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EFFECTS OF SPATIAL REARRANGEMENT OF OBJECT COMPONENTS ON PICTURE RECOGNITION IN PIGEONS

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Five pigeons were first trained to discriminate among line drawings of four objects: a watering can, an iron, a desk lamp, and a sailboat. The birds were then tested with eight versions of each object, in which the object's components were vertically and horizontally rearranged. The pigeons displayed different degrees of generalization decrement to the different scrambled versions of the objects. Two analyses helped to clarify the nature of the varied accuracy scores. First, cluster analyses disclosed subsets of components that were related to test performance. Second, although the clusters varied somewhat across birds for a given object, there was reliable concordance among the subjects in their rankings of the individual scramblings, suggesting that the pigeons may have attended to common aspects of the drawings.

Key words: picture perception, attention, stimulus control, pigeon

Since Herrnstein and Loveland's (1964) original demonstration of object categorization in pigeons, the prime unanswered question has been precisely what aspects of the snapshots actually controlled the birds' discriminative behavior. Largely because of the complexity of photographic images, rather little progress has been made in our understanding of the structural aspects of picture perception by pigeons (for a review of research on pigeons' picture perception, see Wasserman, 1993).

Finding adequately rich but readily modifiable stimuli for experimental investigation is just half of the problem; the other is having some principled reason for creating and modifying the stimuli for study. Interestingly, a recent theory of human object recognition may represent one route for making advancements in the analysis of picture perception by pigeons. Biederman's (1987) theory of recognition by components assumes that a series of stages of information processing extracts both specific and generic information from complex visual stimuli. Essential to Biederman's formulation is that the visual system parses complex visual stimuli into elementary volumetric components, or *geons,* whose spatial concatenation defines virtually any basic-level object or representation thereof. Thus, according to recognition by components, object recognition occurs if the object's geons are present and appear in the appropriate spatial arrangement.

The present project is an extension of an earlier study (Wasserman, Kirkpatrick-Steger, Van Hamme, & Biederman, 1993, Experiment 1) that examined whether pigeons would recognize objects if the original geons were present but the spatial arrangement of the geons was altered relative to the original object. After pigeons had been trained to discriminate among drawings of four different objects (a watering can, an iron, a desk lamp, and a sailboat), they were tested with novel drawings in which the components of the objects (the components being geons) were spatially rearranged. We found a reliable drop in the pigeons' recognition accuracy from a mean of 80.5% correct to the original drawings to a mean of 52.3% correct to the scrambled drawings. Because the pigeons exhibited a significant generalization decrement, it appeared that they had attended to the spatial organization of the objects' geons. However, the geons themselves must have also contributed to picture recognition, because accuracy scores to the scrambled drawings were reliably above chance.

Finer analyses of responding to the individual stimuli in that experiment has since revealed that there were substantial differences in the degree to which the different scramblings of an object's geons led to decrements

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in recognition accuracy, spanning nearly the full range from chance (25% correct) to perfect responding (100% correct). But, because only four different scramblings of each of the four objects were given and each scrambling was seen by each pigeon only twice, neither the reliability nor the importance of this preliminary result could be defended.

In the present investigation, we evaluated the behavioral effects of eight different scramblings of each of the four objects (the four scramblings from the original study plus four new ones), and we did so by showing each of these 32 scrambled drawings 20 times to each of five new pigeons over a total of 80 testing sessions. Again, there were striking differences in recognition accuracy to different object scramblings. Cluster analyses disclosed that the location of a subset of the geons often controlled responding, with the degree of attention to spatial location varying with object type. Despite differences in the shapes of the obtained cluster trees, the five birds ranked the scramblings of each object similarly, suggesting that the pigeons may have similarly discriminated the line drawing pictures. The birds' concordant discrimination behavior in concert with their selective attention to the location of a subset of geons suggests that it may prove possible in future research to pinpoint with even greater precision those aspects of the complex drawings that are important for the pigeons' picture recognition.

METHOD

Subjects

The subjects were 8 feral pigeons naive to the present experimental conditions that were kept at 85% of their free-feeding weights by the delivery of mixed grain during experimental sessions. One pigeon failed to learn the original discrimination and was dropped from the study before testing; 2 others died during the study and their data were excluded from the analyses.

Apparatus

The experimental chambers were four conditioning cubicles (fully described in Bhatt, Wasserman, Reynolds, & Knauss, 1988). A rotary projector presented slides through an opening in the wall behind the front panel of each box; the slide images were back-projected on a frosted plastic screen (7 cm by 7 cm). A key (1.9 cm diameter) was located near each corner of the screen; each of these four keys could be lit a different color by a small projector containing incandescent lamps. The top left key was orange, the top right key was white, the bottom left key was green, and the bottom right key was red. A microswitch behind each of the keys and the clear plastic key in front of the viewing screen recorded the pigeon's pecks. An opening in the front panel below the screen allowed the pigeon access to grain reinforcement. A Hewlett-Packard® 386 computer equipped with the MED-PC® programming system and interface (Tatham & Zurn, 1989) managed experimental control and data collection.

Stimuli

The training stimuli were black-on-white line drawings of four objects (watering can, iron, desk lamp, and sailboat; see Wasserman et al., 1993); each contained four geons. The particular drawings were selected so that each object contained geons that were largely unique. In only two cases did an object share a similar geon with another object (e.g., both the nozzle of the watering can and the base of the desk lamp were flat cylinders). The maximum height or width of each drawing was 5.7 cm on the viewing screen. The testing stimuli were the four previous scramblings of each object used by Wasserman et al. (1993) plus four new scramblings, yielding 32 stimuli (eight scramblings times four objects). The entire set of scramblings as well as the training pictures are shown in Figures 1, 2, 3, and 4. (These drawings are much cruder representations of the pictures than the pigeons actually saw.) The testing stimuli were created by shifting the four geons of each object both vertically and horizontally, with the constraint that the height and width of the scrambled versions equaled those of the original. In no case was a geon rotated or mirror reversed. The geons in both the original and the scrambled drawings contacted each other, but they did not overlap. All stimuli were photographed and transferred to 35-mm slides.

