 16 line drawings portraying a fixed shape and a variable shape. The four variable shapes (a wedge, a cone, a cylinder, and a handle) appeared to the left of, to the right of, above, or below the fixed shape (a cube). Group Shape (S) was required to discriminate the identity of the variable shape that was mated with the cube, whereas Group Location (L) was required to discriminate where the variable shape appeared relative to the cube. Three of the four pigeons in each group mastered their respective tasks. Later tests revealed that the two groups of pigeons had attended to different aspects of the shape pairs, even though the visual stimuli and general procedures they had been given were the same. Group S had attended to the identity of the variable shape and had ignored the identity and location of the cube, whereas Group L had attended to the configuration of the two shapes. The methods and stimuli could be useful in delineating the biological bases of shape and location perception.

One of the most important findings in contemporary neuroscience has been the discovery that the primate visual system processes information about stimulus properties such as shape, colour, location, and motion in a parallel fashion. Specifically, in the lateral geniculate, the magnocellular layers exhibit greater sensitivity to movement and contrast, whereas the parvocellular layers exhibit greater sensitivity to colour (Brannan, 1992; DeYoe & Van Essen, 1988; Goodale & Milner, 1992; Grossberg, Mingolla, & Ross, 1994; Livingstone & Hubel, 1988; Zeki, 1992, 1993). The dissociation between the magnocellular

and parvocellular divisions continues to primary visual cortex, with the parvocellular division coding more local attributes such as form and colour and the magnocellular division coding more global attributes such as movement and spatial organization. At even higher levels of the visual system, this functional division has been documented as well, with the occipitotemporal pathway carrying shape information and the occipitoparietal pathway carrying spatial location information (Ungerleider & Mishkin, 1982).

Although comparable shape and location pathways have not yet been mapped in the avian visual system, it appears that multiple, parallel processing systems do exist (Gunturkun, 1991; Rogers, 1995). Recent behavioural studies on avial visual perception have suggested that birds can concurrently attend to several features of complex stimuli (see Chatlosh & Wasserman, 1993 for a review). In particular, there is mounting evidence that birds can simultaneously attend to both shape and location information (Brown & Dooling, 1993; Kirkpatrick-Steger & Wasserman, 1996; Kirkpatrick-Steger, Wasserman, & Biederman, 1996; Steele, 1990; Wasserman, Kirkpatrick-Steger, Van Hamme, & Biederman, 1993; Watanabe & Ito, 1991).

Kirkpatrick-Steger and Wasserman (1996) used a go/no-go procedure and a specially constructed set of stimuli to examine the pigeon's processing of shape and location information. The stimuli were line drawings portraying 16 pairs of geometric shapes; one of the shapes was fixed (a cube) and one was variable (a wedge, a cylinder, a cone, and a handle). The variable shape could appear in one of four locations relative to the cube (left-of, right-of, above, or below).

Eight pigeons were first trained to peck at all 16 pairs of shapes in order to receive food reinforcement. Then, one of the pairs was made the positive stimulus (S+) and the other 15 were made negative stimuli (S–s). All of the birds quickly learned to respond to the S+ and to withhold responses to the S–s. However, the rates of pecking to the S–s were not uniform. Based on the pattern of responding to the S–s, it was apparent that all eight birds were conjointly controlled by the identity of the variable shape and by the relative locations of the two shapes. The birds were more likely to respond erroneously to the S–s that shared either the same variable shape or the same spatial arrangement as the S+; seven of the eight birds evidenced stronger control by the configuration of the shapes than by the identity of the variable shape. Thus, although all of the pigeons were conjointly controlled by shape identity and location, it appeared that the pigeons may have processed location information more readily than shape information.

The fact that pigeons can simultaneously attend to shape and location documents the importance of the two forms of information to visual perception. But, for the purposes of neural analysis, it may be desirable to isolate the processing of shape and location information. The present experiment addressed two questions: Can pigeons learn a discrimination that nominally requires them to attend to only one stimulus property, either shape or location? And, in

learning these discriminations, do pigeons attend to different attributes of the shape pairs?

We trained pigeons on two discriminations—a shape task and a location task—with stimuli that were very similar to those used by Kirkpatrick-Steger and Wasserman (1996). Two groups of birds were trained with the same 16 shape pairs, but the contingencies of reinforcement differed between the groups. Group Shape (Group S) was taught to respond on the basis of *what* variable shape was presented along with a cube, regardless of that shape's location relative to the cube; Group Location (Group L) was taught to discriminate *where* the variable shape appeared relative to the cube, regardless of the identity of the variable shape.

Following discrimination training, novel testing stimuli were given to determine what aspects of the training stimuli had gained control over the pigeon's discriminative behaviour. Both groups of birds received special tests in which the cube or the variable shapes were deleted or replaced by novel shapes. By examining the accuracy scores to the different types of testing stimuli, a determination could be made as to what stimulus aspects had attracted the birds' attention during training.

The test stimuli could reveal attention to different properties of the shape pairs by the two groups of pigeons. Table 1 displays the outcomes of the four tests given the learning rules that could be used by the pigeons in Group S and Group L. The list only includes those learning rules that would allow for high levels of accuracy to be achieved on the shape and location tasks, and that are most likely given the demands of the two tasks. Because the list is not exhaustive, if the pattern of results from the tests do not conform to one of the listed possibilities, then alternative learning rules will be considered.

