

*CATEGORY DISCRIMINATION BY PIGEONS USING
FIVE POLYMORPHOUS FEATURES*

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Eight pigeons were trained to discriminate between sets of color photographs of natural scenes. The scenes differed along five two-valued dimensions (site, weather, camera distance, camera orientation, and camera height), and all combinations of the feature values were used. One value of each dimension was designated as positive, and slides containing three or more positive feature values were members of the positive stimulus set. Thus, each feature had an equal, low, correlation with reinforcement, and all features had zero correlations with each other. Seven of the 8 pigeons learned this discrimination, and their responding came under the control of all five features. Within the positive and negative stimulus sets, response rates were higher to stimuli that contained more positive feature values. Once discrimination had been achieved, reversal training was given using a subset of the slides. In this subset, only a single feature was correlated with reinforcement. All pigeons learned this reversal successfully and generalized it to additional photographs with the same feature content. After reversal, the original reinforcement contingencies were reinstated, and training was continued using all the slides except those that had been used in reversal. Reversal generalized to these slides to some extent. Analysis of the response rates to individual slides showed that, compared with prereversal training, only the feature that had been subjected to reversal contingencies showed a reversed correlation with response rate. The remaining features showed the same correlation with response rate as they had before reversal training. Thus, reversal on some members of a category following category discrimination training led to generalization to stimuli within the category that were not involved in the reversal, but not to features that were not reversed. It is therefore inappropriate to refer to the pigeons as learning a concept.

Key words: concept discrimination, discrimination reversal, feature analysis, equivalence class, polymorphous concepts, photographs, key peck, pigeons

Pigeons are well known to be able to discriminate between visual stimuli on the basis of their membership of natural categories. Following the original report of discrimination of color slides of people (Herrnstein & Loveland, 1964), a large number of other categories have been investigated. However, less progress has been made in discovering the mechanism un-

derlying such discrimination. Although the discriminations can usefully be termed "concept discriminations" or "natural category discriminations," it is important not to overinterpret the words "concept" or "category." There is little or no evidence that pigeons learn such discriminations by forming a concept corresponding to the experimenter's, or indeed by forming any concept at all (Lea, 1984). Much simpler mechanisms may be able to account for the observed performance.

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The mechanism of natural category discrimination is problematic because no single perceptual feature is likely to be a necessary or sufficient condition for category membership (Herrnstein, 1985); natural categories are "polymorphous concepts" (cf. Ryle, 1951). The obvious mechanism to cope with this difficulty is multiple feature analysis, which at the behavioral level involves responding coming under the control of a number of more or less independent features, each of which is weakly correlated with category membership (Lea & Ryan, 1983). If a multiple feature model de-

scribes the data adequately, it would be superfluous to describe pigeons as forming or possessing concepts.

There are two straightforward ways of testing the multiple feature theory, the analytic approach and the synthetic approach. The analytic approach involves taking the response rates of birds who are performing concept discriminations and trying to identify features of the stimuli that are correlated with responding. Informal versions of this approach have been used by many experimenters in avian concept discrimination, and more formal analyses have been carried out by, for example, Lubow (1974), Morgan, Fitch, Holman, and Lea (1976), and Lea and Ryan (1983). These experiments suggest that between three and six features are probably involved in successful discrimination of natural categories. A fundamental problem with such analyses, however, is their correlational nature: Even if we can predict response rates exactly from a feature model, we can never be sure that the features we identify are the ones the birds are responding to; instead they may be responding to some linearly equivalent set.

The alternative, synthetic, approach involves constructing artificial polymorphous concepts, defined by a number of independent features, none of which is necessary or sufficient for category membership. If feature analysis is an adequate description of pigeon concept discrimination, such artificial concepts should be discriminated very easily. Lea and Harrison (1978) showed that pigeons could learn to discriminate categories when possession of any combination of two out of three positive features made a stimulus positive. But we have had difficulty in extending this result to higher numbers of relevant features. Lea and Ryan (1990) report briefly on an experiment in which the stimuli to be discriminated were stylized drawings of pigeons, differing on five stimulus dimensions; of 4 birds trained, none came under the control of more than one feature. In unpublished work, Lea, Ryan, and Lohmann (1989) used drawings of seed-like stimuli, which also differed along five dimensions. A total of 12 pigeons were trained, but none of them came under the control of all five features, although most discriminated three or four of them.

One possible reason for this difficulty is that experiments on artificial concepts have generally used artificial, geometric stimuli, whereas

the impressive demonstrations of pigeons' categorization abilities have mainly used photographs of natural objects. It is unknown what difference this will make. On the one hand, artificial stimuli lack the richness of detail, and the variety, of photographs of natural scenes. On the other hand, when natural photographs are used, even the features are potentially polymorphous. For example, one of the features used in the present experiment was the site at which the photograph was taken. Honig and Stewart (1988) have shown that pigeons can discriminate slides on the basis of this cue, but it is very unlikely that there are necessary or sufficient cues to identify a scene as coming from one site rather than another.

We report here an experiment that set pigeons to discriminate artificial categories, defined in terms of five independent features, using photographs of natural objects as stimuli. If this discrimination is successfully learned, and responding comes under the control of all five features, we can conclude that the detail and variety of natural photographs are important for category discrimination. If it is not learned, we would have to conclude that discriminations involving large numbers of features are, in general, indeed very difficult for pigeons, as Lea and Ryan (1990) suggested.

Artificial polymorphous concepts using large numbers of features are not only interesting as simulations of more natural concepts. If artificial concept discriminations can be successfully trained, some further questions about the mechanism of concept discrimination are opened to experimental investigation. Suppose a bird discriminates between two sets or categories of stimuli. In what sense are the members of the set connected? Do they simply attract the same response in this one situation, or have they become in some sense a single stimulus? Lea (1984) argued that only if the members of a stimulus set subsequently attract the same response in other situations should we say that the set constitutes a *concept* for the pigeon. In this case, the multiple feature model is, of course, an inadequate description of behavior. The issue here is very similar to the question about whether a group of stimuli constitutes an equivalence class. This question has been the focus of much experimental work with human participants, especially those classified as mentally retarded, starting with the work of Sidman (1971) and recently reviewed by Fields and Verhave (1987).

There is little evidence that animals other than humans can form such equivalence classes. The strongest support for the notion that they can is an experiment by Vaughan (1988) in which pigeons were trained using two randomly selected sets of pictures of trees (a *random pseudoconcept* in the terminology of Lea & Ryan, 1990). Following successful discrimination, the reinforcement contingencies associated with the two stimulus sets were reversed, and a further reversal was then given every four to seven sessions until the contingencies had been reversed 159 times. By the end of the experiment, all 6 of Vaughan's birds were showing substantially reversed discrimination well within the first postreversal cycle through the 40 slides used: The number of slides required to produce a general reversal of behavior ranged from 2 to 16.

Vaughan (1988) argues that his data provide good evidence for equivalence class formation. But he notes that the precise behavioral process involved is not evident. In particular, because we do not know what features were controlling behavior at different stages of Vaughan's experiment, we do not know whether the rapid reversal is mediated by discriminative features that are found in the first stimuli for which the reversed contingencies are encountered and also in subsequent stimuli or whether there is a generalized reversal to all the stimuli, regardless of feature content. Furthermore, Vaughan's experiment involved large numbers of reversals, and generalized reversal emerged only gradually: In an experiment testing transfer after a more typical concept discrimination procedure, Bhatt and Wasserman (1989) found no evidence of concept formation when the criterion suggested by Lea (1984) was used.

