SECONDARY GENERALIZATION AND CATEGORIZATION IN PIGEONS

R. S. BHATT AND E. A. WASSERMAN

THE UNIVERSITY OF IOWA

In Experiment 1, one group of pigeons learned to classify a set of stimuli into the human language classes *cat*, *flower*, *car*, and *chair* (categorization); another group learned to classify the same set into arbitrary classes (pseudocategorization). Then, both groups were trained on a new categorization task and their performance compared to that of a control group that had no initial classification training. Hull's (1943) notion of secondary generalization (generalization that is not based on physical similarity but on mediating associations) predicts that categorization experience will facilitate the learning of a new categorization task, whereas pseudocategorization experience will impair it. However, in Experiment 1, performance on the new categorization task was not differently affected by prior experience. In Experiment 2, pigeons initially trained to classify a set of 48 stimuli (original training) were later trained to classify a subset of four of these stimuli using new responses (reassignment training). Then, they were tested on the 44 remaining stimuli. Performance better accorded with original than with reassignment training, indicating that categorization training did not lead to the formation of equivalence classes of stimuli, in which the equivalence relationship is mediated by secondary generalization. The lack of evidence of secondary generalization implies that our pigeons failed to meet Lea's (1984) criterion for conceptual behavior.

Key words: categorization, conceptual behavior, secondary generalization, equivalence class, pigeons

Traditionally, it has been assumed that the ability to categorize stimuli and to extend the classification to novel members of the categories involves conceptualization (Bhatt, Wasserman, Reynolds, & Knauss, 1988; Herrnstein, 1984). However, Lea (1984) has argued that, before such classification of stimuli from open-ended categories can be viewed as an example of conceptual behavior, it must be established that the within-category generalization that occurs transcends physical similarity and is mediated by a "unique mental structure" that represents the conceptual category. His notion is that conceptual categories involve equivalence classes of stimuli that are tied together by relationships that are not (at least not *only*) based on perceptual similarity. Lea argued that if generalization is based solely on

perceptual similarity, then the idea of a "concept" has no utility and "simple" perceptual discrimination and generalization processes can be used to account for classification of open-ended categories (Keller & Schoenfeld, 1950).

Using Hull's (1943) terminology, Lea's requirement for conceptual behavior can be described as a demand for evidence of secondary generalization among stimuli that constitute categories. Secondary generalization refers to generalization between or among stimuli that is not based on perceptual similarity but on mediating associations. For example, a response that is associated with a chair might generalize to a table, not because the table physically resembles the chair, but because the table and the chair have previously been associated functionally. The experiments described in this paper examined whether categorization training that eventuates in generalization to novel members of categories also leads to the formation of equivalence classes of the sort required by Lea (1984).

EXPERIMENT 1

This experiment studied the role of secondary generalization in categorization by pigeons by examining the effects of prior classification experience on later categorization learning. The specific questions of interest here were:

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(a) Does prior categorization training facilitate the subsequent learning of a new category task? And (b) does prior individual stimulus discrimination training interfere with the subsequent learning of a categorization task?

To study the effects of pigeons' learning to respond to categories of stimuli versus their learning to respond to individual stimuli within these categories, we manipulated the nature of original classification training. One type of task (categorization) involved classifying a set of stimuli in accord with the human language classes *cat*, *flower*, *car*, and *chair*. Another task (pseudocategorization) involved classifying the same set of stimuli into arbitrary pseudocategories that do not accord with human language categories. The pseudocategorization task forces the pigeon to respond to individual stimuli within categories (Bhatt, 1988; Wasserman, Kiedinger, & Bhatt, 1988). Specifically, two groups of pigeons were initially trained on a four-key choice task (Bhatt et al., 1988): The categorization group was trained on a categorization task and the pseudocategorization group was trained on the pseudocategorization task. After reaching performance criterion, birds in both groups were transferred to a categorization task on a four-ply multiple fixed-ratio (FR) schedule procedure (Bhatt et al., 1988). The performance of these two groups on the second task was compared to that of a third (control) group. The control group did not have any initial choice training and was directly trained on the four-ply multiple FR schedule categorization task.

The notion of secondary generalization that was developed by Hull (1943) predicts that prior categorization training will facilitate the later learning of a new category task, whereas prior pseudocategorization training will interfere with the learning of the new task. This conclusion follows from Hull's proposed mechanism for secondary generalization: Assume that two dissimilar stimuli are associated with a common response, such that each of the stimuli evokes the response; then, when one of the stimuli is associated with a new response, the old common response that is evoked by this stimulus also comes to be associated with the new response. Now, when the second stimulus is encountered, the old common response that is evoked in turn evokes the new response. Thus, the second stimulus appears to evoke the new response, even though it itself was not

directly associated with the new response. According to Hull, therefore, secondary generalization is mediated by a response with which each of the stimuli has been associated previously.