Procedure

Discrimination training. Prior to discrimination training, the birds were taught to eat

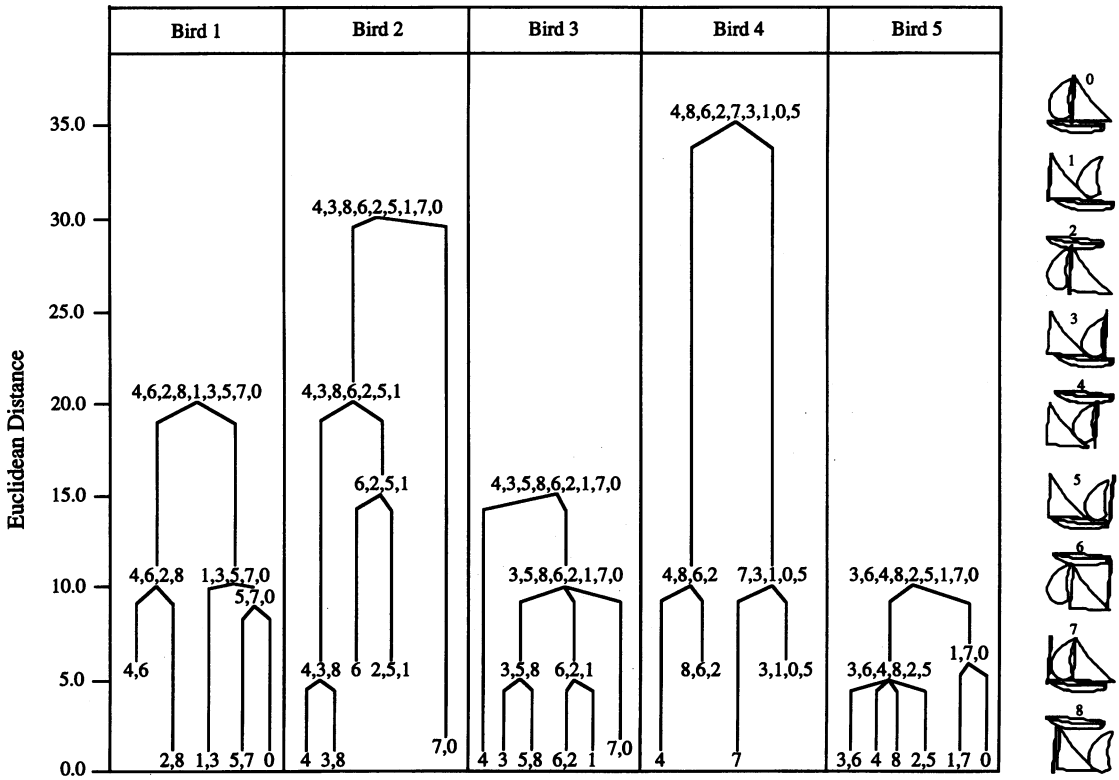

Fig. 1. Cluster diagrams for each of the 5 birds to the sailboat scramblings. Each bird's cluster tree is presented in a panel. The numbers correspond to the drawings on the right. The Euclidean distance of each cluster is indicated by the scale on the left.

from the grain hopper and were trained via handshaping to peck the viewing screen and the report keys. They were then taught the discrimination among the four line drawings. On the four-choice procedure, each of the 48 daily trials began with the display of a drawing for 15 s; the first peck to the viewing screen after 15 s lit the four differently colored report keys. A single choice response was then permitted. If the correct report key was pecked, all of the visual stimuli were turned off and the pigeon was fed mixed grain; if the response was to any of the three incorrect report keys, all of the keylights were turned off and the trial was repeated. Only the first choice response of a trial was scored; correction trials were not analyzed. Trials were separated by a variable intertrial interval averaging 15 s. Line drawing–report key assignments were counterbalanced across the two sets of 4 birds; due to attrition, only three of the four counterbalancings were represented. Each bird was trained with a different slide tray, each containing different orders of drawings; four different slide trays were shifted across birds from 1 day to the next. Training continued for 108 sessions.

Testing. Testing was conducted with four new slide trays, each containing different slide orders and different subsets of testing stimuli. Each tray contained 40 original drawings and eight drawings of scrambled objects: 10 original and two scrambled versions of each of the four objects. Because there were eight scramblings of each object, it took four sessions to show all 32 testing stimuli. The assignment of testing stimuli to the slide trays was different for each four-session block of testing. The entire set of scramblings was given repeatedly until each bird saw each testing stimulus 20 times, requiring 80 testing sessions. Two to 10 retraining sessions were given between each four-session block of testing to maintain the original discrimination at a