TABLE 1
The pattern of anticipated outcomes to the four types of test drawings for Group S and Group L, given the most likely rules that could be employed in learning the shape and location tasks

Learning Rule	Cube-Deletion	Cube-Replacement	Variable-Deletion	Variable-Replacement
Group S				
Variable shape	—	—	↓	↓
Compound	↓	↓	↓	↓
Memorization	↓	↓	↓	↓
Group L				
Configural	↓	—	↓	—
Cube reference	↓	↓	↓	—
Cube position	↓	↓	—	—
Memorization	↓	↓	↓	↓

↓ decrement in performance expected; — intact performance expected.

There are three likely outcomes for the birds trained on the shape task, which normally requires attention to the identity of the variable shapes, with the cube providing no relevant information. The birds in Group S could attend to the identity of the variable shapes and ignore the cube, in which case they should perform poorly when the variable shape is deleted or replaced, but they should perform well when the cube is deleted or replaced. Alternatively, these pigeons might perceive the two shapes as a compound and discriminate on the basis of both shapes, ignoring their configuration (e.g. Cube + Wedge (any location) = Response 1, etc.). Learning the shapes as a compound would result in a decrement in performance when either shape is deleted or replaced, since the compound would be altered by any of these manipulations. However, performance might exceed chance levels, because all of the test stimuli would contain one element of the training compounds. Finally, the birds in Group S might memorize each individual shape pair, a learning rule that would lead to chance performance on all tests.

There are four likely outcomes for the birds trained on the location task (see Table 1), which nominally requires attention to the location of the variable shapes relative to the cube, with the identity of the variable shape providing no relevant information. First, the birds in Group L might learn the configuration of the two shapes, using either shape as a reference. This configural learning would result in greater decrements in performance when either shape is deleted than when either shape is replaced by a novel shape. Second, the birds in Group L might learn the configuration of the shapes, but only use the cube as a reference. In this case, replacing or deleting the cube would result in a decrement in performance, replacing the variable shape would have no effect (because the relative location of the new shapes could still be determined by the familiar cube reference), and deleting the variable shape would result in poor performance (because the configural aspects of the stimulus would be lost). Third, the birds in Group L might learn the absolute placement of the cube on the viewing screen, which would lead to poor performance if the cube is deleted or replaced, but intact performance if the variable shape is deleted or replaced. Finally, the birds in Group L might memorize each individual shape pair, which would lead to poor performance on all tests.

METHOD

Animals

The subjects were eight experimentally naive feral pigeons maintained at 85% of their free-feeding weights by the delivery of 45mg Noyes pigeon pellets during the experimental sessions and by supplements of mixed grain in the home cages when necessary. The birds were housed individually in standard pigeon

cages with water and grit continuously available. The lights in the colony room were on a 14:10 cycle, with lights on at 7.00a.m. and off at 9.00p.m.

Apparatus

The experimental apparatus comprised four specially constructed pigeon chambers. In each chamber, one of the plywood walls contained a large open-ing with a metal frame attached to the outside of the box. The frame held a mylar-coated touch screen (Model 70056-001, Elmwood Sensors, Pawtucket, RI) that transduced the pigeons pecks at a 13-inch colour video monitor; the video monitor was located 0.9cm behind the touch screen at its centre. Responses on the touch screen were processed by a serial controller board (Model E271-2200, Elographics, Oak Ridge, TN). An aluminum panel in front of the touch screen permitted access to circumscribed portions of the video monitor. There were five openings in the panel to allow selective access to five report buttons: a 7.0cm × 7.0cm square centre button on which the line draw-ings appeared and four circular choice buttons (1.9cm diameter) located 2.3cm from each of the four corners of the central opening. The choice buttons were lit with distinctively different colours: the upper-left button was violet, the upper-right button was blue, the lower-left button was green, and the lower-right button was red. Because the monitor produces colours based on a trichromatic red-green-blue system, the colours of the choice buttons are reported as they would appear to humans. A clear Plexiglas food cup was cen-tred on the lower rear wall of each chamber and a houselight was anchored on the upper rear wall above the food cup. In order to discourage perching on the food cup, it was lowered into the wire mesh floor, so that the top of the cup was level with the floor. A rotary magazine dispenser (Model ENV-203M, MED Associates, East Fairfield, VT), located outside of the chamber, delivered 45mg Noyes pigeon pellets through a tygon tube into the food cup. The houselight and pellet dispenser were controlled by a digital input/output inter-face board (Model NB-DIO-24, National Instruments, Austin, TX).

Control of stimuli and recording of responses in each box was accomplished by a Macintosh computer. In each chamber, the pigeon's colour monitor was connected to an identical monitor located in an adjacent room. Two of the chambers accomplished the video connection with a video splitter and the other two used a distribution amplifier. Programs were developed in HyperCard version 2.2.