In the present experiment, the categorization birds were trained in the multiple schedule task to associate common responses with stimuli that were previously (in the choice task) associated with common responses; the pseudocategorization birds, on the other hand, were trained to associate common responses with stimuli that were previously associated with different responses. Thus, secondary generalization, if any, should facilitate the performance of the category birds and impair the performance of the pseudocategory birds. Selective attentional models of discrimination learning, such as that of Sutherland and Mackintosh (1971), also make the same predictions (Bhatt, 1988). These models predict that birds initially trained on a categorization task will learn to attend relatively more to commonalities among exemplars within categories that differentiate categories from each other than to individual features of exemplars, whereas birds initially trained on the pseudocategorization task will learn to attend relatively more to individual features of stimuli than to commonalities among category exemplars. Therefore, categorization training should facilitate the learning of a new categorization task, whereas pseudocategorization training should interfere with the later learning of a categorization task.

To posit that previously learned responses mediate the transfer effects requires that the transfer effects are not based directly on the responses learned in the first task. Thus, as indicated above, two different methods of classification training were used in the present experiment: Initial categorization and pseudocategorization training was on a four-key choice task, whereas subsequent categorization training was on a four-ply multiple fixed-ratio task (see Bhatt et al., 1988).

This attempt to rule out the direct contributions of learned responses to transfer effects is in contrast to the study reported by Siegel and Honig (1970). In that study, pigeons were trained on a successive go/no go discrimination task, in which slides picturing humans signaled a variable-interval (VI) 37.5-s schedule and slides not picturing humans signaled ex-

inction. After classification training, pigeons were tested on a simultaneous discrimination task in which both classes of stimuli were presented simultaneously to the pigeons, and the birds' responses were reinforced on a VI 37.5-s schedule on the screen that portrayed the slide picturing humans. As the authors themselves argued, the good performance shown by the pigeons on this test was probably due to their having learned to approach and peck the human slides and to avoid the nonhuman slides during the successive discrimination training. In other words, the responses learned during initial classification learning directly facilitated performance during the simultaneous discrimination test. Therefore, one cannot argue that the positive transfer was a result of secondary generalization.

METHOD

Subjects. A total of 24 pigeons were studied. They had been trained previously on intermittent schedules of reinforcement in one-key experimental chambers, but they had never seen color slide images nor had they been in choice experiments. These birds were housed in individual cages in a room in which the lights were on from 7 a.m. to 9 p.m. daily. The birds were maintained at 85% of their free-feeding body weights. Unlimited water and grit were provided daily in their home cages.

Apparatus. The apparatus was the same as that used by Bhatt et al. (1988). Four experimental chambers, 29 cm wide, 38 cm high, and 38 cm deep, were used. Each chamber contained a plastic viewing screen (7 cm wide and 7 cm high) on which slides were back-projected using a Kodak Carousel® projector. Located diagonally from each corner of the screen was a 1.9-cm diameter pecking key. Miniature projectors behind the four corner keys in each chamber were used to produce an orange field on the top left key, a white field on the top right key, a green field on the bottom left key, and a red field on the bottom right key. In each chamber, an encased houselight directed light toward the ceiling. The hopper opening was 5.0 cm wide and 6.3 cm high; during reinforcement, it was the only source of illumination. A PDP 8/A® (Digital Equipment Corporation) computer provided the experimental control and data collecting facility.

Stimuli. The stimuli used in this experiment were a subset of the 80 slides (20 from each

of the categories *cat*, *flower*, *car*, and *chair*) used by Bhatt et al. (1988) in their Experiments 1A, 1B, 2A, and 2B. Forty-eight slides (12 slides chosen at random from each of the four categories) were used to train the categorization and pseudocategorization birds. The number of slides used to train the pigeons was based on two requirements. First, the number was such that pigeons in the categorization group would be able to generalize their classification to novel members of the categories, thereby satisfying the commonly required definition of conceptual behavior. Second, the number was such that both the categorization and the pseudocategorization groups could reach 70% correct performance on the choice task before they were transferred to the second task. It was important that both the categorization and the pseudocategorization birds reach the same high level of performance on the choice task prior to being transferred to ensure that any differences obtained in the second task were not due to general factors such as differential degree of stimulus observation. The results of Experiment 1 in Bhatt (1988) revealed that a set of 48 stimuli met both criteria. Ten of the 12 slides from each category were chosen at random and used in the multiple FR schedule category transfer task. A slightly smaller subset was used in the transfer task than in the initial choice task because each trial during the multiple FR schedule required three slots in the slide carousel; it was not possible to fit 48 different slides into a 140-slot tray.

Pretraining. Initially, all birds were trained to eat from the food hopper and to look up at the illuminated houselight. Then, they were autoshaped to peck at the screen when it was illuminated and at the four corner keys when they were illuminated. Each daily autoshaping session consisted of 48 trials. After a 40-s intertrial interval, either the carousel advanced once and a colored pie-chart image appeared on the screen (with a probability of .500) or one of the four corner keys was lit (each corner key had a probability of .125 of being illuminated). When the pigeon completed a required number of responses on the illuminated screen (or on the illuminated key) or after a certain time period elapsed, the carousel advanced to darken the screen (or the corner key was darkened) and the pigeon was allowed 2-s access to food. The response requirement was

gradually increased from 1 to 30 pecks, and the time period was gradually increased from 8 s to 10 min. At the end of 16 days, all birds were responding reliably to the illuminated screen and the corner keys. The birds were then divided randomly into three groups of 8 birds each, constituting the categorization, pseudocategorization, and control groups.