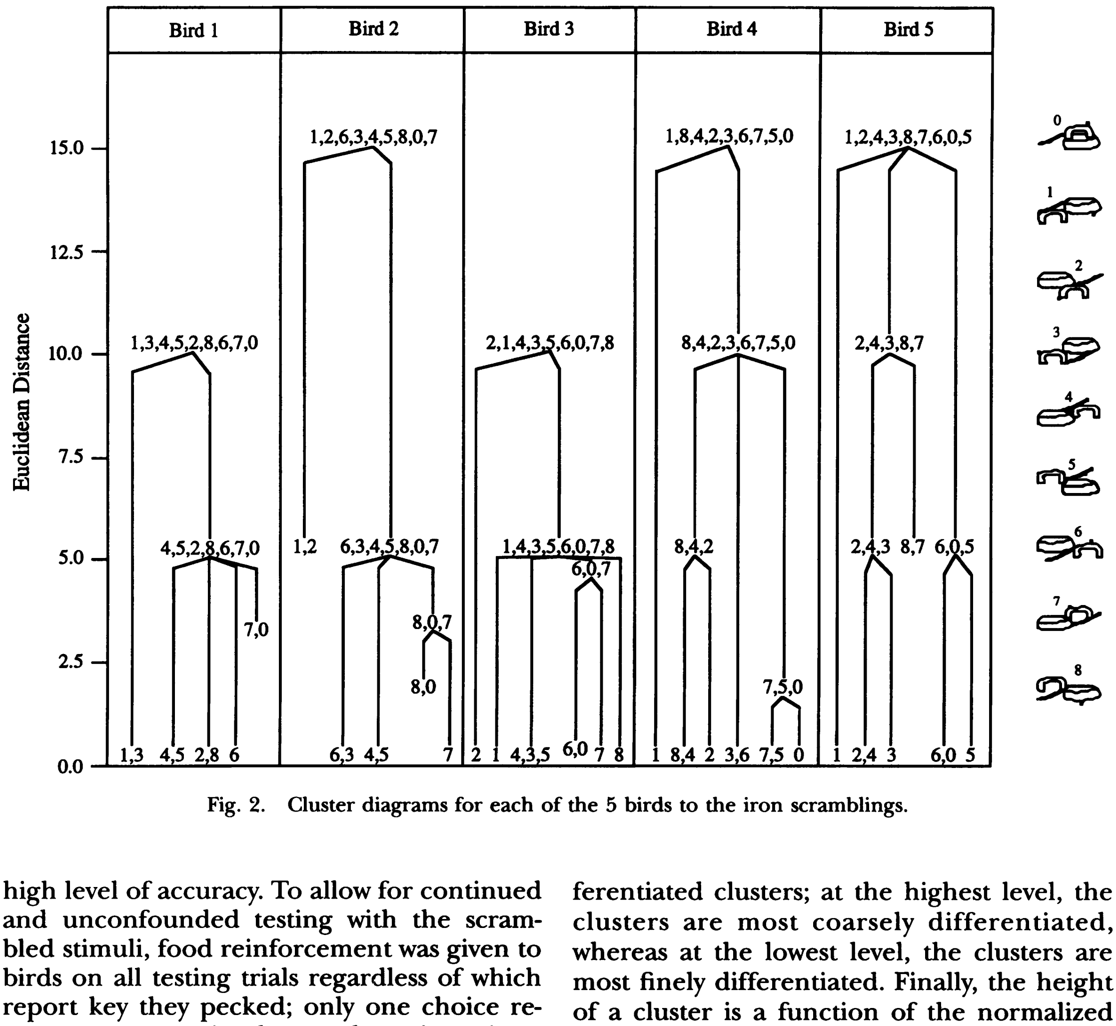

Fig. 2. Cluster diagrams for each of the 5 birds to the iron scramblings.

high level of accuracy. To allow for continued and unconfounded testing with the scrambled stimuli, food reinforcement was given to birds on all testing trials regardless of which report key they pecked; only one choice response was permitted to each testing stimulus, with no subsequent correction for errors. The 40 original drawings in each session were treated the same as in discrimination training—there was correction for errors, and food reinforcement was given at the end of each trial.

Data Analysis

Each bird's accuracy scores to the testing stimuli of each object were subjected to a hierarchical cluster analysis using Systat 5.2. The cluster analysis groups together those versions of an object that produced similar levels of generalization by using a Euclidean distance algorithm. The Euclidean distances serve as a measure of dissimilarity for constructing clusters. The hierarchical cluster analysis produces a series of increasingly differentiated clusters; at the highest level, the clusters are most coarsely differentiated, whereas at the lowest level, the clusters are most finely differentiated. Finally, the height of a cluster is a function of the normalized Euclidean (root mean square) distance among its members; the lower in the diagram a cluster appears, the more similar are the accuracy scores among its members.

Each bird's accuracy scores to the scrambled testing stimuli were ranked, for each object, in order of increasing accuracy levels. The ranks were entered into an analysis of concordance. Concordance measures agreement among judges in their ranking of stimuli. Kendall's W is the index of agreement; it varies from 0 to 1, with 1 indicating maximal agreement. When the number (N) of stimuli exceeds 7 (as it did here), W is distributed as χ^2 with $N - 1$ degrees of freedom. Kendall's W can then be tested for statistical significance against the χ^2 distribution, after a simple mathematical transformation is per-