Stimuli

Figure 1 shows the 10 line-drawing shapes from which the training and testing stimuli were constructed; the components were volumetric shapes with implied three-dimensionality. Each shape (or "geon" as termed by Biederman, 1987) was assigned a name and was identified by three non-accidental structural
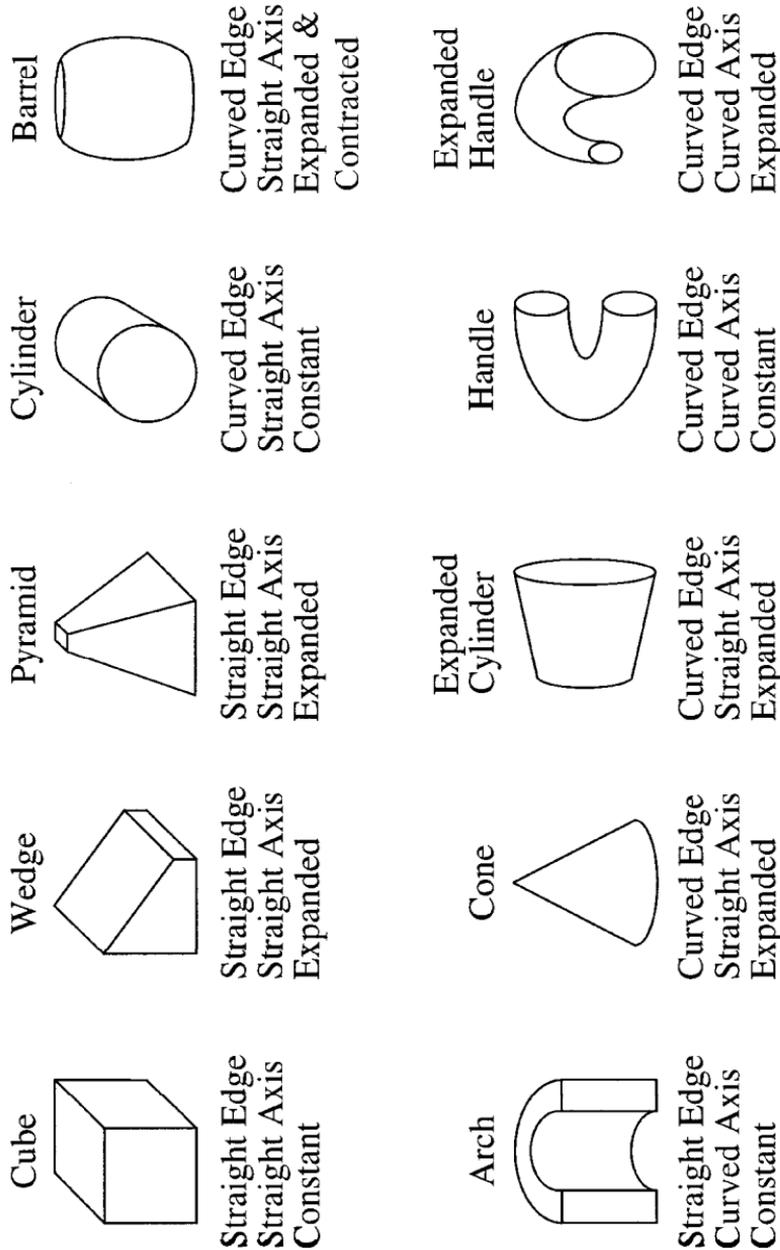
FIG. 1. The 10 shapes that constituted the training and testing stimuli. Above each shape is the shape's name. Below each shape is a specification of three non-accidental properties: Straight or Curved Edges, Straight or Curved Axis, and Constant, Expanded, or Contracted Sides.

Cube
Straight Edge
Straight Axis
Constant

Wedge
Straight Edge
Straight Axis
Expanded

Pyramid
Straight Edge
Straight Axis
Expanded

Cylinder
Curved Edge
Straight Axis
Constant

Barrel
Curved Edge
Straight Axis
Expanded &
Contracted

Arch
Straight Edge
Curved Axis
Constant

Cone
Curved Edge
Straight Axis
Expanded

Expanded
Cylinder
Curved Edge
Straight Axis
Expanded

Handle
Curved Edge
Curved Axis
Constant

Expanded
Handle
Curved Edge
Curved Axis
Expanded

422

FIG. 2. The 16 shape pairs used as training stimuli for the two groups of pigeons.

properties (Witkin & Tenenbaum, 1983): (1) Straight or curved edges, (2) straight or curved axis, and (3) constant, expanded, or expanded and contracted sides.

Five of the shapes in Figure 1—the cube, the wedge, the cylinder, the cone, and the handle—were chosen for the training phase. These shapes were paired together to form the training stimuli, depicted in Figure 2; each training stimulus contained a fixed shape (the cube) and a variable shape (the wedge, the cylinder, the cone, and the handle). The variable shape appeared to the left of, to the right of, above, or below the cube. The shapes in each pair overlapped, to appear as though they were touching one another.
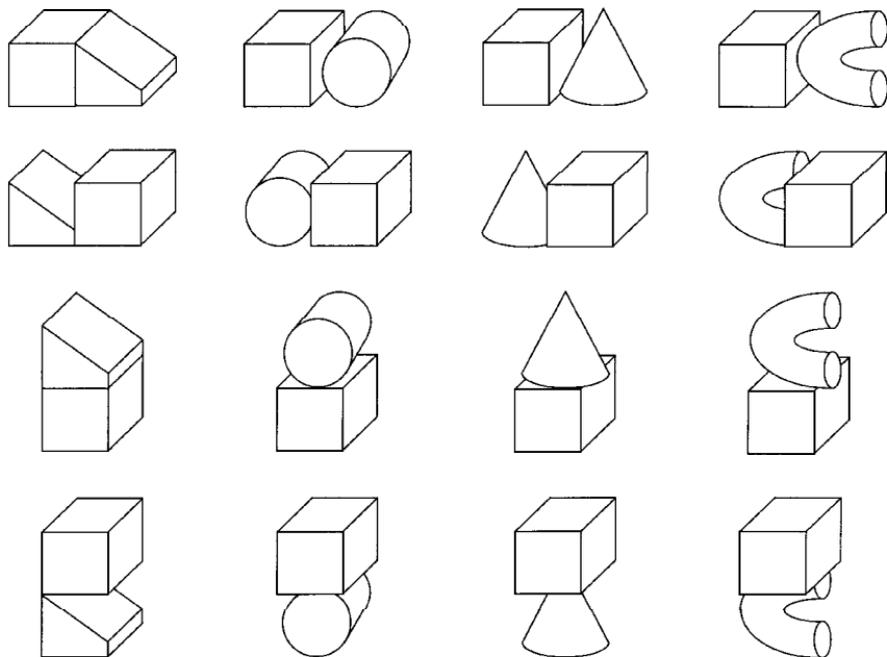
The dimensions of the shape pairs in which the variable shape appeared either left-of or right-of the cube were 2.2cm × 3.8cm; the dimensions of the shape pairs in which the variable shape appeared either above or below the cube were 3.6cm × 2.2cm. Each training pair was placed in four locations on the viewing screen (upper-centre, lower-centre, left-centre, and right-centre) in order to discourage the birds from learning the absolute placement of the shapes.