Classification Training

Four-key choice training. The four-key choice procedure developed by Bhatt et al. (1988) was used to train pigeons to classify the set of training slides. Birds in the categorization group were trained to peck at one of the four keys in the presence of cat slides, to peck at a second key in the presence of flower slides, to peck at a third key in the presence of car slides, and to peck at a fourth key in the presence of chair slides. Birds in the pseudocategorization group were trained to peck at one of the keys in the presence of slides from one pseudocategory, to peck at a second key in the presence of slides from a second pseudocategory, and so on (with each pseudocategory containing an equal number of cat, flower, car, and chair slides). The association of keys to language categories in the categorization group (and to pseudocategories in the pseudocategorization group) was counterbalanced such that, across the 8 birds, each key came to represent each of the four language categories (or the pseudocategories) twice. There were four different key–category associations.

Daily 48-trial sessions began with the illumination of the houselight, followed 50 s later by the first trial. After an intertrial interval (10, 15, or 20 s, each equally likely), the carousel advanced to display a slide. The pigeon was then required to complete a certain number of observing responses on the screen; the observing-response requirement was 5 on Days 1 and 2, 15 on Days 3 and 4, and 30 thereafter. When the pigeon completed the response requirement, the four corner keylights were turned on and a tone was sounded in the chamber to signal the availability of the choice keys. If the pigeon pecked the correct key, the screen and the corner keys were darkened, the tone was switched off, and the pigeon was allowed 2-s access to food. If the pigeon pecked an incorrect choice key, the four corner keys were darkened, the tone was turned off, and the pigeon was required to complete the ob-

serving-response requirement once again before the choice keys and the tone reoccurred. This process was repeated until the pigeon made the correct choice response. These correction trials were not included in the daily total of 48 trials.

During classification training, four trays (A, B, C, and D) were used to display the slides; the trays differed from each other in the order of slide presentation. In each tray, 48 slides were arranged randomly, with the restriction that each block of four trials contained one slide associated with each of the four corner keys. On each day, one of the four trays was chosen at random, with the restriction that each slide tray was used once every 4 days.

The percentage of trials on which the correct key was chosen was used as the index of classification. Correction trials were excluded in the calculation of this index. After the performance criterion (70% or greater in a single session) was reached, each bird was transferred to the four-ply multiple FR schedule category task. Control birds were trained directly on the multiple-schedule categorization task after pretraining.

Multiple FR schedule categorization training. The four-ply multiple FR schedule procedure developed by Bhatt et al. (1988) was used to train all pigeons on the critical second categorization task. The four components of a multiple schedule—FR 20, FR 80, FR 140, and FR 200—were each associated with one of the four categories *cat*, *flower*, *car*, and *chair*. The association of ratios to categories was counterbalanced such that, across the 8 birds in each group, each ratio came to represent each of the categories twice; there were four different sets of ratio–category associations.

Daily 40-trial sessions began with the illumination of the houselight, followed 50 s later by the first trial. After an intertrial interval (programmed as in choice training), the carousel advanced once to illuminate the screen with white light. A peck to the white-illuminated screen advanced the carousel once to display a training slide. The key peck to the white-illuminated screen was to ensure that the pigeon was in the vicinity of the screen when the training slide was projected on it, thereby allowing a proper measure of the time taken to complete the first 20 responses (see below). When the pigeon made the required number of responses to the projected training

Table 1

Number of days of training that were required for birds in Experiment 1 to reach progressively more stringent learning criteria (Cat = Categorization group; Pseudo = Pseudocategorization group).

Criterion	40%		55%		70%		40%		55%		70%				
Bird	Original training						Transfer training								
	Cat	Pseu- do	Cat	Pseu- do	Cat	Pseu- do	Cat	Pseu- do	Con- trol	Cat	Pseu- do	Con- trol	Cat	Pseu- do	Con- trol
1	8	4	20	20	34	29	1	3	3	4	5	8	5	6	18
2	4	4	17	21	17	41	4	3	3	5	3	5	22	8	7
3	6	18	8	18	15	55	3	2	3	5	4	4	14	9	5
4	4	13	14	23	21	29	1	3	2	4	3	6	10	4	13
5	10	12	15	29	29	31	3	5	4	6	7	7	8	8	9
6	5	16	10	31	16	62	3	4	4	6	4	4	12	13	8
7	7	14	10	26	17	38	3	2	2	4	3	2	8	4	4
8	4	11	6	18	11	28	1	2	2	2	3	4	5	7	8

slide, the carousel advanced once to darken the screen and the pigeon was allowed 2-s access to food. The arrangement and use of slide trays were the same as in four-key choice training.

The percentage correct rank-order measure used by Bhatt et al. (1988) was used during four-key multiple FR schedule training. This index is based on the finding that the speed of making the first response and the rate of responding after the first peck are both decreasing functions of increasing response requirements in multiple FR schedules (see Bhatt & Wasserman, 1987). Here, the rank-order measure was computed using the time taken to complete the first 20 responses on each trial. In each block of four trials (in which each FR schedule was in effect once), the categories were rank-ordered in terms of the time taken to complete the first 20 responses in their presence. In terms of this rank order, correct classification consisted of the FR 20 category occupying the first position (shortest duration), the FR 80 category occupying the second position, the FR 140 category occupying the third position, and the FR 200 category occupying the fourth position (longest duration). The rank-order score for each category was thus the percentage of time in 10 blocks that the category occupied the designated position in the rank order.

