Novelty and functional equivalence in superordinate categorization by pigeons

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Superordinate categorization via association with a common response was studied in pigeons. Original training paired disparate classes (e.g., people + chairs and cars + flowers) with a common response (Responses 1 and 2, respectively). Reassignment training taught new responses (Responses 3 and 4, respectively) to one component class from each pair (e.g., people and cars). Superordinate categorization was documented in testing when the pigeons made the same responses to the stimuli that were withheld in reassignment training (e.g., chairs and flowers) as they did to the reassigned stimuli themselves (e.g., people and cars) and when the birds transferred these discriminative responses to novel stimuli from all four component classes. Reassignment training with novel stimuli produced effects that were similar to those of reassignment training with familiar stimuli. Superordinate categorization via association with a common response is thus a robust effect that generalizes to novel stimuli from each of the component classes.

One of the most persistent and fundamental issues in experimental psychology concerns the problem of stimulus equivalence. According to Hull (1939):

The problem of stimulus equivalence is essentially this: How can we account for the fact that a stimulus will sometimes evoke a reaction to which it has never been conditioned, i.e., with which it has never been associated? For example, it is evident that a given physical object as sensed by the eye, say, probably never presents the same physical pattern of light energy to the retina on any two occasions. (p. 9)

Equivalence of one sort or another is not only involved in object recognition, as Hull noted in the above quotation, but also in the labeling function of language (Sidman, 1990) and in object categorization (e.g., Astley & Wasserman, 1996, 1998a; Wasserman & Bhatt, 1992; Wasserman & DeVolder, 1993; Wasserman, DeVolder, & Coppage, 1992). Stimulus equivalence and the processes that underlie it are undoubtedly foundational to many cognitive activities in both human and nonhuman animals.

Recent research with animals has examined many different experiences that may produce stimulus equivalence

and has begun to elucidate the "codes" that make perceptually distinct stimuli functional equivalents of one another. Hall and his colleagues (e.g., Hall, Ray, & Bonardi, 1993; Honey & Hall, 1989) have found that both antecedent and consequent events can foster stimulus equivalence in rats' conditioned suppression of bar-pressing.

Urcuioli, Zentall, and their colleagues have conducted an extensive series of studies studying a phenomenon that they call "common coding" (e.g., Urcuioli, Zentall, Jackson-Smith, & Steirn, 1989; Zentall, Sherburne, & Urcuioli, 1993, 1995; Zentall, Steirn, Sherburne, & Urcuioli, 1991; Zentall, Urcuioli, Jagielo, & Jackson-Smith, 1989). In many of their experiments, initial training was given with many-to-one (MTO) matching-to-sample, in which one comparison stimulus was correct following two of four possible samples and a second correct comparison stimulus was correct following the other two samples. These researchers found evidence that MTO training created a common coding response that was then evoked by the sample stimuli. This common code has been demonstrated in several ways: (1) The shape of retention interval functions (Zentall et al., 1995; Zentall et al., 1989), (2) the differential difficulty of partial versus complete reversal of the MTO task (Zentall et al., 1991), and (3) the effect of stimuli interpolated during the retention interval (Zentall et al., 1993).

A study by Wasserman et al. (1992) further examined the circumstances that may produce equivalence of perceptually distinctive stimuli in pigeons. This study used photographs of stimuli from four different basic-level classes (people, flowers, cars, and chairs). The assign-

This research was supported by National Institute of Mental Health Grant MH51562. The authors would like to thank Lloyd Frei and Keith Miller for technical assistance. We would also like to thank Susan Felts, Brigitte Robinson, Bill Shepherd, Brad Shutters, and Maryann Stec for help with data collection. Jessie Peissig and Mike Young provided helpful commentary throughout the conduct of these experiments. Correspondence should be addressed to S. L. Astley, Department of Psychology, Cornell College, 600 First St. W., Mt. Vernon, IA 52314-1098 (e-mail: astley@cornell-iowa.edu).

ment of classes to the designations C1, C2, C3, and C4 was counterbalanced across subjects. The design of this experiment is schematically represented in Figure 1. In original training, 12 diverse exemplars from each of two classes (C1 and C2) were associated with one common response (R1), and 12 diverse exemplars from each of the other two classes (C3 and C4) were associated with a second common response (R2). In reassignment training, the exemplars from C1 and C3 were associated with two new responses (R3 and R4, respectively), and the exemplars from C2 and C4 were withheld. During testing, performance of R3 versus R4 was measured to the exemplars from C1, C2, C3, and C4. The reinforcement contingencies were the same as in reassignment training for exemplars from C1 and C3, but responses were non-differentially reinforced to exemplars from C2 and C4.