A sub-set of the testing stimuli are presented in Figure 3. They are modifications of the training stimuli created by replacing the cube (top row) or the variable shapes (second row) with new shapes or by deleting the cube (third row) or

Cube-Replacement
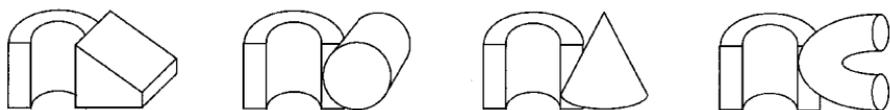
Variable-Replacement
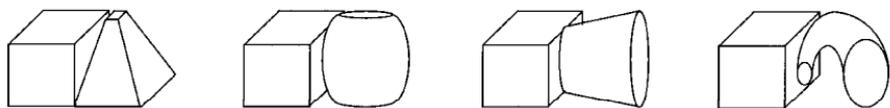
Cube-Deletion

Variable-Deletion
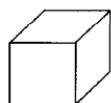
FIG. 3.   A sub-set of the Cube-Replacement, Variable-Replacement, Cube-Deletion, and Variable-Deletion testing stimuli for the variable shapes that appeared to the right of the cube. Similar stimuli were created for the left-of, above, and below locations.

the variable shapes (bottom row). The operation of deleting or replacing the cube or the variable shapes occurred for all 16 original training pairs.

The Cube-Replacement stimuli were constructed by positioning an arch in the same area that the cube had occupied next to all four variable shapes and in all four spatial configurations, yielding 16 drawings. For the Variable-Replacement Test, the wedge was replaced by a pyramid, the cylinder was replaced by a barrel, the cone was replaced by an expanded cylinder, and the handle was replaced by an expanded handle, resulting in 16 novel shape pairs. The novel shapes occupied the same area as the original shapes. In both replacement tests, the old shapes were replaced by new shapes that shared two non-accidental properties, but that were also structurally different. The novel shapes are displayed in Figure 1, along with a specification of their non-accidental properties.

The deletion of the cube resulted in the four variable shapes each appearing alone in four different locations. The deletion of the variable shapes resulted in the cube appearing alone in four different locations. Because the cube's position was the same for a given relation, regardless of the identity of the variable shape, only one Variable-Deletion drawing was required for each of the four

cube positions. Each testing stimulus was presented in each of the four locations on the screen where the training stimuli had appeared (upper-centre) lower-centre, left-centre, and right-centre). The test stimuli were positioned in the same location as the training stimuli by placing the retained shape in the same location as it appeared in the original shape pair. All stimuli were created in Deneba artWORKS™ and were imported into HyperCard for experimental presentation.

Procedure

Magazine training.   The birds received from one to four sessions of magazine training in the experimental chambers. The houselight provided ambient illumination and the centre button was lit yellow. The food cup was filled with pellets and the bird was allowed to eat all of the food; the pellets were then dispensed individually from the feeder until the bird reliably ate from the cup. Following magazine training, the birds were given several handshaping sessions, during which pecks anywhere within the five open areas of the panel were reinforced. Handshaping continued until each bird readily pecked at all five open areas of the touch screen.

Pre-training .   Each pre-training session entailed 160 trials. On 80 of the trials, pecks to the lit centre button resulted in food reinforcement. The other 80 trials consisted of 20 presentations of each of the four circular choice buttons, with pecks to the lit button reinforced. Initially, a Fixed Ratio (FR) 1 pecking requirement was in place, but this requirement was gradually increased to a FR 30. On reaching the FR 30 requirement, the birds were moved to discrimination training.

Discrimination training.   Both groups of pigeons were trained with a four-choice discrimination task. Trial onset was signalled by white-illuminating the centre button. A peck on the button resulted in the presentation of one of the pairs of shapes as a black line drawing on a white background. The pigeons were then required to complete an observing requirement that began as a FR 5 early in training and gradually increased to a FR 30. On completing the FR, the line drawing inverted to a white line drawing on a black background (to signal the completion of the observing requirement and the availability of the choice buttons), the four choice buttons were illuminated with different colours, and a single choice response was allowed. If the correct choice button was pecked, then one, two, or three 45mg pellets were delivered to maintain the birds at 85% of their free-feeding weights; if the incorrect choice button was pecked, then the trial was repeated until the correct choice occurred. Each session presented two blocks of 64 trials containing each of the 16 training stimuli in each of the four locations on the screen, for a total of 128 trials.

Group S was trained to produce a particular report response whenever a particular variable shape was present, regardless of its placement relative to the cube. For example, those drawings in Figure 2 that contained the wedge (Column 1) may have required pecking the upper-left choice button, whereas those drawings that contained the cylinder (Column 2), the cone (Column 3), and the handle (Column 4) may have required pecking the upper-right, lower-left, and lower-right buttons, respectively.