The present experiment explored the effects of reversal of category discrimination training in more detail. A partial reversal design was used. If the feature content of stimulus categories is known, it is possible to give selective reversal training on one or a few features. By giving reversal training on just a few members of the stimulus sets, the subjects can be exposed to reversed reinforcement contingencies on one feature while the contingencies applied to the other features are either left unchanged or, in effect, suspended, so that there is zero correlation between the remaining features and reinforcement.

In the present experiment, the pigeons were

given this kind of selective reversal training and were then exposed to the remaining members of the original categories in a test of generalization of reversal. The transfer stimuli included some that had the same feature content as the reversed stimuli and others of completely different feature content. There are three possible outcomes to these generalization tests, and they lead to three different conclusions about the mechanisms of concept discrimination:

1. If reversal does not generalize at all, this implies that the pigeons had learned to respond to individual stimuli without making use of their feature content.

2. If reversal generalizes only insofar as stimuli contain the features subjected to reversal training, this suggests that pigeons had extracted features from the stimulus categories but had not formed equivalence classes.

3. But if reversal generalizes to stimuli regardless of their feature content, this suggests that the pigeons had indeed formed equivalence classes or concepts.

METHOD

Subjects

Eight experimentally naive pigeons, of retired racing stock, were used in the experiment. They were mildly deprived of food, being kept at 90% of their free-feeding weights, and were maintained on a 10:14-hr light/dark cycle with half-hour simulated dawn and dusk periods. During the dark cycle and part of the light cycle they were housed in an indoor aviary; for 1 or 2 hr before and after the daily test session they were held in individual cages.

Apparatus

Two identical one-key operant chambers were employed. Each measured 69 by 49 by 39 cm (internal dimensions) and consisted of a plywood box whose front wall was a 69- by 39-cm aluminum intelligence panel. The general arrangement of the apparatus was the same as that used by Ryan and Lea (1990) and is shown in Figure 1. Color slides were back-projected from a Kodak® S-RA2000 random access projector equipped with a 70 to 120 mm zoom lens onto a 61- by 42-cm screen. The screen stood 60 cm in front of the experimental chamber. The pigeons could view this screen through the response key (6.5 by

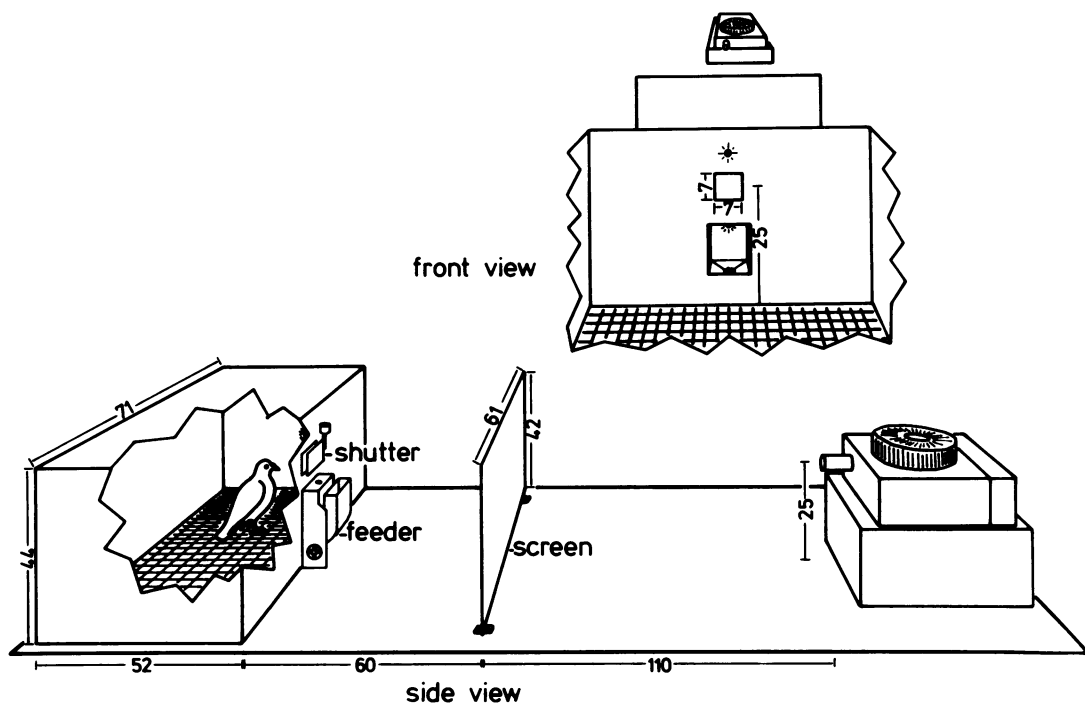


Fig. 1. General arrangement of the experimental apparatus, approximately to scale. Note that the screen between the slide projector and the operant chamber was translucent, and the pecking key was transparent. Thus, the pigeon looked through the key at the image projected on the screen. The inset shows the front view of the intelligence panel.

6.5 cm), which was made of transparent perspex and positioned 26 cm above the floor on the front wall of the operant chamber. A shutter, operated by a rotary solenoid, could be used to prevent the bird from viewing the screen. In addition to the response key, the panel carried a 7- by 7.5-cm aperture that gave access to a solenoid-operated food hopper containing a mixture of food grains. The availability of food was signaled by a white light in the hopper aperture, which was operated when the hopper was presented. The food aperture was positioned 15 cm below the pecking key. A 3.5-W yellow-lensed houselight, 12 cm above the key, gave general illumination. Masking noise was provided by a ventilation fan and through a 35-ohm loudspeaker mounted on the back of the intelligence panel. Both chambers, and their projectors and screens, were housed in a single darkened room. Experimental events were controlled and recorded by an Apple II® microcomputer, using programs written in UCSD Pascal. The computer and its electromechanical interfaces to the operant chambers and projectors were positioned outside the testing room. A videocam-

era could be placed outside either of the chambers, providing a view to the interior via a 10- by 10-cm hole in the rear wall (or, for one chamber, in the roof directly above the key). The camera was fitted with a wide-angle lens and was used for regular observation of the pigeons' behavior in the chamber via a monitor outside the testing room.

Stimulus Materials

About 300 color transparencies of two buildings in Exeter were taken with a Nikon F3® camera. One building was a part of the administrative block of the University of Exeter (Northcote House); the other was a pub in the center of the city (the Crown and Sceptre). Two stimulus sets were selected from these photographs so as to contain all combinations of five two-valued features. Figure 2 shows black and white tracings of two of the slides used, containing opposite values of all five features. The features were chosen to be of obvious importance to a free-flying pigeon, so that the bird's visual system was likely to be able to process the information needed to discriminate them. The features were as follows,

with the values used in parentheses (the value shown in Figure 2a is given first in each case):

1. The *site* at which the photograph was taken (Crown and Sceptre or Northcote House).

2. *Weather* conditions when the photograph was taken (sunny or cloudy).

3. Apparent *distance* of the building from the picture (near or far). This was manipulated by using a 50 mm/1.4 Nikon lens for near views and a wider angle lens (28 mm/3.5 Nikon) for far views; the camera distance was unchanged.

4. The *orientation* of the building in the picture (horizontal or oblique). Half the photographs were taken with the camera held normally (horizontally); the remainder were taken with the camera at a substantial angle (30° to 50° approximately).