RESULTS AND DISCUSSION

Original learning. Table 1 depicts the number of days of training on the initial choice task for birds to reach successively more stringent

performance criteria. All of the birds in the categorization and pseudocategorization groups reached the 70% performance criterion before being transferred to the multiple FR schedule categorization task. However, it took longer for pigeons to learn the pseudocategorization than the categorization task. It took means of 13.38, 23.25, and 39.12 days, respectively, for the pseudocategorization birds to reach the criteria of 40%, 55%, and 70% correct performance in a session; the corresponding scores were 6.00, 12.50, and 20.00 days for the categorization group. One-factor (Task) ANOVAs conducted on these scores revealed significant Task main effects at each of the three performance criteria, 40%: $F(1, 14) = 16.04$, $p < .01$; 55%: $F(1, 14) = 19.52$, $p < .01$; 70%: $F(1, 14) = 12.86$, $p < .01$.

This result replicates our earlier finding (Bhatt, 1988; Experiment 2 in Wasserman et al., 1988; see also Cook, Wright, & Kendrick (in press); Delius & Nowak, 1982; Edwards & Honig, 1987; Herrnstein & de Villers, 1980; Malott & Siddall, 1972) that pigeons learn to classify a set of stimuli into categories that accord with human language categories faster than they learn to classify the same stimuli into pseudocategories that do not accord with human language categories. This categorization versus pseudocategorization learning speed difference indicates that categorization learning does not involve the mere formation of stimulus-response associations between disparate stimuli and responses; instead, the results suggest that similarity relationships

Fig. 1. Mean rank-order scores of pigeons in Experiment 1.

among the stimuli influence the speed of categorization learning. Specifically, the results suggest that similar stimuli occasioning the same response lead to faster acquisition than do similar stimuli occasioning different responses. The fact that similarity relationships affect categorization learning is consistent with the widely accepted notion that similarity relationships underlie transfer of classification to novel members of categories. In fact, the context theory of classification proposed by Medin and Schaffer (1978)—which has been highly successful as a model of categorization in humans—was based on the assumption that similarity relationships affect ease of categorization learning and performance on novel stimuli in essentially the same manner.

Transfer performance. Figure 1 depicts the performance of the categorization, pseudocategorization, and control groups during multiple FR schedule categorization training. The scores plotted are the mean rank-order scores of 8 birds from each of the groups, averaged over 2-day blocks. As can be seen, acquisition was fairly rapid and, contrary to expectations, proceeded at about the same speed in all three groups. A Block $\times$ Group ANOVA revealed a significant main effect of Block, $F(11, 231) = 46.58, p < .01$, suggesting that performance rose as a function of training. However, neither the main effect of Group, $F(2, 21) < 1$,

nor the Block $\times$ Group interaction, $F(22, 231) < 1$, was significant.¹ Thus, in the present experiment, there was no evidence to suggest that performance on a multiple FR schedule categorization task was affected differently by prior categorization versus pseudocategorization learning on a choice procedure. Moreover, there was no evidence to suggest that the performance of birds that had no prior explicit classification experience was different from those with categorization or pseudocategorization experience.

Individual birds' performances on the transfer task are depicted in Table 1. The scores shown are the number of days of training required for birds to reach successively more stringent performance criteria. It took means of 2.38, 4.50, and 10.50 days of training, respectively, for the categorization birds to reach the criteria of 40%, 55%, and 70% rank-order scores in a session; the corresponding scores were 3.00, 4.00, and 7.38 days for the pseudocategorization group and 2.88, 5.00, and 9.00 days for the control group. Consistent with the results obtained with the rank-order scores, one-factor (Group) ANOVAs performed on these scores revealed no significant effects at any of the three performance criteria, 40%: $F(2, 21) < 1$; 55%: $F(2, 21) < 1$; 70%: $F(2, 21) < 1$.

Although there was no evidence to suggest that performance was differently affected by prior classification experience, it is possible that, within each of the groups, there was a correlation between performance on the original and transfer tasks. It may be argued that those birds in the categorization group that learned the original task faster may have formed stronger stimulus-response associa-

¹ An Appendix containing the actual times taken to complete the first 20 responses for each subject at each FR value and for each 2-day block is available, free of charge, from the Business Manager of the journal (see current issue for name and address). Consistent with the conclusions arrived at using the rank-order method, analysis of these actual time scores provided no evidence to suggest that there was any difference among the groups in terms of the speed of learning the transfer task: A Ratio $\times$ Block $\times$ Group ANOVA revealed a significant Ratio main effect, $F(3, 63) = 16.25, p < .001$, a significant Block main effect, $F(11, 231) = 2.72, p < .01$, and a significant Ratio $\times$ Block interaction, $F(33, 693) = 5.48, p < .001$; all other effects were nonsignificant [Group: $F(2, 21) < 1$; Ratio $\times$ Group: $F(6, 63) < 1$; Block $\times$ Group: $F(22, 231) < 1$; Ratio $\times$ Block $\times$ Group: $F(66, 693) < 1$].