Group L was trained to discriminate among the shape pairs based on their location relative to the cube. So, for example, whenever the variable shape appeared to the right of the cube (Row 1 of Figure 2), the upper-left choice response might have produced reinforcement. Similarly, the other shape locations (Rows 2, 3, and 4 of Figure 2) each required different choice responses (e.g. left-of = upper-right, above = lower-left, and below = lower-right).

The correct choice buttons for a given set of stimuli were counterbalanced across the birds in each group. Bird 4 in Group S developed an avoidance of one of the choice buttons. To rectify the problem, this bird had to peck a choice button twice in a row (on both first attempts and correction trials) in order to advance through a trial. The two-peck choice requirement was maintained throughout the remainder of discrimination training and throughout the entire testing sequence. This bird also only advanced to a FR 20 observing requirement. Only the first choice attempt on each trial was scored. A variable intertrial interval averaging 10sec (range: 5 to 15sec) separated trials. The birds were maintained on the discrimination task with the FR 30 (or FR 20) observing requirement until reaching 70% correct on each of the four keys, at which time testing began. Each bird independently advanced to the testing phase.

Testing.   Testing trials were intermixed with training trials. 160 trials were given during each testing session; the trials were presented in 32 5-trial blocks, each of which contained 4 training trials and 1 testing trial. The testing stimuli occurred on Trial 5 of each block. Both groups received 64 Cube-Replacement (16 drawings × 4 locations), 64-Variable-Replacement (16 drawings × 4 locations), 64 Cube-Deletion (16 drawings × 4 locations), and 64 Variable-Deletion (4 drawings × 4 locations × 4 repeats) trials. Each of the four types of tests (Cube-Replacement, Variable-Replacement, Cube-Deletion, and Variable-Deletion) was given on separate days. Each test type was given in a separate session along with the original training objects, to assess any detrimental effects of a particular test on original task performance.

The Original training stimuli were also presented as testing stimuli in each testing session; all of the Original drawings were given as testing stimuli in conjunction with each type of test. Each testing session involved 16 Replacement/Deletion (testing) stimuli and 16 Original (testing) stimuli. Four testing sessions of each type were required to present all of the testing stimuli. Table 2 displays the assignment of drawings to each of the four testing sessions in the

TABLE 2
The assignment of testing drawings for the four Cube-Deletion testing
sessions

	Location			
Shape Pair	Test A	Test B	Test C	Test D
Cone-Above	upper-centre	right-centre	lower-centre	left-centre
Cone-Below	right-centre	left-centre	upper-centre	lower-centre
Cone-Left	right-centre	upper-centre	lower-centre	left-centre
Cone-Right	lower-centre	upper-centre	left-centre	right-centre
Cylinder-Above	upper-centre	right-centre	lower-centre	left-centre
Cylinder-Below	right-centre	left-centre	upper-centre	lower-centre
Cylinder-Left	left-centre	upper-centre	right-centre	lower-centre
Cylinder-Right	right-centre	upper-centre	left-centre	lower-centre
Handle-Above	left-centre	lower-centre	right-centre	upper-centre
Handle-Below	right-centre	lower-centre	upper-centre	left-centre
Handle-Left	upper-centre	lower-centre	left-centre	right-centre
Handle-Right	right-centre	left-centre	upper-centre	lower-centre
Wedge-Above	right-centre	lower-centre	upper-centre	left-centre
Wedge-Below	left-centre	right-centre	upper-centre	lower-centre
Wedge-Left	right-centre	left-centre	lower-centre	upper-centre
Wedge-Right	lower-centre	right-centre	left-centre	upper-centre

The 16 Original and 16 Cube-Deletion shape pairs were delivered in each test session.
Each shape pair was displayed in one of four possible locations on the screen
(upper-centre, lower-centre, left-centre, and right-centre) during a testing session.

Cube-Deletion test. Within a testing session, all 16 Original shape pairs and all
16 Deletion/Replacement test pairs were presented; each testing stimulus was
displayed in one randomly determined location on the viewing screen. Differ-
ent random assignments were used for each of the four types of tests. Within a
test type, both the Deletion/Replacement and the Original testing stimuli were
shown in the same set of locations. For example, the Cone-Above pair was dis-
played in the upper-center portion of the viewing screen during test session A;
this was the case for both the Cube-Deletion and Original stimulus. Since the
full set of Original stimuli were seen in conjunction with each test and the Orig-
inal stimuli were presented in the same positions on the screen as the testing
stimuli within a given testing session, we could examine whether the presenta-
tion of the testing stimuli in any way interfered with performance on the origi-
nal discrimination.

Sixteen sessions were needed to show the full set of testing stimuli; the com-
plete set of tests was given twice, resulting in thirty-two testing sessions. Each
of the testing stimuli was thus seen eight times (twice in each of the four
locations on the screen). The tests were given in four-session blocks, which
contained one testing session of each type; the order of testing sessions within a
block was randomly determined.

Choice responses on training trials were subject to the normal differential contingencies of reinforcement. The first choice response on testing trials was always reinforced regardless of which key was pecked, even when the training stimuli were presented as tests; choice responses to the testing stimuli were coded as "correct" or "incorrect", even though the birds did not receive differential reinforcement. This response coding was straightforward in all but two cases: The Variable-Deletion and Variable-Replacement stimuli in Group S. Here, ambiguities arose because the stimulus elements necessary for the discrimination were missing. Thus, for the Variable-Deletion stimuli, in which the cube remained alone on the screen, the "correct" choices were randomly assigned. For the Variable-Replacement stimuli, because the new variable shapes that replaced original shapes shared similar non-accidental properties, the Variable-Replacement stimuli were coded according to which shape was previously paired with the cube in the training stimuli. So, if Response 1 was correct for the wedge-cube pair in training, then Response 1 was coded as correct when it occurred in the presence of the pyramid-cube pair in testing. For all other tests, the correct choice was coded according to the stimulus attributes possessed by the testing pair. For example, if the cube was deleted, then the correct choices in Group S were determined by the identity of the remaining variable shape, and the correct choices in Group L were determined by the location of the variable shape on the centre button (the variable shapes appeared in the same position as if the cube were present).