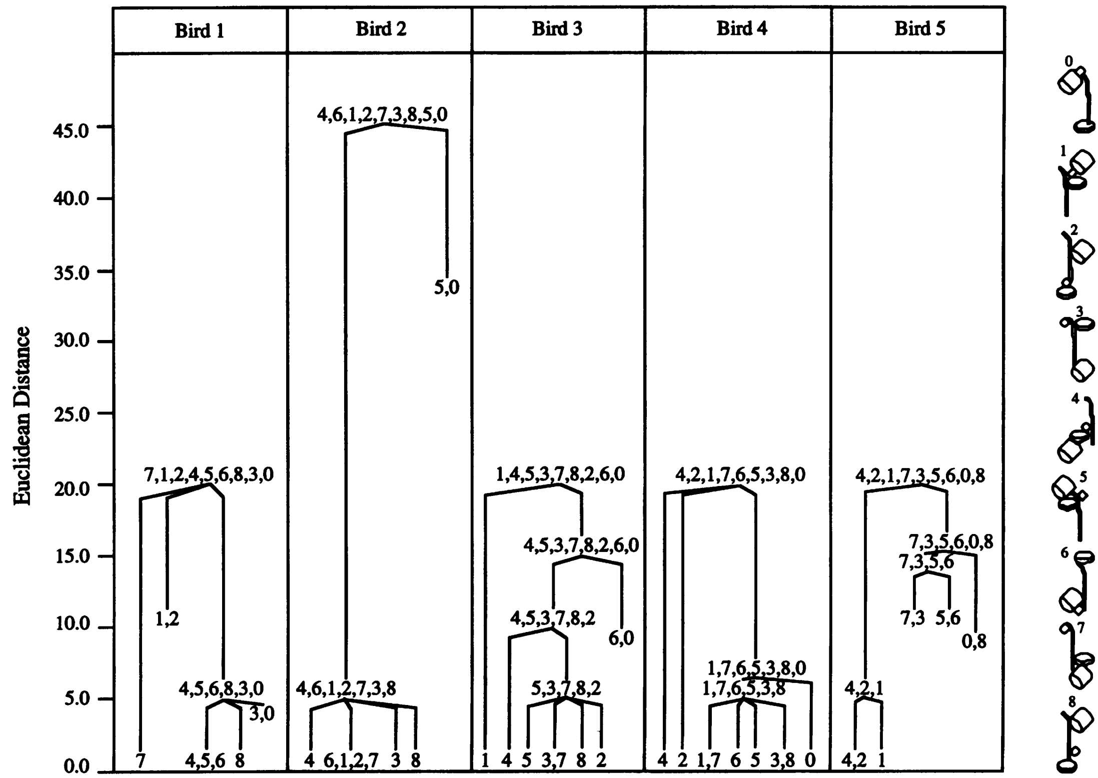

Fig. 3. Cluster diagrams for each of the 5 birds to the desk lamp scramblings.

formed: $\chi^2 = k(N - 1)W$, where k = number of judges and N = number of stimuli.

RESULTS

Discrimination Training

Accuracy scores during the final 4-day block of training were quite high: 82.3%, 96.4%, 85.9%, 91.0%, and 87.0% correct for Birds 1, 2, 3, 4, and 5, respectively (M = 88.5%).

Testing

Accuracy scores. The birds continued to discriminate the training stimuli at high levels on testing days; the mean percentage of correct responses to those pictures was 88.9%. In contrast, mean accuracy to the old scramblings was 53.5% and to the new scramblings was 66.0%. An ANOVA involving each subject's overall accuracies to the original drawings, the old scramblings, and the new scramblings revealed a statistically significant effect of stimulus version, $F(2, 38) = 46.80$, $p < .001$. Tukey follow-ups revealed that both the old and the new scramblings produced a statistically significant decrement in accuracy relative to the original pictures ($p < .01$), but they did not differ significantly from one another. Nevertheless, both sets of scramblings were discriminated above chance by binomial test ($p < .01$).

Cluster analyses. The hierarchical cluster analysis was conducted separately for each of the 5 birds and for each of the four objects. The results of these analyses are displayed in Figures 1, 2, 3, and 4. To aid in the interpretation of these figures, a sample cluster diagram for the sailboat is shown in Figure 5, which displays the accuracy scores produced by Bird 1 below each drawing. This pigeon strongly attended to the position of the hull of the sailboat. At the point of the first branch of the tree, two clusters were produced: one containing all of the versions of the sailboat that displayed the hull above the mast and sails (the mean accuracy of this cluster was 23.8% correct) and the other contain-

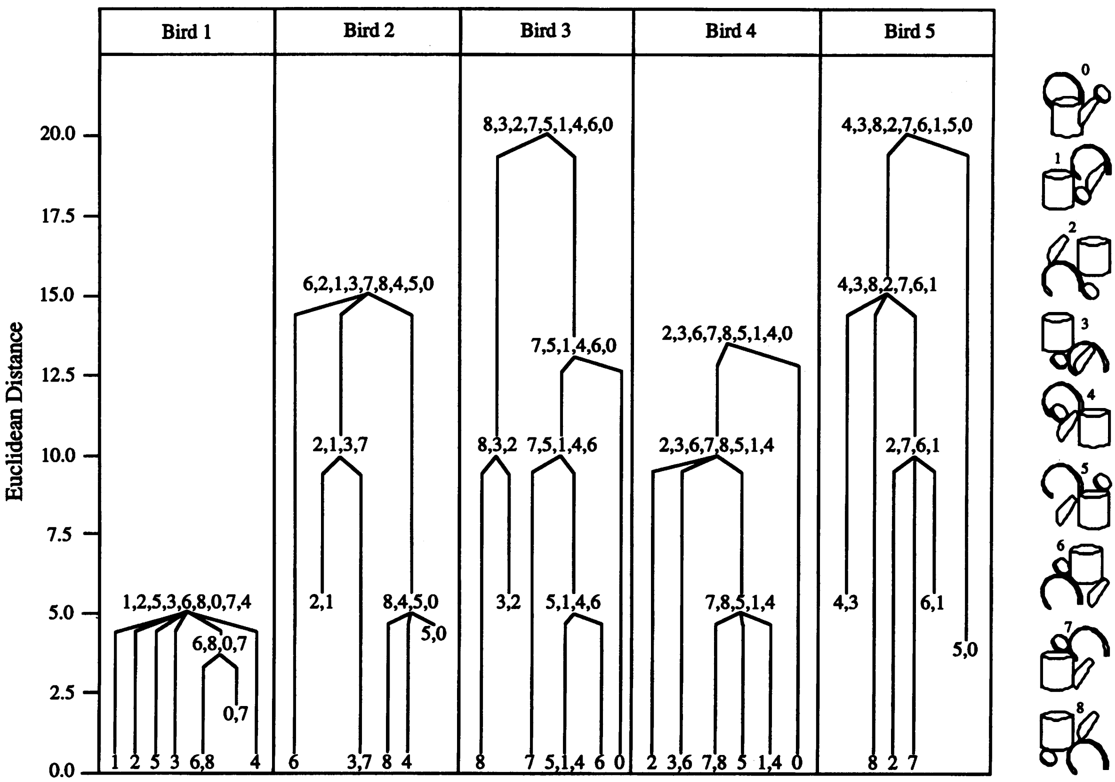

Fig. 4. Cluster diagrams for each of the 5 birds to the watering can scramblings.

ing all of the versions of the sailboat that displayed the hull below the mast and sails (the mean accuracy of this cluster was 58.1% correct). The relative position of the two sails to one another seemed to be unimportant for this bird, as did the position of the mast.