tions, which should lead to enhanced secondary generalization and, therefore, faster learning on the transfer task. On the other hand, the stronger stimulus-response associations formed by those birds in the pseudocategorization group that learned their original task more rapidly should hinder performance on the transfer task to a greater degree and, therefore, they should learn the transfer task more slowly. In other words, there should be a positive correlation between speed of learning the original and transfer tasks for the categorization group and a negative correlation between speed of learning the original and transfer tasks for the pseudocategorization group. Contrary to these predictions, the Pearson correlation coefficient between the number of days of training required to reach the 70% criterion on the original and transfer tasks was $-.33$ ($p > .05$, on a two-tailed test) for the categorization group and $+.78$ ($p < .05$, on a two-tailed test) for the pseudocategorization group. Thus, only the birds in the pseudocategorization group showed a significant relationship between original and transfer task performance, and this relationship was opposite to that predicted by the analysis detailed above.

The absence of the predicted transfer effects suggests that secondary generalization was not a factor in the performance of the birds on the second categorization task. Possible reasons for the absence of any evidence of secondary generalization are presented in the General Discussion section.

EXPERIMENT 2

In this experiment, we used a procedure suggested by Lea (1984) to examine further whether categorization training that leads to the generalization of classification to novel members of categories also leads to the formation of equivalence classes, in which the equivalence relationship is mediated by secondary generalization. In Lea's experimental design, subjects first are trained to classify stimuli by associating different responses with members of different categories (original training). Then, the subjects are trained to classify a subset of the stimuli used during original training (consisting of one stimulus from each of the categories) by associating different new responses to members of the different categories (reassignment training). Finally, the

subjects are tested on the rest of the stimuli that were used during original training (generalization tests). Lea argued that, if the original training led to the formation of concepts, then performance on these stimuli would accord with the contingencies in effect during reassignment training; on the other hand, if performance accorded with the contingencies in effect during original training, then it would suggest that the original classification training did not result in the formation of conceptual categories. In other words, Lea argued that conceptual categories are equivalence classes in the sense that, if one member of the class is associated with some environmental contingency, then all members of the class will come to signal that environmental contingency. Moreover, this equivalence relationship should not be based only on perceptual similarity. That is, in the experimental design described above, one must ensure that any generalization that occurs from individual instances of the categories to other members of the categories (which would be indicated by performance in accord with reassignment training during generalization tests) should not be based only on perceptual similarity between those individual instances and other members of the categories. Thus, the critical question is whether categorization training leads to the formation of equivalence classes in which the equivalence relationship is based on secondary generalization.

Lea's (1984) design was used in the present experiment to examine the role of secondary generalization in categorization. Original training consisted of conditioning pigeons on a four-key task to classify 48 different stimuli, 12 from each of the categories *cat*, *flower*, *car*, and *chair*. Reassignment training involved training pigeons to classify a set of four stimuli, one from each of the categories. These four stimuli were a subset of the stimuli used during original training. During reassignment training, the association of keys with categories was different from that used during original training. That is, the key that was associated with the cat category in original training might be associated with the flower stimulus during reassignment training; the key that was associated with the flower category during original training might be associated with the car stimulus during reassignment training, and so on.

The pigeons were then tested on the 44 stim-

uli that were used during original training, but not during reassignment training (generalization test). The question of interest was this: Would performance on these slides accord with original training or with reassignment training? Performance according to reassignment training would indicate that the categories were equivalence classes, in that the pigeons generalized their responses from the single members of the categories used during reassignment training to other members of the categories.

Importantly, Experiment 1 in Bhatt (1988) revealed that pigeons trained on the set of four stimuli used during reassignment training (using the same procedure that was used during reassignment training in the present experiment) failed to show any generalization to new stimuli from these categories. Thus, if birds in the present experiment did generalize their responding from these stimuli to other members of the categories (i.e., if they responded according to reassignment training during the generalization tests), then it would indicate that this generalization was a result of the original classification training. Performance according to reassignment training is also predicted by selective attentional models of discrimination learning (Bhatt, 1988). These models predict that categorization training would increase similarity relationships among category members as a result of pigeons' learning to attend selectively to commonalities among exemplars within categories, which should lead to enhanced generalization from individual members to other category members, and therefore, performance according to reassignment training.

Two groups of pigeons were studied in this experiment. Both groups experienced the same original and reassignment training. The groups differed in terms of the contingencies that were in effect during generalization testing. In Group R (reinforcement), any choice made by the pigeons on trials in which they were tested on the 44 original stimuli produced food; in Group NR (no reinforcement) no choice made during these trials produced food.

METHOD

Subjects. Three pigeons from the categorization group of Experiment 1 constituted Group R; 4 pigeons from the categorization

group of Experiment 1 constituted Group NR.

Apparatus. The apparatus was the same as in Experiment 1.

Stimuli. During original training, pigeons were trained on the 48 stimuli used during the choice training in Experiment 1. During reassignment training, the stimuli used were a subset of four stimuli, consisting of one stimulus from each of the categories.