The birds were maintained on testing as long as their discrimination accuracy on each key remained above 70% correct. If performance lapsed, then the birds were retrained on the original discrimination until accuracy recovered. Following retraining sessions, the birds were returned to the testing series in the place where they had left off. Each bird independently advanced through testing.

RESULTS

Discrimination training

Both the shape and the location discriminations proved to be difficult for the pigeons to master. One of the four birds in each group failed to acquire the discrimination (Bird 3 in Group S and Bird 6 in Group L). Even after the completion of more than 200 training sessions, these two birds had failed to exceed chance levels of discrimination, so their training was discontinued. For the six birds that did successfully learn their discriminations, the overall mean accuracy scores (averaged across all stimuli and all locations) exceeded 80% correct. The overall mean accuracy scores over the final two days of discrimination training for Birds 1, 2, and 4 in Group S were 83.6%, 82.8%, and 80.1%,

respectively. The mean accuracy scores over the final two days of training for Birds 5, 7, and 8 in Group L were 89.1%, 87.5%, and 80.1 %, respectively.

The rates of learning the shape and the location tasks were also examined to see whether there were any systematic differences (see Table 3). The rate of learning was measured by determining the number of sessions required to reach successively stringent criteria of 40% correct overall, 55% correct overall, 70% correct overall, and 70% correct on each of the four keys. There was a very slight trend for Group S to reach each criterion in fewer sessions than Group L. Note that Bird 4 in Group S, the pigeon that developed the key aversion problem, required substantially more sessions to complete the criteria than the other two birds in Group S, but this bird's asymptotic accuracy levels were comparable to the other two birds in the group (see accuracy scores listed earlier). A two-way ANOVA conducted on the number of sessions to reach successive criteria revealed a significant main effect of Criterion, $F(3,12) = 12.7$, $p < .001$, but neither the main effect of Group $F(1,4) < 1$, nor the Group × Criterion interaction, $F(3,12) < 1$, were significant.

Testing

Both groups of pigeons required occasional retraining sessions during the 32-session testing series. Birds 1, 2, and 4 in Group S required 79, 39, and 30 total retraining sessions, respectively; Birds 5, 7, and 8 in Group L required 19, 22, and 12 total retraining sessions, respectively. Although the birds in Group S required more retraining sessions during the testing phase, the difference was not significant, $t(2) = 1.8$, $p > .05$.

TABLE 3
The number of sessions required by each bird in
Group S and Group L to reach successively more
stringent criteria

	Criterion			
Pigeon	40%	55%	70%	70% per key
Group S				
Bird 1	8	23	48	84
Bird 2	16	24	32	61
Bird 4	64	125	175	206
Mean	29	57	85	117
Group L				
Bird 5	49	53	57	101
Bird 7	70	88	136	200
Bird 8	58	64	75	91
Mean	59	68	89	131

The overall testing results for Group S and Group L are displayed in Figure 4. There were no differences in performance to the Original shape pairs (given as testing stimuli) among the four tests, so the data for the Original testing drawings were averaged across the tests. Additionally, there were no systematic effects of either display location or testing session on discrimination performance, so accuracy scores were averaged across locations and sessions. Both groups continued to discriminate the Original stimuli at similarly high accuracy levels (Group S: 81.8% correct; Group L: 84.3% correct), but the two groups responded differently to the different kinds of testing stimuli.

The presentation of the Cube-Deletion and Cube-Replacement drawings to Group S (gray bars) produced little or no adverse effect on accuracy scores. On the other hand, presentation of the Variable-Deletion and Variable-Replacement drawings produced significant decrements in discrimination accuracy. However, despite the removal of the original stimulus relevant to the shape discrimination, the accuracy scores to the Variable-Replacement drawings remained reliably above chance, binomial test, $p < .01$.
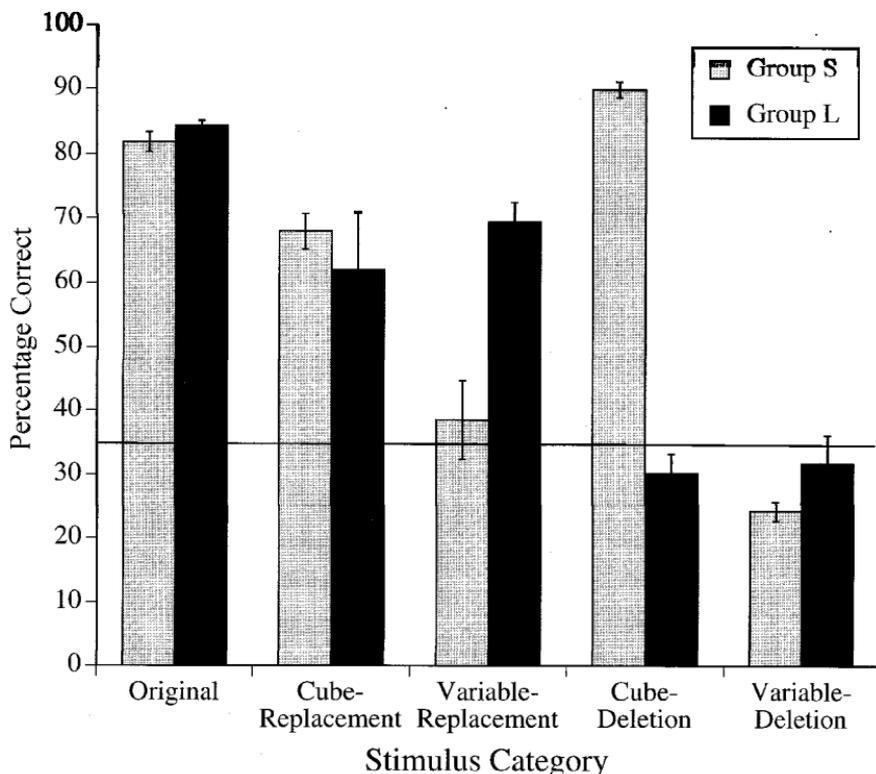