If association with a common response bound the C1 + C2 and C3 + C4 combinations together, then in testing, exemplars from C2 should predominantly occasion R3 and exemplars from C4 should predominantly occasion R4, even though these stimulus-response combinations were never explicitly trained. The results were consistent with this hypothesis: After several blocks of original training, each followed by a block of reassignment training, responses in testing that accorded with the reassignment training contingencies significantly exceeded chance for the reassigned classes (C1 and C3 = 87%) and for the nonreassigned classes (C2 and C4 = 72%), although responding to the reassigned stimuli significantly surpassed that to the nonreassigned stimuli. These results show that association with a common response can produce categories of perceptually different but functionally equivalent stimuli even when the com-

ponent classes themselves comprise many complex and multidimensional stimuli.

These studies clearly demonstrate the ability of pigeons to form categories that go beyond perceptual similarity. The importance of this demonstration relates to Herrnstein's (1990) assertion that a true concept comprises stimuli that are tied together by relations that are not based solely on perceptual similarity. In a truly conceptual category, Herrnstein argued, "The effects of contingencies applied to members of the set propagate to other members more than can be accounted for by the similarities among members of the set" (Herrnstein, 1990, p. 150). The studies cited above (Hall et al., 1993; Honey & Hall, 1989; Urcuioli et al., 1989; Wasserman et al., 1992) satisfy Herrnstein's criterion.

These results notwithstanding, we may wish to consider an additional issue in the documentation of true conceptual behavior. A brief discussion of a type of nonsimilarity-based category shown in humans may be helpful as an introduction.

Rosch and her colleagues have noted that our linguistic labeling system for objects has a hierarchical quality (e.g., Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). Categories like tree, table, and car are at the basic level. Nested within the basic level and, thus, more narrowly defined are subordinate categories—groupings like oak tree, kitchen table, and sports car. Inclusive of several basic-level categories and, thus, more broadly constituted are superordinate categories—groupings like plant, furniture, and vehicle.

Rosch et al. (1976) found that perceptual similarity is not the basis for superordinate categories; superordinate categories encompass perceptually diverse basic-level categories. An additional noteworthy attribute of superordinate categories is that they are open ended; the name "furniture," for example, is not reserved for the familiar lamps and chairs in our own homes, but it is also applicable to other lamps and chairs that we see for the first time. If we are effectively to model in animals the sorts of cognitive processes that may underlie superordinate categorization in humans, then we must document that the categories formed by common associates are open sets; that is, we must show that the categorization that is created by association with a common response generalizes to novel exemplars.

The first three experiments that we report examine generalization to novel exemplars from the classes joined by a common response using the experimental design of Wasserman et al. (1992). Experiment 4 also examines generalization in the opposite direction: from novel exemplars to the exemplars joined by a common response in the first phase of training.

EXPERIMENT 1

In this first experiment, we sought to replicate the findings of Wasserman et al. (1992) with our laboratory's current instrumentation, which uses touch-screen technology rather than mechanical recording of pecks and

Figure 1. A schematic diagram of the three-phase procedure used in Wasserman, DeVolder, and Coppage (1992) and in Experiments 1–3. The designations C1, C2, C3, and C4 represent the perceptual classes *people*, *flowers*, *cars*, and *chairs*. The designations R1, R2, R3, and R4 represent pecks to one of the four keys surrounding the area on which the photographic stimuli were displayed.

presentation of stimuli from CD ROM rather than slide projectors. Most importantly, we introduced novel stimuli from the component classes joined in the first phase of training in order to see whether the categorization produced by a common response would generalize to novel exemplars.

If original training created a superordinate category that is truly conceptual—that is, the effects of training generalize to new exemplars—then the percentage of correct choices in the presence of novel C1, C2, C3, and C4 stimuli should be above chance. Accuracy may not, however, equal that to the C1 and C3 stimuli used in reassignment training.

Figure 2 depicts the processes of primary and secondary stimulus generalization that may operate in this paradigm. This analysis predicts that responding to the reassigned stimuli (C1 and C3) should be highest because they have received direct reassignment training. The percentage of correct choices should be lower to the novel reassigned-class stimuli (depicted as C1' and C3') due to primary stimulus generalization decrement. The percentage of correct choices should also be lower to familiar nonreassigned-class stimuli (C2 and C4) due to secondary generalization decrement (Hull, 1943). These stimuli should only indirectly benefit from reassignment training; although not presented during reassignment training, these stimuli are associated via a common response with the stimuli that receive reassignment training.