Sailboat. A replica of Bird 1's cluster tree is shown in the left panel of Figure 1, along with the cluster analyses for the other 4 birds. (Table 1 presents the corresponding accuracy scores for each bird to the sailboat scramblings.) A copy of each scrambling is placed on the far right side of the figure to allow visual reference. As in Figure 5, a scale indicating the height of each cluster's position is placed to the left of the trees. Bird 4 also appeared to attend primarily to the location of the hull; specifically, those scramblings depicting the hull above the mast and sails (Sailboats 2, 4, 6, and 8; $M = 26.3\%$ correct) were clustered separately from those scramblings depicting the hull below the mast and sails (Sailboats 0, 1, 3, 5, and 7; $M = 84.0\%$ correct). Bird 3 appeared to attend to the relative position of the two sails. When the sails were properly aligned (Sailboats 0, 2, 6, and 7), accuracy was high ($M = 87.8\%$ correct); when the sails were reversed (Sailboats 3, 4, 5, and 8), accuracy was lower ($M = 63.8\%$ correct). The only exception was Sailboat 1, which exhibited a high level of accuracy (85% correct) but had the sails reversed. For Birds 2 and 5, either disruptions of the position of the hull or the interrelation of the two sails caused decrements in accuracy scores. The cluster analysis for Bird 2 revealed that Sailboat 7, in which only the mast was moved, was the only scrambling to be clustered with the original sailboat. Bird 5 exhibited strong generalization to Sailboat 7 as well, but it also did so to Sailboat 1, in which the two sails were reversed but the hull remained in place and the mast remained adjoined to the triangular sail. Thus, Birds 2 and 5 best discriminated those instances in which only one spatial relation was disturbed; if more than one relation was disrupted, then accuracy was low (Bird 2, mean accuracy of Sailboats 1, 2, 3, 4,

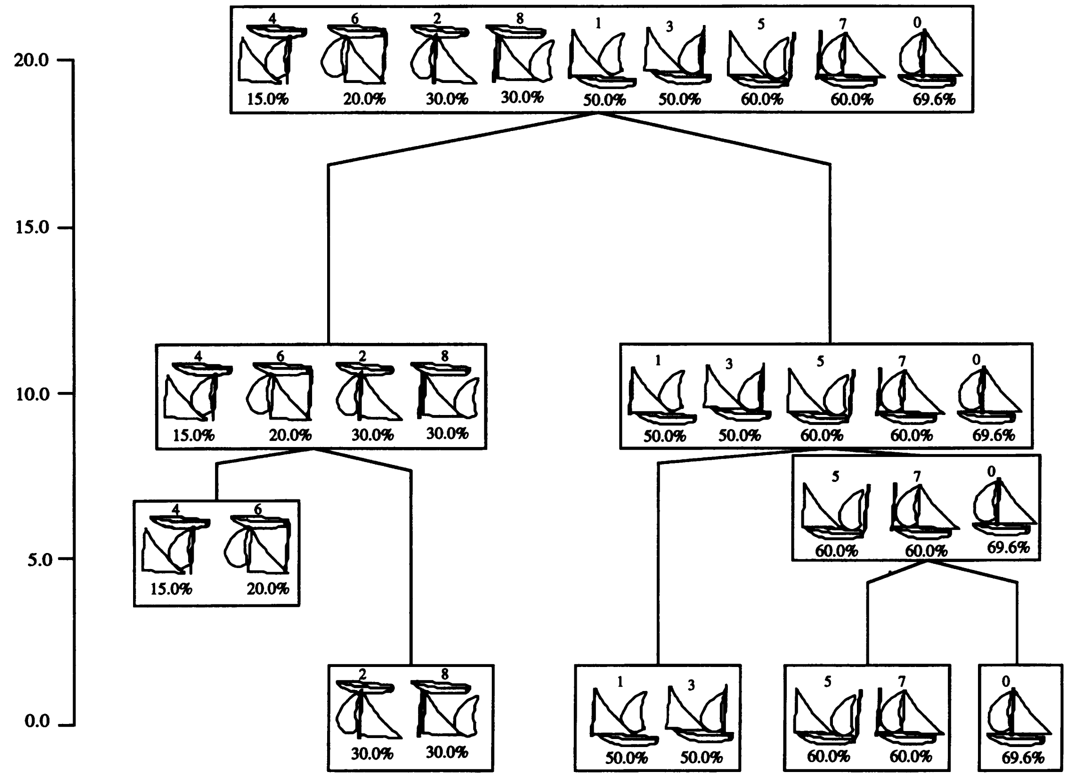

Fig. 5. Results of a cluster analysis conducted on the accuracy scores produced by Bird 1 to the sailboat line drawings. The Euclidean distance of each cluster is indicated by the scale on the left. The number above each drawing identifies the scrambling. Sailboat 0 was the original training stimulus; Sailboats 1, 2, 3, and 4 were the old scramblings; and Sailboats 5, 6, 7, and 8 were the new scramblings. The members of each cluster were arranged so that the stimulus that occasioned the worst accuracy was on the left and successively better scramblings were arranged in order from left to right.