FIG. 4.   The mean ± the standard error of the mean of accuracy scores produced by each group to the Original, Cube-Replacement, Variable-Replacement, Cube-Deletion, and Variable-Deletion testing stimuli. The horizontal line denotes the level that the accuracy scores had to exceed in order to be significantly above chance (binomial test, $p < .01$).

The birds in Group L (black bars) produced a different pattern of results compared to the birds in Group S. Here, deletion of either the cube or the variable shapes produced large decrements in discrimination accuracy, but replacement of either of the shapes had smaller effects on accuracy scores. Neither the Cube-Deletion nor the Variable-Deletion drawings sustained discrimination accuracy above chance, binomial test, $p < .01$, but both the Cube-Replacement and Variable-Replacement drawings were recognized at near the level of the Original drawings.

A two-way ANOVA on the accuracy scores produced by the two groups to the different types of test stimuli (Original, Cube-Deletion, Cube-Replacement, Variable-Deletion, and Variable-Replacement) disclosed a significant main effect of Test Type, $F(4,16) = 45.4$, $p < .001$, and a significant Group × Test Type interaction, $F(4,16) = 31.9$, $p < .001$, but the Group main effect, $F(1,4) = 4.3$, $p > .05$, was not significant.

Scheffé post-hoc tests were conducted on the Group × Test Type interaction. Accuracy scores to the different test types were contrasted separately for each group.

In Group S, two comparisons were significant: (1) The mean of the Original, Cube-Deletion, and Cube-Replacement accuracy scores was significantly greater than the mean of the Variable-Deletion and Variable-Replacement accuracy scores, $t(4) = 12.7$, $p < 01$; and (2) the mean of the Cube-Deletion and Cube-Replacement accuracy scores was significantly greater than the mean of the Variable-Deletion and Variable-Replacement accuracy scores, $t(4) = 11.3$, $p < .01$. Thus, there was an overall effect of cube vs. variable shape manipulations, with variable shape manipulations producing significant decrements in accuracy scores. There were no differential effects of replacement or deletion of the cube or variable shapes.

In Group L, there were also two significant comparisons: (1) the mean of the Original, Cube-Replacement, Variable-Replacement accuracy scores was significantly greater than the mean of the Cube-Deletion and Variable-Deletion accuracy scores, $t(4) = 10.7$, $p < .01$; and (2) the mean of the Cube-Replacement and Variable-Replacement accuracy scores was significantly greater than the mean of the Cube-Deletion and Variable-Deletion accuracy scores, $t(4) = 8.3$, $p < .01$. Thus, there was an overall effect of replacement vs. deletion manipulations, with deletion manipulations producing significant decrements in accuracy scores relative to the Original drawings. There were no differential effects of cube or variable shape manipulations.

DISCUSSION

Three out of the four pigeons in Group S and Group L learned their discriminations, but mastery of both discriminations proved to be rather difficult. The successful learning of the location task joins a host of other observations of

discriminative control by the spatial interrelations of stimulus components (Kirkpatrick-Steger & Wasserman, 1996; Kirkpatrick-Steger et al., 1996; Steele, 1990; Wasserman et al., 1993; Watanabe & Ito, 1991); these findings refute Cerella's (1980) claim that pigeons are incapable of attending to more than simple particulate features of drawings such as line segments.

The results of the four tests revealed that, in learning their respective tasks, the two groups of pigeons attended to different aspects of the training pairs.

In Group S, variable shape manipulations (either deletion or replacement) had a large detrimental effect on accuracy scores, but cube manipulations had little or no effect. This pattern of test results is consistent with the conclusion that the pigeons in Group S learned the identity of the variable shapes (see Table 1). The fact that replacement or deletion of the cube had no major effects on discrimination accuracy (relative to the Original) indicates that the cube was unimportant for learning the shape task. Thus, the results are inconsistent with the "Compound" and "Memorization" learning rules (see Table 1), which would have resulted in reductions in responding when the cube was deleted or replaced.

Interestingly, deleting the cube did produce a modest enhancement of accuracy scores, suggesting that the presence of the cube in the Original training pairs might have interfered with performance. Closer examination of accuracy scores to the Original drawings revealed that performance was not uniformly high to all shape pairs (Table 4). When the variable shape was unoccluded by the cube (above and right-of, mean = 88.7%) performance was better than when the variable shape was partially occluded by the cube (below and left-of, mean = 75.9%), but these differences failed to attain statistical significance, $t(2) = 3.44$, $p > .05$. Thus, occlusion by the cube produced some detrimental effect on accuracy in the Original shape discrimination. Deletion of the cube may have alleviated some of these effects because the performance to the Cube-Deletion stimuli was uniformly high across all locations (see Table 4).