It is difficult to say whether primary stimulus generalization decrement or secondary stimulus generalization decrement will be stronger; so, it is difficult to predict whether there will be higher accuracy to C1' and C3' or to C2 and C4. Bhatt, Wasserman, Reynolds, and Knauss (1988) studied generalization to novel exemplars after four-choice classification training with stimuli like those used here; their data provide an estimate of the degree of primary stimulus generalization decrement that we might expect. There, accuracy to the old slides averaged 81%

and to the new ones it averaged 64%. The Wasserman et al. (1992) study of nonsimilarity-based categorization gives us an estimate of the amount of secondary stimulus generalization decrement that we might expect. There, accuracy to the reassigned stimuli averaged 89% and to the nonreassigned stimuli it averaged 72%. Although the decrements in these two experiments were numerically equivalent (−17%), the latter actually represents a greater decline because there were only two choice alternatives there rather than the four choice alternatives in Bhatt et al. Thus, we anticipate that accuracy to the novel reassigned-class exemplars (C1' and C3') will be higher, on average, than accuracy to the familiar nonreassigned class exemplars (C2 and C4); that is, secondary stimulus generalization decrement should exceed primary stimulus generalization decrement.

Lowest in accuracy, but possibly still above chance, should be the novel nonreassigned-class stimuli (C2' and C4'). As can be seen in Figure 2, the C2' and C4' stimuli receive primary generalization from the C2 and C4 stimuli and the C2 and C4 stimuli receive secondary generalization from the C1 and C3 stimuli. Because there is likely to be generalization decrement over both of these links (C1 and C3 to C2 and C4; C2 and C4 to C2' and C4'), the C2' and C4' stimuli are likely to suffer a double decrement and correct responding to them is likely to be rather low.

In summary, then, we expect the highest accuracy to the C1 and C3 stimuli, next highest accuracy to the C1' and C3' stimuli, second lowest accuracy to the C2 and C4 stimuli, and lowest accuracy of all to the C2' and C4' stimuli.

Method

Subjects

Sixteen experimentally naive pigeons served as subjects.¹ Originally obtained from the wild, the pigeons were kept in the laboratory colony for several weeks before the experiment to acclimate

Figure 2. The processes hypothesized to be responsible for transfer among stimuli in Experiments 1–3. The symbols C1, C2, C3, and C4 represent familiar stimuli in the perceptual classes *people*, *flowers*, *cars*, and *chairs*, and the symbols C1', C2', C3', and C4' represent novel exemplars from these classes.

them to handling by humans and to establish ad-lib weights. Throughout the experiment, the pigeons were housed in individual cages kept in a room in which the lights were turned on at 7:00 A.M. and off at 9:00 P.M. daily. The birds were maintained at 85% of their free-feeding weights. Unlimited water and grit were provided daily in their home cages.

Apparatus

All of the experiments used four locally built wooden chambers. The walls of each chamber were lined with brushed aluminum panels. One wall of the chamber contained a large opening framed with a panel of brushed aluminum. The frame held a clear touch screen (Elmwood Sensors, DuraTouch Model 70056-001). Pecks to the touch screen were processed by a serial controller board (Elographics, Model E271-2200). A brushed aluminum panel was placed directly in front of the touch screen to allow the pigeon access to circumscribed areas of the touch screen and a video monitor behind the touch screen. The 13-in. Apple color monitor was located behind the touch screen (0.9 cm from the monitor's center and 1.1 cm from its outer edges, the difference being due to the monitor's convex curvature). There were five openings in the panel covering the touch screen. One opening in the center of the panel was a 7×7 cm display area for photographs. Four round (1.9 cm in diameter) openings each located 2.3 cm from one of the four corners of the central opening served as report buttons. When the report buttons were operative, each was lit with a different color; the upper left was yellow, the upper right was red, the lower left was green, and the lower right was blue.

A clear Plexiglas food cup was centered on the rear wall of the chamber. To discourage the pigeon from perching on the food cup, it was recessed into the mesh floor so that the top of the cup was level with the floor. A pellet dispenser (MED Associates, Model ENV-203M) delivered 45-mg Noyes pigeon pellets through a vinyl tube into the food cup. A houselight, mounted on the upper rear wall of the chamber, provided constant illumination during experimental sessions. The houselight and pellet dispenser were controlled by a digital input/output (I/O) interface board (National Instruments, Model NB-DIO-24).