5, 6, and 8 = 39.3% correct; Bird 5, mean accuracy of Sailboats 2, 3, 4, 5, 6, and 8 = 62.5% correct).

Iron. For all 5 birds, Iron 1 produced modest accuracy levels and it dropped out early in the cluster analysis (see Figure 2 for the cluster analyses and Table 2 for accuracy scores). This scrambling portrayed both the handle and the knob below the base of the iron. Birds 2, 3, and 5 appeared to attend primarily to the relative position of the handle and base. Bird 2 attended most strongly to these two geons: Irons 1, 2, 3, and 6 (in which the handle-base relation was vertically reversed, M = 76.3% correct) produced moderate accuracy levels, whereas Irons 0, 4, 5, 7, and 8 (in which the vertical handle-base relation was more or less intact, M = 94.4% correct) produced higher accuracy levels. Birds 3 and 5 exhibited more modest control by the handle-base relation. For both of these birds, Irons 1, 2, and 3 were separated from the original (Bird 3, M = 78.3% correct; Bird 5, M = 46.7% correct), but Iron 6 was clustered with the original iron. Iron 6 may have produced higher accuracy scores in these birds because the handle-knob and handle-cord relations were intact, even though the handle-base relation was reversed. The behavior of Birds 1 and 4 was difficult to diagnose; the handle-base relation did not appear to exert notable control over their behavior, nor did any other relation for that matter.

Desk lamp. The results of the cluster analyses on the desk lamp scramblings are shown in Figure 3 (see Table 3 for corresponding accuracy scores). Four of the birds (Birds 1, 2, 4, and 5) produced similar results. For these 4 birds, Desk Lamps 1, 2, 4, and 7 were poorly discriminated (Bird 1 = 45.0% cor-

Table 1

Accuracy scores (as percentage correct) produced by each bird to each of the nine versions of the sailboat. SB-0 denotes the original training stimulus. SB-1, SB-2, SB-3, and SB-4 are the old sailboat scramblings, and SB-5, SB-6, SB-7, and SB-8 are the new sailboat scramblings. An ANOVA on the mean accuracy scores to all nine stimuli given in testing revealed a significant effect of stimulus version, $F(8, 32) = 8.54$, $p < .001$. Tukey post hoc tests revealed significant differences between the original training stimulus and Sailboats 2, 3, 4, 6, and 8 (denoted by asterisks). Of all nine stimuli, only the mean accuracy score to Sailboat 4 failed to exceed the 25% chance level, as measured by binomial test.

Stimulus	Bird 1	Bird 2	Bird 3	Bird 4	Bird 5	*M*
SB-0	70.4	96.5	96.3	89.8	86.5	87.9
SB-1	50.0	65.0	85.0	85.0	80.0	73.0
SB-2	30.0	55.0	80.0	35.0	70.0	54.0*
SB-3	50.0	20.0	65.0	80.0	55.0	54.0*
SB-4	15.0	15.0	50.0	15.0	60.0	31.0*
SB-5	60.0	60.0	70.0	95.0	70.0	71.0
SB-6	20.0	40.0	80.0	30.0	55.0	45.0*
SB-7	60.0	95.0	95.0	70.0	80.0	80.0
SB-8	30.0	20.0	70.0	25.0	65.0	42.0*
M	42.8	51.8	76.8	58.3	69.1	59.8

Table 2

Accuracy scores (as percentage correct) produced by each bird to each of the nine versions of the iron. I-0 denotes the original training stimulus. I-1, I-2, I-3, and I-4 are the old iron scramblings, and I-5, I-6, I-7, and I-8 are the new iron scramblings. An ANOVA on the nine testing stimuli disclosed a significant effect of stimulus version, $F(8, 32) = 7.62$, $p < .001$. Post hoc tests indicated that Irons 1, 2, 3, and 4 produced significant generalization decrements relative to the original (denoted by asterisks); all nine versions were, however, discriminated above chance ($p < .01$).

Stimulus	Bird 1	Bird 2	Bird 3	Bird 4	Bird 5	*M*
I-0	93.3	96.9	90.2	91.9	85.0	91.5
I-1	65.0	65.0	80.0	50.0	35.0	59.0*
I-2	80.0	70.0	70.0	70.0	50.0	68.0*
I-3	65.0	85.0	85.0	80.0	55.0	74.0*
I-4	75.0	90.0	85.0	65.0	50.0	73.0*
I-5	75.0	90.0	85.0	90.0	90.0	86.0
I-6	85.0	85.0	90.0	80.0	85.0	85.0
I-7	90.0	100.0	95.0	90.0	70.0	89.0
I-8	80.0	95.0	100.0	65.0	65.0	81.0
M	78.7	86.3	86.7	75.8	65.0	78.5

rect, Bird 2 = 3.8% correct, Bird 4 = 55.0% correct, and Bird 5 = 17.5% correct), and these stimuli were separated from the original early in the analysis. These four scramblings all shared one commonality: The base of the lamp touched the fixture or the shade. This relation was true as well for Desk Lamp 5. Desk Lamp 5 was clustered with the original for Bird 2; for the other 3 birds, it ended up by itself (Birds 4 and 5) or with Desk Lamps 4 and 6 (Bird 1). For Birds 1, 4, and 5, Desk Lamps 0, 3, 5, 6, and 8 were clustered together (Bird 1 = 75.8% correct, Bird 4 = 83.4% correct, and Bird 5 = 71.3% correct); Desk Lamps 0, 3, 6, and 8 all share the same basic structure, with at least one component at the top of the stem and at least one component at the bottom of the stem. The best discriminated scrambling varied for Birds 1, 4, and 5. Bird 1 best discriminated Desk Lamp 3, which shared a similar structure with the original, in that two geons were grouped near the top of the stem and one component was placed at the bottom of the stem. Bird 4 did not have any other scramblings in the final cluster with the original. For Bird 5, Desk Lamp 8 (which had the base at the bottom of the stem, the shade near the top of the stem, and the fixture attached to the side of the stem) was clustered with the original desk lamp. Thus, in general, Birds 1, 2, 4, and 5 appeared to attend to two attributes of the images: (a) If the base contacted the stem but no other geons, accuracy was high; if the base contacted either the fixture or the shade, accuracy was low; and (b) the overall structure