5. The camera *height* from which the photographs were taken (aerial or ground). The two buildings used were selected because both could conveniently be photographed from ground level (with the camera at about the height of a pigeon's eye when the bird is standing on the ground) and also from approximately 20 m higher, above roof level for each building, with less than 3 m difference in horizontal distance.

In all, 32 feature-value combinations are possible. Two photographs were selected for each combination. These were always slightly different from each other (for instance, the clouds might vary in position, there might be different parked cars or passers-by in view, or the camera position might vary slightly). Thus, 64 slides were selected in total. For each bird, one value of each feature was defined as positive, and stimuli containing three or more positive feature values were positive. This rule divides the 64 stimuli into two artificial polymorphous categories (cf. Lea & Ryan, 1990) of equal size. In such categories, each feature is correlated with reward, but none of them is a perfectly reliable cue. In the present categories, the features themselves are naturalistic and, therefore, also potentially polymorphous.

For Birds 15, 19, 20, and 21, the feature values Crown and Sceptre, sunny, near, horizontal, and aerial were defined as positive, and stimuli containing three or more of these features were positive. For Birds 16, 17, 22, and 23, the feature values Northcote House, cloudy, distant, oblique, and ground were defined as positive. Table 1 shows the feature-

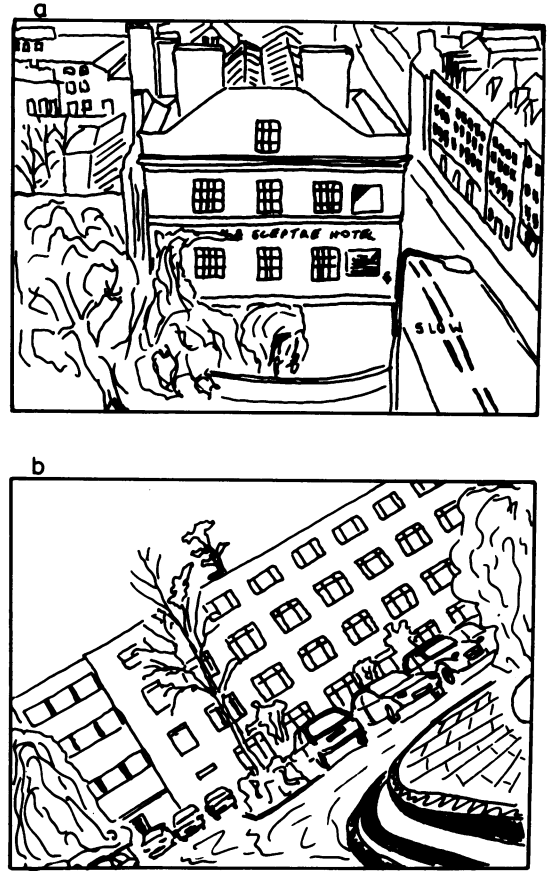


Fig. 2. Outline tracings of two of the slides used as stimuli. The two pictures contain opposite values for all five features. Figure 2a contains the feature values that were positive for Birds 15, 19, 20, and 21; it shows the Crown and Sceptre photographed on a sunny day, in a near, horizontal, aerial view. Figure 2b contains the feature values that were positive for Birds 16, 17, 22, and 23; it shows Northcote House on a cloudy day in a distant, oblique, ground view. Note that the weather feature (cloudy or sunny) is not well represented in this monochrome drawing.

value combinations that fell into the positive and negative categories for the first group of birds. Note that the stimuli within the categories differ: There is one feature combination that is a "perfect" exemplar, having all five positive feature values, five "good" exemplars, having four of five positive feature values, and the remaining 10 exemplars are "poor," having the minimum of three positive feature values. The negative category can be divided in exactly the same way.

For most of the experiment, the full set of 64 slides was used. However, for some phases,

Table 1

Symbolic representation of the feature combinations for the entire stimulus set and for a single-feature subset. Stimuli described as "positive" and "negative" were positive and negative for Birds 15, 19, 20 and 21; for the remaining birds, the opposite reinforcement contingencies were used. The perfect positive and negative exemplars are the stimuli represented in Figure 2. The feature-values are represented as follows: site: p = Crown and Sceptre (pub), u = Northcote House (university); weather: s = sunny, c = cloudy; distance: n = near, f = far; orientation: h = horizontal, o = oblique; height: a = aerial, g = ground. Feature combinations belonging to the single-feature subset based on the height feature are shown in **bold type**.

Type of exemplar	Feature combinations				
Perfect positive			psnha		
Good positive	psnhg	psnoa	psfha	pcnha	usnha
Poor positive	psnog	psfhg	psfoa	pcnhg	pcnoa
	pcfha	usnhg	usnoa	pcfha	ucnha
Poor negative	usnog	pcfoa	pcfhg	pcnog	psfог
	ucfha	ucnoa	ucnhg	usfoa	usfhg
Good negative	ucfoa	ucfhg	ucnog	usfog	pcfog
Perfect negative			ucfog		

subsets were used within which a single feature could function as a necessary and sufficient cue to discrimination. These are referred to as *single-feature subsets*. As an example, the single-feature subset based on the height feature is illustrated in Table 1. This subset includes all the stimuli in which two of the remaining four features took their positive values and the other two took their negative values. So, for example, if height was the critical feature, for Bird 15 the subset would include the positive slide showing the Crown and Sceptre in a sunny, distant, oblique, aerial view. Notice that within this subset, category membership is completely determined by the height feature, and all other features have zero correlation with category. There is a different single-feature subset corresponding to each feature. Each such subset includes 12 feature combinations and, hence, 24 slides, because there were two instances of each feature combination.

Procedure

The pigeons were first trained by standard procedures to find food in the hopper and to peck the key when the shutter was opened and the screen was transilluminated with white light from the projector. There were no slides in the projector at this stage. The schedule of reinforcement used was gradually extended to a fixed interval of 30 s, with a 10-s timeout after each food reinforcement during which the shutter was closed and the projector moved to a new position, chosen at random. Reinforcement normally consisted of a 5-s hopper op-

eration, but this period was reduced to 4 s for 1 bird that gained weight excessively.

Once key pecking was established, the birds were exposed to the following successive discrimination procedure. Sessions were divided into a number of trials (between 64 and 80 depending on the condition). Each trial began with a 10-s period during which the shutter was closed and a slide was selected. The shutter then opened, and the slide was projected for 30 s. If the slide was defined as positive, the slide then remained on until the next peck, when the pigeon was rewarded with food. If the slide was negative, the shutter closed at once and the houselight was turned off. This blackout period lasted as long as the food hopper operation given on positive trials.

If slides were used more than once in a session, a complete cycle through all the slides in use was completed before any slide was shown again. A new pseudorandom sequence was generated for every cycle through the slides. All sequences were subject to the constraint that no more than three positive or three negative stimuli were used in succession.

In the first phase of training, all 64 slides were used, once each in each session. In this and some subsequent phases, training continued until performance reached a criterion designed to ensure that the birds' behavior was under the control of all five features, as follows. After each session, response rates to the 64 stimuli for each bird were subjected to a five-factor analysis of variance, in which the factors were the five features. If, within a block of 10

Table 2

Numbers of sessions given to each bird in each condition, features used in single-feature training sessions where necessary, and features used in reversal training.