In two of the chambers, the control of the peripheral stimuli (through the I/O interface card) and the recording of subjects' responses (through the controller board) were accomplished by two Apple Macintosh IIfx computers equipped with Apple external CD ROM drives. In the other two chambers, the control of the peripheral stimuli and the recording of the subjects' responses were accomplished by two Apple Macintosh Quadra 650 computers with internal CD ROM drives. A video splitter (Network Technologies, Model Vopex 2M) and distribution amplifier (Extron, Model MAC/2 DA2) connected each computer to the pigeon's monitor and to an identical monitor in an adjacent room. Programs were developed in HyperCard (Version 2.2).

Materials

Ninety-two different slides—24 each of people, flowers, cars, and chairs—were used in this experiment. The stimulus objects were originally photographed with a 35-mm SLR Pentax Superprogram camera. Most of the images used in this and in subsequent experiments were also used by Wasserman et al. (1992); 6 additional images were chosen from the set of 2,000 originally used in Experiment 3 of Bhatt et al. (1988). The additional images were chosen using the criteria described in Astley and Wasserman (1992). Briefly, the images were selected for the simplicity and uniformity of the background across classes and for the diversity of the focal object. In addition, each of the images, except for flowers, contained no more than one example of the class. For the flower class, the images contained no more than five blooms from one plant. In addition, each of the exemplars was wholly or almost wholly represented within the viewing area, except for objects in

the class of people. The images of people contained at least a head and shoulders view. Every effort was made to ensure that a wide variety of backgrounds was represented within classes and that the backgrounds were similar across classes. Both indoor and outdoor photographs were used in all of the classes.

The photographs were transferred to a Kodak PhotoCD to be read by the HyperCard programs controlling the experimental events. The HyperCard programs displayed only the PICT files for the 384×256 images.

Procedure

Pretraining. Each of the pigeons was hand-shaped to peck the center and four corner buttons while the buttons were illuminated with uniform color stimuli. Once the pigeons reliably pecked the center and four corner buttons, the birds were transferred to training on a fixed-ratio (FR) schedule in which the response requirement gradually increased from FR 1 to FR 30. Every block of eight trials in FR pretraining comprised one trial with each of the four corner buttons and four trials with the center button.

Throughout each phase of this experiment, the intertrial interval (ITI) was randomly chosen from intervals of 11, 12, and 13 sec. In addition, the number of pellets given as reinforcement after correct choices was adjusted to maintain the weights of the pigeons at the 85% mark without supplemental feedings, to the extent possible. Experimental sessions were conducted daily.

Experimental training. Original training immediately followed FR pretraining. Twelve images each from the classes people, flowers, cars, and chairs were shown in this phase. Trials began with the presentation of an image in the central viewing area on the front panel of the chamber. Upon the pigeon's completion of an FI 10-sec requirement, two of the report buttons, the lower left (green) and the upper right (red), were illuminated. A single peck to one of these buttons constituted a choice, and, if correct, led to food. Incorrect choices led to a brief period (1.0–1.5 sec) during which the houselight was off followed by a correction trial. Correction trials were not scored and were given until a bird made the correct response.

For explanatory purposes, the four classes will be referred to as C1, C2, C3, and C4. The assignment of the actual classes to the abstract designations in different subgroups of subjects is depicted in Table 1. In addition, the responses to the lower left (green) and upper right (red) report buttons will be referred to as R1 and R2, respectively. The design of original training is schematically represented in the top portion of Figure 1. Note that R1 was the correct (i.e., reinforced) response when images from C1 and C2 were on the screen, whereas R2 was the correct response when images from C3 and C4 were on the screen. There were 192 trials in each daily session of original training; each block of 8 trials included two stimuli from each of the classes C1, C2, C3, and C4. Original training continued until a pigeon met a criterion of a mean of 80% correct in a single session.

Reassignment training began on the next session. The design of this phase of training is schematically represented in the middle portion of Figure 1. Trials in reassignment training were like those of original training except that images from only two of the classes, C1 and C3, were presented. In addition, two new report buttons, the upper left (yellow) and lower right (blue), were available upon completion of the FI requirement. The upper left and lower right report

Table 1
Assignment of Stimuli to C1, C2, C3, and C4
for the Subjects in all Four Experiments

Assignment	C1	C2	C3	C4
1	people	flowers	cars	chairs
2	flowers	people	chairs	cars
3	people	chairs	cars	flowers
4	chairs	people	flowers	cars

buttons, respectively, were assigned to the designations R3 and R4 equally often, so that the locations of the correct choices in reassignment training were either vertically or horizontally displaced from the locations of the correct choices in original training for a particular bird. Half of the birds got reassignment in a vertical direction; for C1 images the button designated as correct was the lower left button in original training and the upper left button in reassignment training, and for C3 images the button designated as correct was the upper right button in original training and the lower right button in reassignment training. The other half of the birds got reassignment in a horizontal direction. There were 192 trials in each daily session of reassignment training; each block of 8 trials included 4 trials each of stimuli from C1 and C3. Reassignment training continued until a bird met a criterion of a mean of 80% correct in a single session. Thereafter, alternating blocks of original training and reassignment training were given to criteria of 85% and then to 90% correct on each.