Table 3

Accuracy scores (as percentage correct) produced by each bird to each of the nine versions of the desk lamp. DL-0 denotes the original training stimulus. DL-1, DL-2, DL-3, and DL-4 are the old desk lamp scramblings, and DL-5, DL-6, DL-7, and DL-8 are the new desk lamp scramblings. An ANOVA conducted on the nine versions of the desk lamp disclosed a significant effect of stimulus version, $F(8, 32) = 5.79$, $p < .001$. Post hoc tests indicated that Desk Lamps 1, 2, 4, and 7 produced significant generalization decrements relative to the original drawing (denoted by asterisks). All drawings but Desk Lamps 1 and 4 were discriminated above chance ($p < .01$).

Stimulus	Bird 1	Bird 2	Bird 3	Bird 4	Bird 5	*M*
DL-0	83.8	98.5	84.0	91.9	86.3	89.9
DL-1	40.0	5.0	15.0	70.0	15.0	29.0*
DL-2	50.0	5.0	60.0	50.0	10.0	35.0*
DL-3	80.0	15.0	50.0	85.0	45.0	55.0
DL-4	70.0	0.0	35.0	30.0	10.0	29.0*
DL-5	70.0	65.0	45.0	80.0	60.0	64.0
DL-6	70.0	5.0	75.0	75.0	70.0	59.0
DL-7	20.0	5.0	50.0	70.0	35.0	36.0*
DL-8	75.0	10.0	55.0	85.0	95.0	64.0
M	62.1	23.2	52.1	70.8	47.4	51.1

Table 4

Accuracy scores (as percentage correct) produced by each bird to each of the nine versions of the watering can. WC-0 denotes the original training stimulus. WC-1, WC-2, WC-3, and WC-4 are the old watering can scramblings, and WC-5, WC-6, WC-7, and WC-8 are the new watering can scramblings. An ANOVA conducted on the nine versions of the watering can revealed a significant main effect of stimulus version, $F(8, 32) = 2.95$, $p < .05$. Tukey follow-ups indicated that Watering Cans 2 and 3 produced significantly lower accuracy levels than the original (denoted by asterisks); all nine versions produced above-chance levels of responding ($p < .01$).

Stimulus	Bird 1	Bird 2	Bird 3	Bird 4	Bird 5	*M*
WC-0	83.7	99.0	88.1	78.3	88.5	87.5
WC-1	60.0	60.0	70.0	65.0	65.0	64.0
WC-2	65.0	55.0	40.0	35.0	40.0	47.0*
WC-3	75.0	70.0	35.0	45.0	10.0	47.0*
WC-4	90.0	90.0	70.0	65.0	5.0	64.0
WC-5	70.0	95.0	70.0	60.0	85.0	76.0
WC-6	80.0	40.0	75.0	45.0	60.0	60.0
WC-7	85.0	70.0	60.0	55.0	50.0	64.0
WC-8	80.0	85.0	25.0	55.0	25.0	54.0
M	76.5	73.8	59.2	55.9	47.6	62.6

of the desk lamp, which portrayed a component touching the top of the stem and a component touching the bottom of the stem. The behavior of Bird 3 was difficult to diagnose. One note regarding this bird: The best discriminated scrambling was Desk Lamp 6, which did share the same overall structure as the original.

Watering can. The cluster analyses for the watering can, displayed in Figure 4, yielded highly variable results (Table 4 provides the accuracy scores to the watering can scramblings). Two pigeons, Birds 3 and 4, appeared to attend to the relative position of the handle and can of the watering can. Bird 3 produced two main clusters. One cluster contained Watering Cans 2, 3, and 8, which all portrayed the handle below the can; all of these scramblings produced low levels of accuracy ($M = 33.3\%$ correct). The other cluster contained Watering Cans 0, 1, 4, 5, 6, and 7; all of these except Watering Can 6 portrayed the handle above the can (mean accuracy for these six scramblings = 72.2% correct). For Bird 4, Watering Cans 2, 3, and 6 separated off early in the analysis; these three scramblings produced low levels of accuracy ($M = 41.7\%$ correct), and all had the handle-can relation reversed. The original watering can appeared alone at the initial level of the analysis. Finally, a cluster containing Watering Cans 1, 4, 5, 7, and 8 was produced ($M = 60\%$ correct); all of these scramblings except Watering Can 8 displayed the handle above the can. Thus, for both Birds 3 and 4, there was evidence that the handle-can relation was important for stimulus recognition. The behavior of the other 3 birds was difficult to comprehend. It was true, however, that the best discriminated scramblings for each of these birds displayed the handle above the can: Bird 1 best discriminated Watering Cans 4 and 7, and Birds 2 and 5 best discriminated Watering Can 5.

Error analysis. One possible contributor to the wide range of accuracy scores to the different scramblings of an object is that some scramblings may have been spatially arranged in such a way that they appeared more like a different object than like the original version of the object. For example, perhaps Iron 1, which was recognized poorly by all 5 birds, looked to the pigeons more like a sailboat than like an iron. Thus, the errors made by each bird to each scrambling of an object were analyzed to determine whether the errors were distributed evenly across the three incorrect alternatives. An examination of the individual scramblings revealed that the distribution of errors across all eight scramblings of an object was not random in nature. However, the pattern of errors was similar for all scramblings of each object; thus, errors were not related to individual scramblings, but rather to the object itself.