Bird	Initial training (sessions)	Single-feature (features, sessions)	Post single-feature (sessions)	Reversal feature 5+10 sessions	Postreversal retraining (sessions)
15	42			height	11
19	30	distance 13			
		orientation 17	10	site	14
20	30	orientation 16	20	site	10
21	30	orientation 39			
		site 6			
		distance 7	10	site	44 ^a
16	42			distance	13
17	30	distance 40 ^a			
22	45			height	12
23	20			distance	14

^a Training abandoned because no progress was being made.

consecutive sessions, the main effect of each feature was significant for at least six sessions, then the criterion was reached.

After 30 sessions, mean response rates from the previous 10 sessions (i.e., Sessions 21 to 30) were calculated and subjected to a five-factor analysis of variance using the features as factors. Birds that showed a significant effect of every feature on response rate continued in normal training until they reached the original six sessions out of 10 criterion (which is more stringent). Birds that did not show significant effects of every feature on mean response rate were given single-feature training, as follows. The five features were ranked according to the number of sessions out of the previous 10 in which a significant main effect had been found. The highest ranking feature that had *not* reached the criterion of six significant sessions was selected. The birds were then given training sessions using the single feature subset of slides corresponding to this feature. Training was continued until the main effect of the selected feature was significant for at least six sessions within a block of 10 consecutive sessions. If more than one feature had failed to reach the six of 10 criterion in initial training, the single-feature training procedure was repeated for the next best feature, and so on until criterion had been reached for all features. The birds were then given further sessions of the original training procedure until they met the original criterion of six sessions with significant discrimination on each feature within a block of 10 consecutive sessions. Table 2 in-

cludes details of the single-feature training given to the 4 birds that required it.

Once criterion had been reached, with or without intervening single-feature training, the birds proceeded to reversal training, as follows. The feature that had most strongly influenced behavior in the last 10 sessions of training was selected (assessing strength of influence by the difference of mean response rates between slides containing the positive value of the feature and those containing the negative value). The birds were trained using the single-feature subset of slides corresponding to this feature, but with reinforcement contingencies reversed. For the first 10 sessions, one of the two slides in each of the 12 feature combinations within that subset was chosen at random, and the birds were trained using only these 12 slides. Each session consisted of 72 trials (i.e., there were six cycles through the 12 slides). Following this, the other slides of the same feature combinations were introduced, and the pigeons were given five sessions consisting of three cycles through these 24 slides, still with the contingencies of reinforcement reversed from what they had been in training.

Following reversal, a transfer test was carried out using only the 40 slides not used during reversal training. Reinforcement contingencies were as in original training. Ten sessions were given, each consisting of two cycles through the 40 slides (80 trials in all). Finally, the entire set of stimuli was reintroduced, and initial training contingencies were reestablished and continued until the bird again

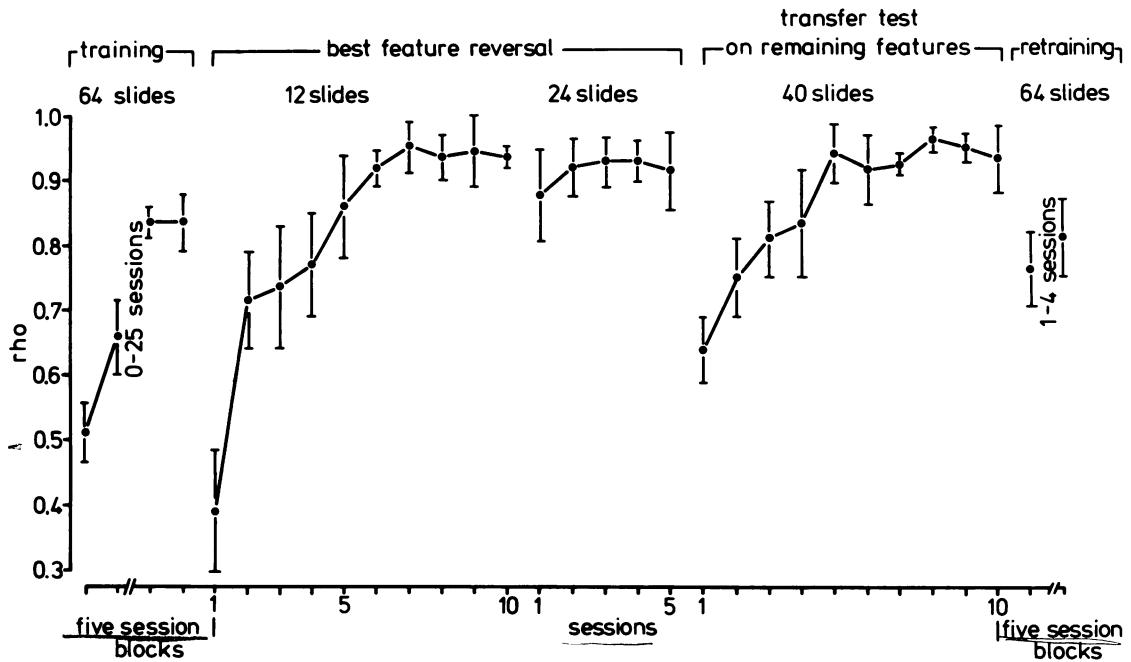


Fig. 3. Performance in all phases of the experiment by the 4 birds that reached the criterion in initial training without single-feature training (Birds 15, 16, 22, and 23). The vertical axis is the rho statistic of Herrnstein et al. (1976); high values of rho indicate good discrimination, values below .5 indicate reverse discrimination. All data points show means of rho values for the 4 birds, with tie bars showing ranges. Data are reported as means over five-session blocks for initial training and final retraining, and for single sessions during reversal and postreversal transfer tests. Birds 15 and 22 were given reversal training on the height feature, Birds 16 and 23 on the distance feature.

met the criterion of six out of 10 sessions with a significant main effect of each feature. In the case of Bird 21, this criterion was not met within 44 sessions and training was abandoned.

Sessions were normally given one per day, 6 days per week. The numbers of sessions given to each bird in each phase are listed in Table 2.

RESULTS AND DISCUSSION

Initial Training

The left-hand sections of Figures 3 and 4 show performances during initial training of all birds except Bird 17. Discriminative performance is measured by the Herrnstein, Loveland, and Cable (1976) rho statistic, which measures the overlap between stimulus sets in mean response rate; a value of .5 indicates random responding, and a value of 1.0 indicates that all positive stimuli elicit a higher response rate than any negative stimulus.

Four of the birds reached the criterion of five-feature discrimination without single-feature training (range, 20 to 45 sessions includ-

ing the 10 sessions of criterial performance; fuller details in Table 1). Data from these birds are summarized in Figure 3. The remaining 4 birds required single-feature training on from one to three features. All except Bird 17 successfully completed this; Bird 17 discriminated only the height feature consistently, and this bird was dropped from the experiment after 40 sessions of single-feature training on his next best feature, distance. Figure 4 summarizes the data from the 3 birds for which single-feature training was successful.