Original training. Recall that the categorization group in Experiment 1 was trained initially on a four-key choice categorization task and then transferred to a multiple FR schedule categorization task. After this training, 7 of the birds in the categorization group that were the subjects in the present experiment were retrained on the initial four-key choice task. This choice training constituted the original training for the present experiment. After 16 days of this training, when the birds' performance had become stable, the birds were transferred to reassignment training.

Reassignment training. In this phase, pigeons were trained on the choice procedure to classify a set of four stimuli, one from each of the categories. As described above, the association of categories with choice keys was different from original training. For each bird, reassignment training was in effect until a performance criterion of 70% correct or better in two consecutive sessions was reached.

Generalization tests. After reassignment training, the birds were tested on the 44 stimuli used in original training and not used during reassignment training. Generalization testing was spread out over six sessions. On the first 5 days, each bird was tested on 8 of the 44 stimuli; on the 6th day, the birds were tested on the remaining four stimuli. During the first 5 days, these stimuli and the reassignment training stimuli were arranged in two new slide orders E and F. Every block of four slides in these orders contained one slide from each of the four categories; the first two blocks contained all reassignment training slides (to set the context of the categorization task for the tests); the next eight blocks each contained three reassignment training slides and one of the 44 test slides (chosen at random without replacement); the last two blocks, once again, consisted of all reassignment training slides. On the sixth generalization test, the test stimuli were arranged in the first half of the carousel

Table 2

Performance of pigeons in Group R and Group NR on the 44 test stimuli in Experiment 2.

Bird	% Correct choices on last day of original training	% Choices during generalization tests		
		In accord with original training	In accord with reassignment training	Not in accord with original training that were in accord with reassignment training
R1	86.36*	54.54*	15.90	34.97
R2	81.18*	45.50*	15.90	29.17
R3	84.09*	59.09*	6.80	16.62
NR1	79.54*	59.09*	27.27	66.66
NR2	84.09*	75.00*	18.18	72.72
NR3	86.36*	75.00*	13.64	54.56
NR4	65.91*	59.09*	11.36	27.78

* $p < .05$ by one-tailed binomial test, $N = 44$; chance performance is 25% correct.

in the slide order E; in the second half, reassignment training stimuli were arranged in place of the novel stimuli. On trials in which the pigeons were exposed to the reassignment training stimuli, reassignment training contingencies were in effect. On trials in which the pigeons were tested on the 44 stimuli, different contingencies were in effect for Group R and Group NR. For birds in Group R, any choice response was reinforced with food. That is, on these trials, after the pigeons completed the observing-response requirement and the four choice keys were illuminated, a peck to any of the choice keys resulted in the darkening of the screen and the pigeon was allowed 2-s access to food. Then, the next intertrial interval started. For birds in Group NR, no choice response was reinforced with food. That is, on these trials, after the pigeons completed the observing-response requirement and the choice keys were illuminated, a peck to any of the choice keys resulted in the darkening of the screen and the next intertrial interval started.

RESULTS AND DISCUSSION

By the end of the 16 days of original training, all Group R birds were responding at a high accuracy level. The percentages of correct choice responses made by the 3 birds on the last day were 87.50, 79.17, and 83.33. On the first day of reassignment training, the percentages of correct choice responses made were 15.38, 9.30, and 8.33—below the chance level of 25%, as would be expected from the change in the category to choice key associations. However, reassignment learning was rapid:

The performance of the 3 birds on the 5th day was at 79.17%, 89.58%, and 77.08% correct. On this day, all birds reached the performance criterion of 70% or better in two consecutive sessions.

The performance of the Group NR birds was similar. On the last day of original training, the birds' scores were 77.08%, 85.42%, 85.42%, and 68.75% correct. On the 1st day of reassignment training, the birds' respective scores were 16.66%, 27.08%, 8.33%, and 14.58% correct. Birds NR1, NR2, and NR4 reached the performance criterion of 70% correct or better in two consecutive sessions on the 5th day of reassignment training, and their scores on that day were, respectively, 79.16%, 95.84%, and 89.58% correct. Bird NR3 reached this criterion on the 4th day; its score on that day was 95.83% correct.

Table 2 details the performance of the birds during the generalization tests. For Group R, the mean percentage of correct choices made to the 44 stimuli that were used during original training but not during reassignment training was 12.87% according to the reassignment contingencies, whereas it was 53.05% according to the original training contingencies; for Group NR, the corresponding scores were 17.62% and 67.04%. With $N = 44$ and chance performance at 25%, statistical significance on a one-tailed binomial test at the .05 level is reached at 38.64% correct responding. All 7 of the birds met this criterion when their performance was calculated according to the original training contingencies; none of the birds met this criterion when their performance was

calculated according to the reassignment contingencies. Thus, it is clear that performance on the 44 stimuli was in accord with original training rather than with reassignment training.

Table 2 also reveals that in general there was a drop in accuracy of responding to the 44 stimuli when the birds' generalization performance is compared to their performance on the last day of original training. Reassignment training and/or the passage of time between original training and generalization testing may have caused this drop in accuracy.