Table 5 presents the mean percentage of errors made to the three incorrect alternatives for each object. The watering can attracted the most incorrect responses, whether the correct object was the iron, the desk lamp, or the sailboat. When the correct object was the watering can, the sailboat was responded to erroneously most often. These general trends were present in the error patterns of all 5 birds. Separate ANOVAs were conducted on the error scores for each object. Two ANOVAs and subsequent Tukey follow-up tests revealed significant results; errors to the sailboat scramblings were most often made to the watering can ($p < .01$) and errors to the watering can scramblings were most often made to the sailboat ($p < .01$). The most obvious attribute that these two objects share is their height:width ratio (watering can = 5.3

Table 5

The mean percentage of errors to the three incorrect alternatives for each object. The percentages are the average of all errors made to the individual scramblings by the 5 birds. The error distributions are presented in a matrix, with each object in a different row. The percentages in each row add to 100%. The total number of errors made to each object are presented in the right column. Empty cells signify the correct alternatives.

	Percentage of errors				
Object	Watering can	Iron	Desk lamp	Sailboat	Total errors
Watering can		15.3	23.7	61.0	322
Iron	56.7		19.1	24.2	185
Desk lamp	52.3	23.9		23.8	431
Sailboat	64.4	20.2	15.4		350

cm by 5.7 cm; iron = 2.2 cm by 5.7 cm; desk lamp = 5.7 cm by 2.9 cm; sailboat = 4.7 cm by 5.7 cm). The watering can and sailboat are almost as tall as they are wide, the iron is much wider than it is tall, and the desk lamp is much taller than it is wide.

Concordance analyses. The accuracy scores produced by each bird to all nine versions of each object were ranked; these ranks relate positively to accuracy. Analyses of concordance (Kendall's W) on these ranks disclosed that there was significant agreement among the 5 birds in their rankings of the nine versions of the sailboat ($W = .77$, $p < .001$), the iron ($W = .68$, $p < .001$), the desk lamp ($W = .69$, $p < .001$), and the watering can ($W = .46$, $p < .05$). The lower concordance to the watering can was not surprising, because it was the only stimulus for which the birds produced highly different cluster trees.

DISCUSSION

This project with new experimental pigeons replicated the two main results reported by Wasserman et al. (1993). First, the scrambled drawings led to reliable overall decrements in recognition accuracy relative to the original drawings. Second, although they were lower than those to the original drawings, the mean accuracy scores to both the old and the new scrambled drawings were reliably above chance. These results further support the conclusion that pigeons are sensitive both to the components of the drawings and to their spatial organization (also see Steele, 1990; Watanabe & Ito, 1991). From this perspective, the pigeons' discrimination of a stimulus can be modeled by a structural description that specifies the object's geons as well as the relations among those geons (Biederman, 1987).

We also replicated our previously unreported finding that the pigeons discriminated the different scramblings of each object at very different levels. The cluster analyses revealed features of the scramblings that were related to generalization performance in 14 of the 20 cases. For the sailboat, the location of the hull was important for 2 subjects (Birds 1 and 4), the interrelation of the two sails was critical for another subject (Bird 3), and either movement of the hull or disruptions of the interrelations of the sails caused decrements in accuracy for 2 other subjects (Birds 2 and 5). The behavior of 3 subjects was primarily controlled by the handle-base relation of the iron (Birds 2, 3, and 5). Four subjects (Birds 1, 2, 4, and 5) were sensitive to both the overall structure of the desk lamp and the position of the base relative to the fixture and the shade. Finally, 2 subjects (Birds 3 and 4) attended to the handle-base relation of the watering can. Thus, for the cluster trees that were readily interpreted, it appears that the pigeons primarily attended either to the position of one geon relative to an object's other geons or to the interrelation of two geons. Moreover, in the case of the desk lamp, 4 birds attended to the overall structure of the object (a stem with geons affixed to the top and bottom).

It is not entirely surprising that the pigeons produced somewhat different cluster trees. For example, in a classic study on attention in the pigeon, Reynolds (1961) found idiosyncratic stimulus control by properties of visual stimuli. He trained 2 birds to respond to a white triangle on a red background and to withhold responding to a white circle on a green background. Because the discriminative stimuli were compounds comprising both shape and color elements, the pigeons could have attended to either or both of these visual attributes while forming the original discrimination. The critical test, in which the elements constituting the compound stimuli were uncoupled (resulting in the singular presentation of red, green, triangle, and circle), revealed that 1 pigeon had selectively attended to the color of the background and that the other pigeon had selectively attended to the shape of the white form.

Although the cluster trees were different for different birds, the analysis of concordance revealed that the pigeons ranked the different scramblings of an object similarly, indicating that the pigeons agreed as to which were good and bad facsimiles of the original object. The error analysis failed to elucidate any additional factors that may have contributed to the pigeons' incorrect responses to individual scramblings of an object. The pigeons appeared to be more likely to confuse objects (particularly the sailboat and watering can) than individual scramblings. The most likely reason for the confusion of the sailboat and watering can is that the two stimuli share a similar height:width ratio, a ratio that was quite different for the iron and the desk lamp.

As Skinner (1935) noted six decades ago, "When a defining property [of a stimulus] has been decided upon, the stimuli that elicit responses possessing it are discovered by exploration. Subsequently the defining property of the stimulus is inferred from the part common to the different stimuli that are thus found to be effective" (pp. 48–49). The present research pursued Skinner's plan for defining the controlling properties of complex line drawings. The pigeons' concordant discrimination performance plus the promising results of the cluster analyses clearly justify further experimental study of the stimulus control of picture perception.

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