Feature Analysis

Figure 5 shows the effects of the five features at the end of initial training. The figure shows the difference in mean response rate between stimuli containing positive and negative feature values for each feature, so the more positive the value for a feature, the more strongly that feature controlled differential responding. For example, for Bird 15 the mean response rate to slides containing the positive value of the height feature, for this bird the aerial view,

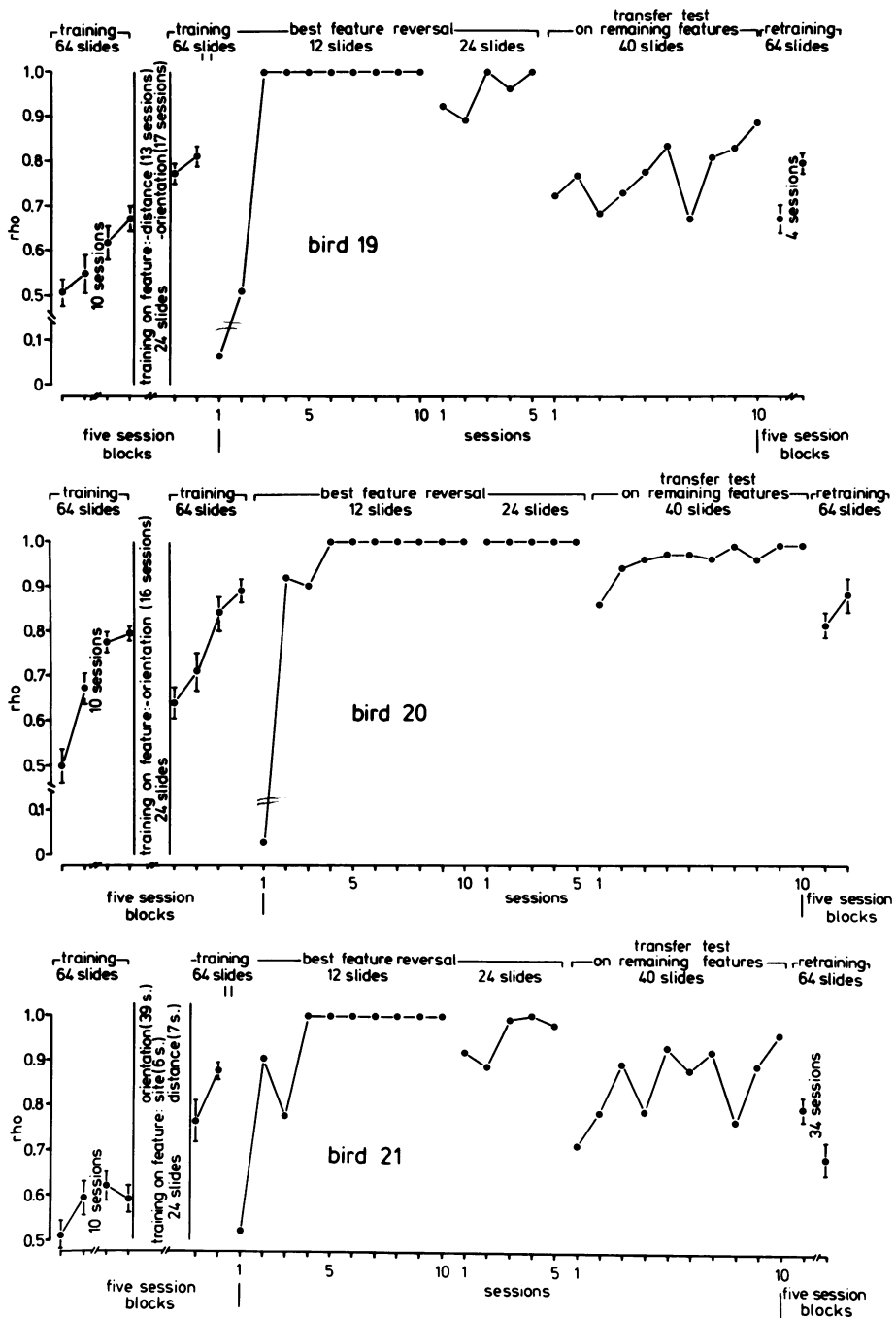


Fig. 4. Performance in all phases of the experiment except single-feature training by the 3 birds that required single-feature training and completed it successfully. All 3 of these birds were given reversal training on the site feature. Other details as in Figure 3.

was approximately 22.5 pecks per trial more than the mean response rate to slides containing the negative value of the feature, for this bird the ground view. The data are based on

mean response rates for the last five sessions of training. For Bird 17, which never used all five features, data are based on the five sessions before the start of single-stimulus training.

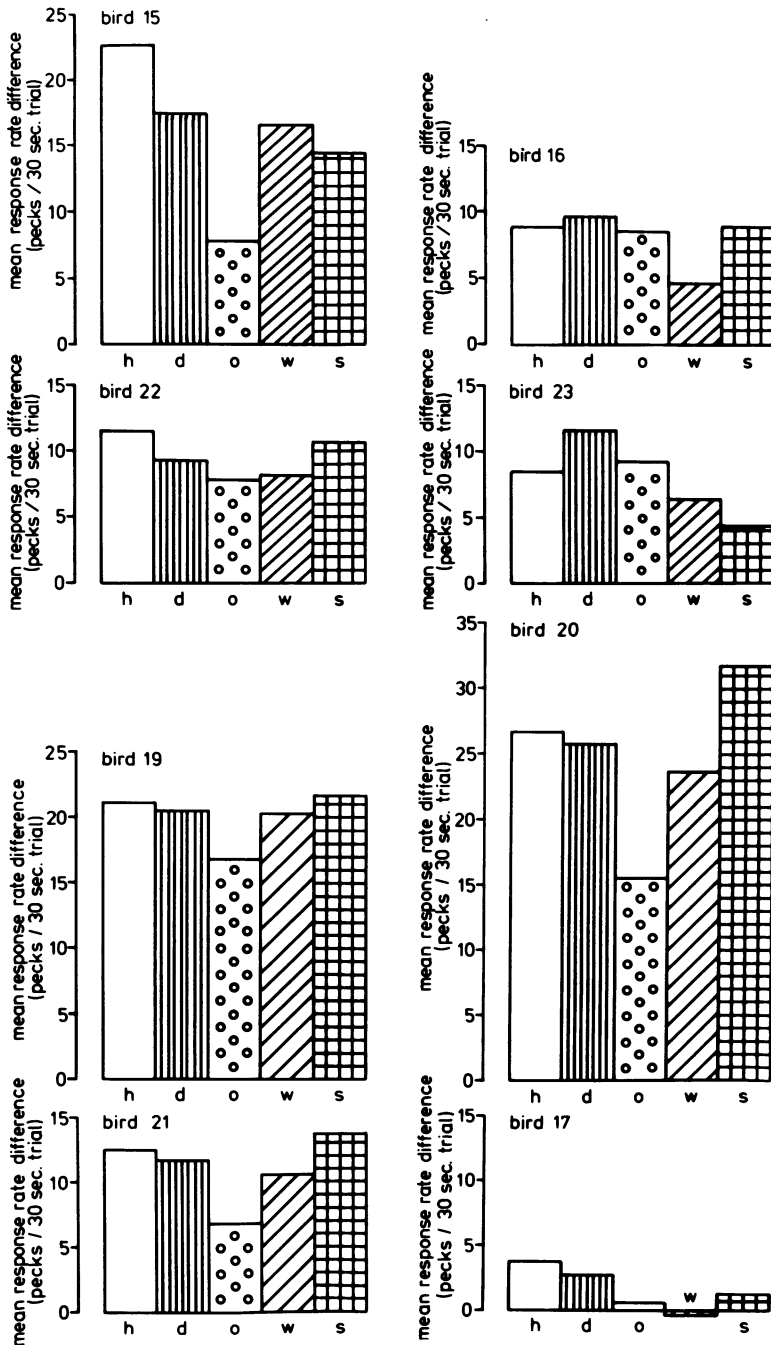


Fig. 5. Relative control over behavior by the five features in the five-session block immediately before reversal training. The vertical axis is the mean response rate to slides containing the positive value of the feature minus the mean response rate to slides containing its negative value. The letters on the horizontal axis indicate the features, as follows: h, height; d, distance; o, orientation; w, weather; and s, site.