Although performance on the 44 stimuli was predominantly consistent with the original training, it is instructive to examine whether the responses that did not accord with the original contingencies did accord with the reassignment contingencies; if so, it would indicate that the effects of secondary generalization did play roles in the pigeons' performance during the generalization tests (even if clearly superseded by original training). For this purpose, the percentage of the choice responses not in accord with original training that were in accord with reassignment training was computed. For example, this score was 34.97% for Bird R1, equal to $[15.90 / (100 - 54.54)] \times 100$. As Table 2 shows, the scores of 3 of the Group NR birds and 1 of the Group R birds were higher than 33.33%, which is the score expected by chance. However, one-tailed binomial tests revealed that only the scores of Birds NR1 and NR2 were at significantly greater-than-chance levels ($p < .05$; N = number of stimuli out of 44 to which responding was not according to original training). These results suggest that there may have been a small amount of generalization of responding from the single exemplar of each of the categories used during reassignment training to the other members of the categories. However, this generalization was not seen in the performance of 5 of the 7 birds.

In any case, responding failed to generalize from the reassignment stimuli to the other members of the categories, and this result was obtained whether or not the pigeon's responses were reinforced on generalization test trials. Thus, in this experiment, categorization training did not lead to the formation of equivalence classes of the sort required by Lea (1984) as evidence of conceptualization. Specifically, the results suggest that secondary generalization

did not supersede the stimulus-response associations that were formed during original training.

GENERAL DISCUSSION

In Experiment 1, performance on a multiple FR schedule categorization task was not affected differentially by prior experience with categorization versus pseudocategorization. In Experiment 2, pigeons originally trained to classify a set of stimuli and later trained to classify a subset of the stimuli using new responses failed to generalize their responding on the subset to other members of the categories. As detailed above, these results contradict predictions based on Hull's (1943) notion of secondary generalization. The lack of evidence of secondary generalization indicates that categorization training which leads to generalization of classification to discriminably different novel members of the categories (thereby meeting the normally accepted evidential requirements of conceptualization) does not necessarily lead to the formation of equivalence classes of stimuli of the sort required by Lea (1984) as evidence of conceptualization.

A variety of factors may account for the null results obtained in these experiments. For example, in Experiment 1, it is possible that learning the categorization task on the multiple FR schedule may have been too rapid in all cases to disclose the effects of secondary generalization; other procedures may be more sensitive. It could also be argued that the effects of secondary generalization were pitted against the associations formed during original training in Experiment 1; the FR 30 observing-response requirement that was in effect during the initial choice training may have masked differences in the speed of learning the transfer task which involved associating different FR schedules with different categories. But, the fact that the learning speed of the control group that was not trained on the choice task did not differ from those of the categorization and pseudocategorization groups argues against this interpretation. And, clearly, the effects of secondary generalization were pitted against the associations formed during original learning in Experiment 2. Better evidence of secondary generalization might be obtained if the response requirements during the original training were different from the ones used during

reassignment training. For instance, it would be instructive to determine whether pigeons trained on the multiple FR schedule procedure during original training in a study using Lea's (1984) procedure (rather than on the four-key choice procedure) would respond according to the choice contingencies of the reassignment training during the generalization tests. This generalization (which would be indicative of secondary generalization) would not have to compete against the associations formed during original training because the original training would not have involved choice contingencies. However, if Lea's criterion for evidence of conceptualization requires that the effects of secondary generalization override the effects of original training, then the experiment proposed above clearly does not provide the answer.

In any case, pigeons in Experiments 1 and 2 failed to meet Lea's (1984) criterion for conceptual behavior. In contrast to these results, Vaughan and Herrnstein (1987; also see Herrnstein, 1985) argued that their pigeons showed evidence of conceptual behavior in the sense required by Lea. Vaughan and Herrnstein trained pigeons to discriminate a set of slides depicting trees from a set of slides not depicting trees by associating different variable-interval (VI) schedules with the two categories of stimuli. Later, the pigeons were trained to classify a novel set of tree and nontree slides by associating two new VI schedules with stimuli from these two categories. After the pigeons experienced this "reassignment" training, they were exposed to the original set of tree and nontree slides. The pigeons responded to these slides in accord with the VI schedules that were in effect during the reassignment training rather than in accord with the schedules in effect when the birds were initially trained on this set of stimuli. Vaughan and Herrnstein (1987) argued that the results "suggest that pigeons can conceptualize, not merely categorize" (p. 15). However, alternative explanations for the pigeons' performance are possible. There was a gap of about 140 sessions between the original training and generalization testing. Moreover, the pigeons were trained on 40 tree and 40 nontree slides during reassignment training. Therefore, it is possible that the original training was forgotten and/or the pigeons' performance according to the reassigned contingencies was due to gen-

eralization based on the perceptual similarity between the original training and reassignment training slides. The large number of slides used during reassignment training makes this similarity-based generalization particularly plausible. Hence, the results obtained by Vaughan and Herrnstein (1987) do not necessarily meet the critical criterion for conceptualization, namely, generalization that is not based on perceptual similarity.