The effects of occlusion of the variable shapes by the cube on accuracy scores in Group S suggest that these pigeons were attending to the whole variable shape. If the birds had attended only to the selective portion of the variable shapes that was displayed in both occluded and unoccluded drawings, then their discrimination should have been equally good regardless of whether the variable shape was partially occluded by the cube. If, however, the birds had attended to the entire shape, then they should have discriminated the partially occluded views more poorly than the unoccluded views because of the decrease in the available shape information, as was the case. The sensitivity of the birds in Group S to the whole variable shape is consistent with previous research indicating that pigeons attended to more than the vertices or pieces of contour in line drawings of objects (Van Hamme, Wasserman, & Biederman, 1992).

In contrast to performance by the pigeons in Group S, the birds in Group L appeared to be controlled by more global, configural aspects of the shape pairs.

TABLE 4
Accuracy scores produced by the three birds in Group S to the Original and
Cube-Deletion drawings as a function of the location of the variable shape

Pigeon	Above	Below	Left-of	Right-of	Occluded	Unoccluded
Original						
Bird 5	96.1	68.8	82.8	89.1	75.8	92.6
Bird 6	88.3	86.7	71.1	81.3	78.9	84.8
Bird 8	92.2	66.4	73.4	85.2	69.9	88.7
Mean	92.2	74.0	75.8	85.2	74.9	88.7
Cube-Deletion						
Bird 5	90.6	81.3	93.8	84.4	87.5	87.5
Bird 6	93.8	96.9	87.5	87.5	92.2	90.6
Bird 8	93.8	90.6	90.6	87.5	90.6	90.6
Mean	92.7	89.6	90.6	86.5	90.1	89.6

The scores to the Occluded versions are the average of the accuracy scores to the Below and
Left-of drawings; the scores to the Unoccluded versions are the average of the accuracy scores
to the Above and Right-of drawings.

The tests administered to Group L revealed that replacement of either shape
resulted in superior performance compared to the effects of deleting either
shape. These results are consistent with learning the configuration of the shapes
(see Table 1), with both shapes capable of serving as a reference point.

Replacing one of the shapes did impair accuracy scores slightly, with some-
what greater effects when the cube was replaced. The greater effect of cube
replacement on discrimination accuracy indicates that the cube may have been
slightly favored as a reference shape. Thus, the tests results are most consistent
with the "Configural" learning rule (Table 1). The test results are inconsistent
with the "Cube position" and "Memorization" learning rules.

The fact that the testing stimuli had very different effects on discrimination
accuracy in the two groups of pigeons indicates that the birds in each group had
indeed learned something different about the stimuli. Even though the number
of individual shape pairs was small enough that the birds could have memo-
rized each drawing (Vaughn & Greene, 1984), it can be concluded that neither
group used rote memorization in learning their respective tasks because memo-
rization would resulted in poor generalization to all of the test stimuli. Instead,
both groups employed more general learning rules.

In Group S, learning of the variable shape identity required perception of
local features (e.g. the form of the variable shape), and categorization based on
common local features. In Group L, learning the configuration of the shapes
required perception of the individual shapes, perception of the spatial configu-
ration of the shapes, and categorization based on the relationship of the shapes.

In comparing the demands of the two tasks, it appears that the location dis-
crimination was more complex than the shape discrimination. Whereas

learning the variable shape identity by Group S required only perception of local features, the configural learning by Group L required perception of both local and global features. The pigeons in Group L could not have generalized to either Cube-Replacement or Variable-Replacement drawings unless they recognized the intact shape as a familiar reference. Thus, perception of both local and global attributes was required.

With respect to the form of categorization employed, the shape task required that the pairs be grouped on the basis of local features only, whereas the location task required that the shape pairs be grouped on the basis of relational features. Thus, the shape task required basic object categorization (e.g. Bhatt, Wasserman, Reynolds, & Knauss, 1988; Herrnstein, 1990; Herrnstein & Loveland, 1964), whereas the location task required abstract concept formation (cf. Herrnstein, 1990). Basic object categorization can be conceived of as involving two processes: within-category generalization among perceptually similar exemplars (those pairs containing the same variable shape), and between-category discrimination among perceptually different exemplars (those pairs containing different variable shapes). On the other hand, abstract concept formation requires learning "not the exemplars themselves, but the relations between and among concepts" (Herrnstein, 1990, p. 12). Thus, in order to be able to categorize a set of stimuli on the basis of abstract spatial relations, one must first already possess the concept of "cube", "wedge", "cone", etc.

The stimuli used here provide a well-controlled means of studying the perception of component shape and location. Whether employed with a four-choice method (as in the present experiment) or a go/no-go method (Kirkpatrick-Steger & Wasserman, 1996), this set of shape pairs allows for a novel approach to understanding the process (both perceptual and conceptual aspects) by which shape and location information is discriminated. The procedures could be employed with a wide range of species for conducting either behavioural or neural analysis. The four-choice method provides a unique situation where two groups of participants are required to learn different aspects of the same set of stimuli with the same general procedures. Using the same stimuli for both discriminations rules out any differences in learning and performance that might be due to differences inherent in the stimulus set. Moreover, the stimulus attributes that control discriminative behaviour in the two tasks can be isolated by replacing or deleting the fixed and the variable shapes. On the other hand, by applying the go/no-go method, one can examine whether shape and location are processed conjointly, which type of information is likely to gain primary control over behaviour, and whether shifts in attention occur while the discrimination is being learned. The two methods applied together with the same set of shape pairs could serve as a powerful tool for understanding the neural processing of shape and location information.

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