In any concept discrimination in which the same slides are used repeatedly, it is possible for the subjects to learn how to respond to each individual slide without making any use of the

features as such. One way of testing whether such "rote learning" is occurring is to consider the variation of response rates between stimuli within the positive (or the negative) stimulus

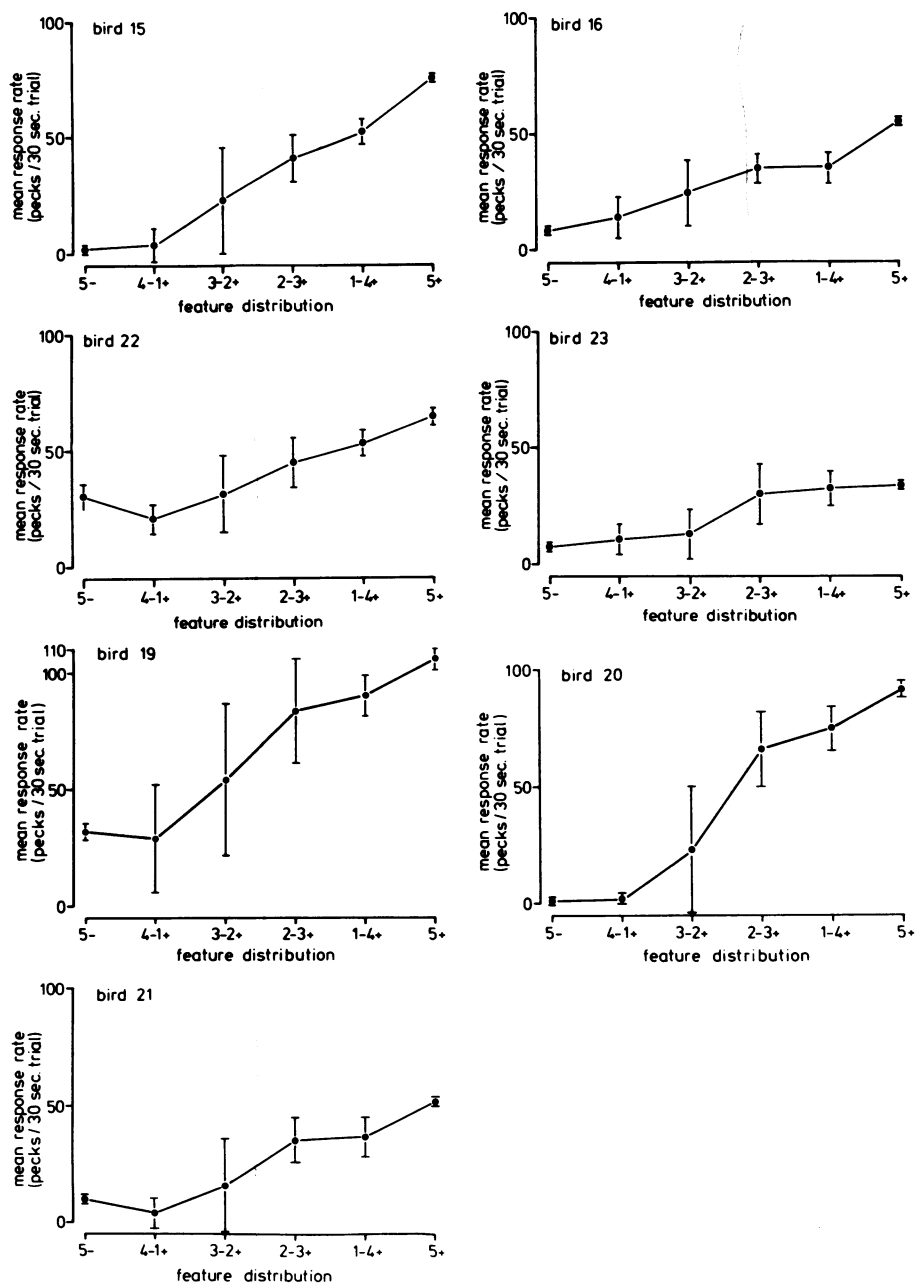


Fig. 6. Response rate as a function of distribution of positive and negative feature values contained in a slide. The x axis shows the numbers of negative and positive feature values contained in a slide (e.g., 3-2+ means three negative and two positive feature values). Slides with three or more positive feature values were positive stimuli. Data are means from the last five sessions before reversal training. Points show means for all slides with the corresponding numbers of positive feature values; tie bars show ranges across slides.

set (cf. Vaughan & Herrnstein, 1987). Within the positive set, some slides contain more positive features than others: If these slides systematically attract higher response rates, responding must be under the control of features

and not just of individual slides. In Figure 6, asymptotic mean response rates to stimuli are plotted against the number of features taking their positive value in the stimulus. It can be seen that stimuli with three or more positive-

valued features generally control higher response rates than stimuli with two or fewer; that simply restates the fact that the birds did discriminate the stimulus sets successfully. But it can also be seen that, within the positive and negative sets, the stimuli with more positive-valued features controlled higher response rates. This effect was statistically significant: Kendall's coefficient of concordance among the 7 birds as to the ordering of the three kinds of stimuli was .76 for the negative stimuli and 1.00 for the positive stimuli ($p < .01$ in each case). Thus, we can reject the hypothesis that the birds had simply learned how to respond to each of the 64 stimuli independently. Behavior was influenced by the feature content of the slides, despite the ill-defined nature of the features involved.

To summarize our conclusions so far: The results of the initial phase of training, and the largely successful outcome of the single-feature training given to the birds that did not reach criterion, show that birds can discriminate artificial polymorphous concepts requiring as many as five features to control behavior simultaneously. Four birds did so spontaneously, and 3 of the remainder were trained to do so without much difficulty. Figure 5 shows that a reasonably even pattern of feature use was achieved, and in particular, there was no one feature that was quickest (or slowest) to gain control over behavior for all birds. Figure 6 confirms that the birds were responding to features and not just to individual stimuli.

Reversal Training and Postreversal Tests

The features used in reversal training for each bird are included in Table 2. For example, for Bird 15, the best discriminated feature was height (see Figure 5). So for that bird, the positive value of height (aerial) was made negative and ground was made positive, and the stimuli used in reversal training were those in which two of the remaining four features (site, weather, orientation, and distance) were positive and two were negative. The results of this stage of training are included in Figures 3 and 4. Within 10 sessions, all 7 birds learned the reversal well, using the original selection of one copy of each of the possible six positive and six negative feature combinations. Adding the second copy in the succeeding five sessions led to no detectable loss of discrimination, so the reversal apparently generalized

completely to stimuli of similar feature content.

In the first session of postreversal generalization testing, during which all the stimuli except those used in reversal training were in use with the original reinforcement contingencies in force, there was considerable evidence that reversal had generalized. Figures 3 and 4 show that the rho values in the sessions immediately after the end of reversal were markedly lower than in the sessions immediately before reversal. To make a more precise comparison between pre- and postreversal performance, we extracted the data from the last exposure to the 40 nonreversed slides during the session immediately before reversal (this session also included the subsequently reversed slides) and the first exposure to the same slides during the first session after reversal (this session also included a second exposure to each slide). Rho values were calculated across these two 40-trial sets for each bird. The mean value of rho during the first postreversal exposure was .39 (range, .14 to .68), compared to .83 (range, .70 to 1.00) during the last prereversal exposure. All 7 birds showed a reduction in rho in postreversal compared with prereversal testing ($p < .02$, two-tailed binomial test).