More recently, Vaughan (1988) reinforced pigeons' responding to a set of 20 slides depicting trees (positive set) and did not reinforce responding to another set of 20 slides depicting trees (negative set). Later, the reinforcement contingencies were reversed, so that the positive set became the negative set and the negative set became the positive set. Then, the contingencies were reversed once again, and so on. Initially, during the first reversal sessions, the pigeons inappropriately responded to the negative set more than to the positive set. However, after a number of reversals, the pigeons began to respond appropriately even during the first reversal sessions. That is, the pigeons generalized their responding from the first few slides that signaled the contingency reversals to other members of the sets. Given that the positive and negative sets were chosen randomly from the set of 40 slides, all of which depicted trees, this result is clear evidence of equivalence classes in pigeons in which the equivalence relationship is not based on perceptual similarity.

However, evidence of this equivalence relationship was seen only after a large number of reversals, suggesting that the pigeons had to associate common responses with stimuli many times before secondary generalization took place. Moreover, in Vaughan's (1988) study, it took experience with more than a single stimulus from the two sets for the pigeons to reverse their responding during the first sessions of the reversals (see Table 3 in Vaughan), suggesting that reassignment training with only one stimulus from each of the categories may not be sufficient for pigeons to generalize their responding to other members of the categories. Thus, Vaughan's pigeons did not show evidence of the strict equivalence relationship demanded by Lea (1984), in the sense that there is generalization from each member of a category to others. Even if Vaughan's study is assumed to be an example

of the formation of the type of equivalence class required by Lea, the present experiments suggest that standard categorization training does not necessarily lead to the formation of such equivalence classes.

The results of the present experiments are also relevant to the question of what kind of information is used by pigeons in the generalization of categorization to novel stimuli. The failure to see any facilitating effects of prior categorization experience on the later learning of a categorization task in Experiment 1 and responding in accord with the original training rather than with reassignment training in Experiment 2 suggest that even if generic, category-level information (e.g., a prototype) is abstracted during categorization training and is used in responding to novel stimuli, training pigeons on a new task does not lead to the association of new responses to the generic information; rather, the new responses seem to be associated with the individual stimuli on which the pigeons are trained in the new task. At this point, it may be more parsimonious to assume that categorization training leads to the formation of stimulus-response connections between individual training stimuli and responses, and that generalization of categorization is based on the similarity relationship between the novel stimuli and the set of individual stimuli that forms the category representations (see Medin & Schaffer, 1978).

REFERENCES

- Bhatt, R. S. (1988). *Categorization in pigeons: Effects of category size, congruity with human categories, selective attention, and secondary generalization*. Unpublished doctoral dissertation, University of Iowa, Iowa City.
- Bhatt, R. S., & Wasserman, E. A. (1987). Choice behavior of pigeons on progressive and multiple schedules: A test of optimal foraging theory. *Journal of Experimental Psychology: Animal Behavior Processes*, **13**, 40-51.
- Bhatt, R. S., Wasserman, E. A., Reynolds, W. F., Jr., & Knauss, K. S. (1988). Conceptual behavior in pigeons: Categorization of both familiar and novel examples from four classes of natural and artificial stimuli. *Journal of Experimental Psychology: Animal Behavior Processes*, **14**, 219-234.
- Cook, R. S., Wright, A. A., & Kendrick, D. F. (in press). Visual categorization by pigeons. In M. L. Commons & R. J. Herrnstein (Eds.), *Quantitative analyses of behavior: Vol. 8. Pattern recognition*. Hillsdale, NJ: Erlbaum.
- Delius, D. J., & Nowak, B. (1982). Visual symmetry recognition by pigeons. *Psychological Research*, **44**, 199-212.
- Edwards, C. A., & Honig, W. K. (1987). Memorization and "feature selection" in the acquisition of natural concepts in pigeons. *Learning and Motivation*, **18**, 235-260.
- Herrnstein, R. J. (1984). Objects, categories, and discriminative stimuli. In H. L. Roitblat, T. G. Bever, & H. S. Terrace (Eds.), *Animal cognition* (pp. 233-261). Hillsdale, NJ: Erlbaum.
- Herrnstein, R. J. (1985). Riddles of natural categorization. *Philosophical Transactions of the Royal Society, B*, **308**, 129-144.
- Herrnstein, R. J., & de Villers, P. A. (1980). Fish as a natural category for people and pigeons. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 14, pp. 59-95). New York: Academic Press.
- Hull, C. L. (1943). *Principles of behavior*. New York: Appleton-Century-Crofts.
- Keller, F. S., & Schoenfeld, W. N. (1950). *Principles of psychology*. New York: Appleton-Century-Crofts.
- 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.
- Malott, W. R., & Siddall, J. W. (1972). Acquisition of the people concept in pigeons. *Psychological Reports*, **31**, 3-13.
- Medin, D. L., & Schaffer, M. M. (1978). Context theory of classification learning. *Psychological Review*, **85**, 207-238.
- Siegel, R. K., & Honig, W. K. (1970). Pigeon concept formation: Successive and simultaneous acquisition. *Journal of the Experimental Analysis of Behavior*, **13**, 385-390.
- Sutherland, N. S., & Mackintosh, N. J. (1971). *Mechanisms of animal discrimination learning*. New York: Academic Press.
- Vaughan, W., Jr. (1988). Formation of equivalence sets in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, **14**, 36-42.
- Vaughan, W., Jr., & Herrnstein, R. J. (1987). Choosing among natural stimuli. *Journal of the Experimental Analysis of Behavior*, **47**, 5-16.
- 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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