The above analysis shows that reversal training did transfer to nonreversed feature combinations. However, Figure 7, which reports the control over behavior exerted by each of the five features in the first postreversal session, shows that the generalization of reversal was almost entirely due to the effects of the one feature involved in reversal training. Figure 7 should be compared with Figure 5, which shows the asymptotic feature effects before reversal. The conclusion is clear. The effects of reversal training on the features to which it was applied continue; all 7 birds showed less responding to stimuli containing the originally positive value of this feature than to stimuli containing the value of it which was positive during reversal training. But there is no systematic reversal to other features.

Results from the final phase of the experiment, when the original contingencies were fully restored using all 64 slides, are included in Figures 3 and 4. Category discrimination was impaired to some extent, but within 10 to 14 sessions discrimination performance recovered and again reached the original criterion of six sessions' significant discrimination of each

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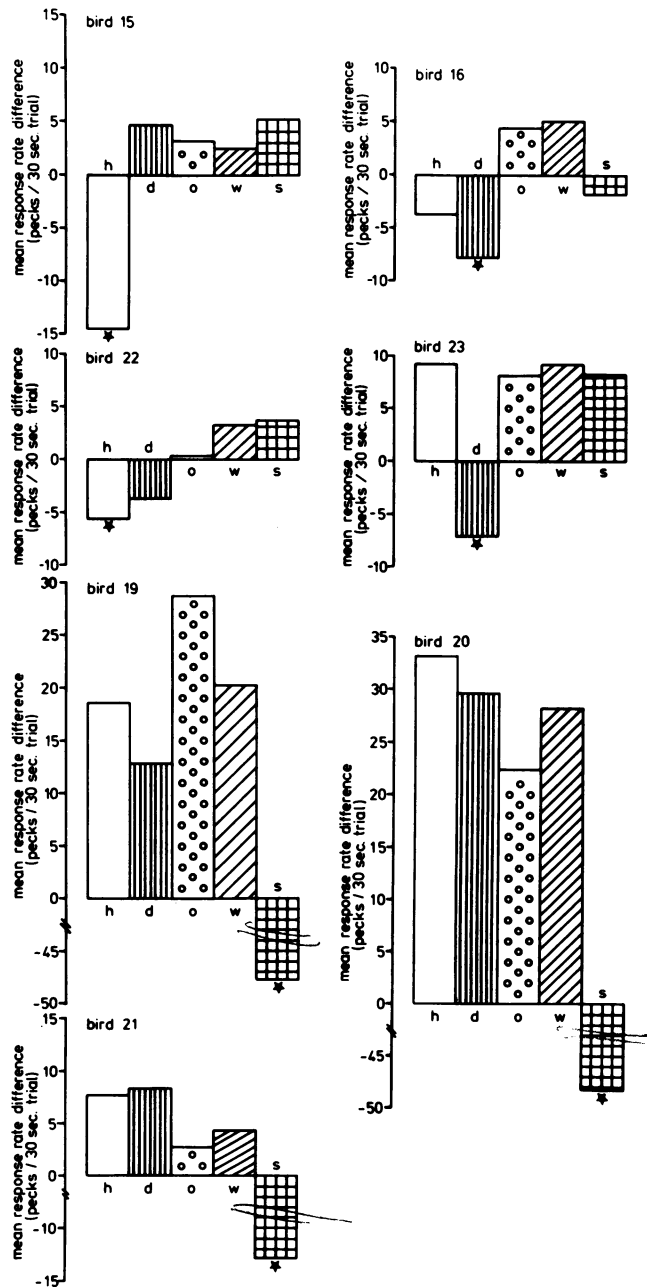


Fig. 7. Relative control over behavior by the five features in the first session after reversal training. In this session all slides except those used in reversal training were in use, and contingencies of reinforcement were as in initial training. The ordinate is the mean response rate to slides containing the positive value of the feature minus the mean response rate to slides containing its negative value. The letters on the horizontal axis indicate the features, as follows: h, height; d, distance; o, orientation; w, weather; and s, site. For each bird the feature that had been subjected to reversal training is marked with a star.

feature within a block of 10 sessions. Bird 21 was an exception. After 44 sessions of postreversal training with all 64 slides, this bird's behavior was still not strongly enough under the control of the orientation feature to meet the original criterion. This bird had required extensive single-feature training on orientation (39 sessions, over twice as many as any other bird had needed for any feature) earlier in the experiment. Note that there was no difficulty with the site feature, which had been subjected to reversed contingencies. Even this bird, however, did recover category discrimination to some extent: When mean response rates over the final five sessions of postreversal training were submitted to analysis of variance, all five features had significant main effects.

GENERAL DISCUSSION

We can draw three conclusions from these results. First, pigeons can learn to discriminate stimulus categories using as many as five features. The difficulties reported by Lea and Ryan (1990) and Lea et al. (1989) are clearly not absolute. However, there are reasons to suspect that the conditions of the present experiment did approach the limits of pigeons' capacities for feature analysis and integration. Four of the birds did not make the five-feature discrimination spontaneously. One of these (Bird 17) could not be trained to abstract even a single feature that it had not spontaneously discriminated. A second was successfully trained to discriminate all five features, but following the reversal training and subsequent testing, the feature that had given most trouble in initial training did not regain control over behavior. Thus, although we achieved better discrimination in this experiment than in earlier work, the present results agree with those of Lea and Ryan (1990) and Lea et al. (1989) in suggesting that pigeons can cope with only a limited number of mutually orthogonal features.

The features in the present experiment were themselves natural categories, with the usual polymorphous properties of such categories. Logically, therefore, the stimuli were highly complex, and, so far as we know, this experiment is the first demonstration that pigeons can discriminate categories that have been synthesized from other natural categories in this way. But the individual stimuli used had the

richness of detail and perhaps relevance to the pigeon's natural way of life that characterize the stimuli used in the most successful category discrimination experiments. The present discrimination seems to have been easier for the pigeons than those used by Lea and Ryan (1990) and Lea et al. (1989). The results thus suggest that the richness and relevance of the individual stimuli are more important than the logical complexity of the category definitions in determining the difficulty of a category discrimination. However, this conclusion cannot be drawn finally until the two types of stimuli are compared within a single experiment.

Our second conclusion is that, even with this degree of complexity of stimulus and of category definition, pigeons do not just learn the stimuli by rote if there are discriminative features available. The number of slides, 64, was small enough to allow such "absolute discrimination" if there had been no relevant features, as previous research by Vaughan and Greene (1984) and by von Fersen and Delius (1989) has shown. The present results are consistent with the evidence that birds learn a true concept discrimination faster than a pseudoconcept discrimination, in which the categories to be discriminated are random selections of stimuli from the same sets (e.g., Ryan & Lea, 1990; Vaughan & Greene, 1984; Wasserman, Kiedinger & Bhatt, 1988).

Finally, however, we conclude that pigeons do not readily form equivalence classes or concepts. As Lea (1984) has argued, the discrimination of stimulus sets defined in terms of concepts held by the experimenter does not require the subject to possess or form a corresponding concept or any concept at all. The repeated-reversals experiment of Vaughan (1988) remains the most convincing evidence that pigeons can form novel concepts, and, because of the different procedures involved, the present results do not contradict Vaughan's. Vaughan used repeated reversals with stimuli with no obvious discriminative feature content, whereas we used a single reversal with stimuli where there were features (albeit polymorphous ones that were imperfectly correlated with reinforcement) to aid discrimination. On the other hand, our procedures are relatively similar to those of Bhatt and Wasserman (1989), and our results agree with theirs in finding no evidence of concept formation.

Two obvious extensions of the present re-

search would involve giving repeated reversals, both with the kinds of categories used here and with pseudoconcept discriminations, using partitions from the same stimulus set designed to eliminate the correlation between features and reinforcement. Such experiments might well find evidence of gradual concept formation over a series of reversals. However, as regards the normal concept discrimination performance of pigeons in the great majority of experiments that have been done, the present results suggest that multiple feature analysis would be an adequate account of behavior.

In contrast with our final conclusion, McLaren, Kaye, and Mackintosh (1989) have invoked within-compound associations, of the kind we are here rejecting, to explain phenomena such as latent inhibition in Pavlovian discrimination with compound stimuli and perceptual learning. Kehoe (1988, 1989) has shown how such associations might be mediated by a simple network of the sort used in parallel-distributed processing theories. And in unpublished experiments, Lea, Ryan, and Kirby (1990) have reported some signs of cross-feature generalization following reversal of the letter-group discriminations described by Lea and Ryan (1983, 1990).

None of these results can be taken with confidence as being in conflict with the present conclusion. But if there is a conflict, one way in which it might be resolved is to point to a difference between the structure of real-world concepts and the artificial categories used in the present experiment. In our experiment, the feature space was completely densely occupied: All combinations of feature value occurred, and there was no correlation between features at all. That was necessary in order to assess the independent contributions of the different features reliably, but it may not be a good model of the situations in which people (and, just possibly pigeons) would find it useful to form concepts. A concept would help organize the perceptual world in precisely those situations in which one feature value or (in the terms used by McLaren et al., 1989, and by Kehoe, 1988, 1989) one stimulus element is a good predictor of another. That is probably true of natural concepts; it was true of the artificial concepts used by Lea et al. (1990) (the stimuli are described by Lea & Ryan, 1983, 1990), but it was by design untrue of the artificial concepts we used. Perhaps the difficulty of discriminating artificial polymor-

phous features lies in this ^{or novel} unnatural aspect of their feature content.

REFERENCES

- Bhatt, R. S., & Wasserman, E. A. (1989). Secondary generalization and categorization in pigeons. *Journal of the Experimental Analysis of Behavior*, *52*, 213-224.
- Fields, L., & Verhave, T. (1987). The structure of equivalence classes. *Journal of the Experimental Analysis of Behavior*, *48*, 317-332.
- Herrnstein, R. J. (1985). Riddles of natural categorization. *Philosophical Transactions of the Royal Society*, *B*, *308*, 129-144.
- Herrnstein, R. J., & Loveland, D. H. (1964). Complex visual concept in the pigeon. *Science*, *146*, 549-551.
- Herrnstein, R. J., Loveland, D. H., & Cable, C. (1976). Natural concepts in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, *2*, 285-302.
- Honig, W. K., & Stewart, K. E. (1988). Pigeons can discriminate locations presented in pictures. *Journal of the Experimental Analysis of Behavior*, *50*, 541-551.
- Kehoe, E. J. (1988). A layered network model of associative learning: Learning to learn and configuration. *Psychological Review*, *95*, 411-433.
- Kehoe, E. J. (1989). Connectionist models of conditioning: A tutorial. *Journal of the Experimental Analysis of Behavior*, *52*, 427-440.
- Lea, S. E. G. (1984). In what sense do pigeons learn concepts? In H. L. Roitblat, T. G. Bever, & H. S. Terrace (Eds.), *Animal cognition* (pp. 263-276). Hillsdale, NJ: Erlbaum.
- Lea, S. E. G., & Harrison, S. N. (1978). Discrimination of polymorphous stimulus sets by pigeons. *Quarterly Journal of Experimental Psychology*, *30*, 521-537.
- Lea, S. E. G., & Ryan, C. M. E. (1983). Feature analysis of pigeons' acquisition of concept discrimination. In M. L. Commons, R. J. Herrnstein, & A. R. Wagner (Eds.), *Quantitative analyses of behavior: Vol. 4. Discrimination processes* (pp. 239-253). Cambridge, MA: Ballinger.
- Lea, S. E. G., & Ryan, C. M. E. (1990). Unnatural concepts and the theory of concept discrimination in birds. In M. L. Commons, R. J. Herrnstein, S. Kosslyn, & D. Mumford (Eds.), *Quantitative analyses of behavior: Vol. 8. Behavioral approaches to pattern recognition and concept formation* (pp. 165-185). Hillsdale, NJ: Erlbaum.
- Lea, S. E. G., Ryan, C. M. E., & Kirby, R. M. (1990). Reversal following category discrimination in pigeons. Internal Report No. 90/1, Animal Behaviour Research Group, Department of Psychology, University of Exeter.
- Lea, S. E. G., Ryan, C. M. E., & Lohmann, A. (1989). Discrimination of five-dimensional stimuli by pigeons: Limitations of feature analysis. Internal Report No. 89/1, Animal Behaviour Research Group, Department of Psychology, University of Exeter.
- Lubow, R. E. (1974). High-order concept formation in the pigeon. *Journal of the Experimental Analysis of Behavior*, *21*, 475-483.
- McLaren, I. P. L., Kaye, H., & Mackintosh, N. J. (1989). An associative theory of the representation of stimuli: Applications to perceptual learning and latent inhibition. In R. G. M. Morris (Ed.), *Parallel distributed*

- processing (pp. 102-130). London: Oxford University Press.
- Morgan, M. J., Fitch, M. D., Holman, J. G., & Lea, S. E. G. (1976). Pigeons learn the concept of an 'A.' *Perception*, *5*, 57-66.
- Ryan, C. M. E., & Lea, S. E. G. (1990). Pattern recognition, 'updating' and filial imprinting in the domestic chicken (*Gallus gallus*). In M. L. Commons, R. J. Herrnstein, S. Kosslyn, & D. Mumford (Eds.), *Quantitative analyses of behavior: Vol. 8. Behavioral approaches to pattern recognition and concept formation* (pp. 89-110). Hillsdale, NJ: Erlbaum.
- Ryle, G. (1951). Thinking and language. *Proceedings of the Aristotelian Society*, Suppl., *25*, 65-82.
- Sidman, M. (1971). Reading and auditory-visual equivalences. *Journal of Speech and Hearing Research*, *14*, 5-13.
- Vaughan, W., Jr. (1988). Formation of equivalence sets in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, *14*, 36-42.
- Vaughan, W., Jr., & Greene, S. L. (1984). Pigeon visual memory capacity. *Journal of Experimental Psychology: Animal Behavior Processes*, *10*, 256-271.
- Vaughan, W., Jr., & Herrnstein, R. J. (1987). Choosing among natural stimuli. *Journal of the Experimental Analysis of Behavior*, *47*, 5-16.
- von Fersen, L., & Delius, J. D. (1989). Long-term retention of many visual patterns by pigeons. *Ethology*, *82*, 141-155.
- Wasserman, E. A., Kiedinger, R. E., & Bhatt, R. S. (1988). Conceptual behavior in pigeons: Categories, subcategories, and pseudocategories. *Journal of Experimental Psychology: Animal Behavior Processes*, *14*, 235-246.

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