Test 1 began on the day immediately following attainment of the 90% correct criterion in reassignment training. Test 1 was designed to see whether we could replicate the functional stimulus equivalence observed in the Wasserman et al. (1992) study. Although we used most of the stimuli of the Wasserman et al. study, we could not use all of them because the area for presenting the photographs was now slightly narrower. In addition, our training procedure differed somewhat from that of the earlier experiment. Since our first goal was to see whether we could replicate the general findings of the Wasserman et al. study, Test 1 included only the exemplars used in original and assignment training.

During Test 1, performance of R3 versus R4 was measured to exemplars from the four classes (C1, C2, C3, and C4). If original training bound the C1 + C2 and C3 + C4 combinations into higher order categories, then exemplars from C2 should predominantly evoke R3 and exemplars from C4 should predominantly evoke R4, even though these stimulus-response combinations were not conditioned in training. In Test 1, responses to the C1 and C3 exemplars were differentially reinforced as they were in assignment training. Responses to the C2 and C4 exemplars were nondifferentially reinforced; pigeons received food whether they chose R3 or R4. Thus, there was no real "correct" response to the C2 and C4 exemplars. For convenience, however, we will refer to the choice of R3 to the C2 exemplars and to the choice of R4 to the C4 exemplars as correct responses. Each daily Test 1 session comprised 208 trials. There were 160 trials with stimuli from C1 and C3, and 48 trials with stimuli from C2 and C4 in each Test 1 session. Each block of 26 trials comprised 10 trials each with randomly selected stimuli from C1 and C3 and 3 trials each with randomly selected stimuli from C2 and C4. A relatively large proportion of trials with the C1 and the C3 stimuli was given in hopes that differential reinforcement would help maintain systematic responding in the Test 1 sessions. Test 1 lasted 2 days.

Following Test 1, each pigeon was given two further alternations of original and reassignment training to criteria of 90% correct. Each reexposure to original training lasted for a minimum of 2 days. Test 2A began on the session following the attainment of criterion on the second round of reassignment training.

During Test 2A, only R3 and R4 were available. Trials were given with both familiar exemplars (i.e., from original training) and novel exemplars (never-before-seen) from C1, C2, C3, and C4. The novel stimuli from the four classes will be designated as C1', C2', C3', and C4'. Responses to familiar C1 and C3 exemplars were differentially reinforced as in reassignment training and Test 1. Responses to familiar stimuli from C2 and C4 and to all novel exemplars were nondifferentially reinforced. As before, choice of R3 to the C2 exemplars and choice of R4 to the C4 exemplars (for both familiar and novel stimuli) were considered correct responses since this responding corresponded with the pairings established in orig-

inal training. In addition, choices for the C1' and C3' exemplars were considered to be correct if they corresponded with the choices differentially reinforced to the C1 and C3 exemplars.

Each Test 2A session comprised 160 trials. The first block of 16 trials was warm-up training with C1 and C3 stimuli only. Thereafter, trials were organized in blocks of 24, with each block containing 9 trials each with exemplars from C1 and C3, 1 trial each with a single exemplar from C2 and C4, and 1 trial each with a novel exemplar from the four classes C1', C2', C3', and C4'. Testing was conducted over four sessions so that each familiar C1 and C3 exemplar was presented a mean of 18 times, each familiar C2 and C4 exemplar was presented twice, and each novel exemplar from C1, C2, C3, and C4 was presented twice. Following Test 2A, pigeons were given one more exposure to original training and reassignment training to a criterion of 90% before embarking on Test 2B, which was identical to Test 2A.

Statistical analyses and data presentation. The Type I error rate was set at .05 for all analyses. The accuracy data described in the results sections of this and later experiments are that for testing sessions encompassing the first presentation of each test (nonreassigned and/or novel) stimulus. The first presentation data provides the best measure of response tendencies free from the effects of the nondifferential contingencies of reinforcement used in test sessions. Mean data over all testing sessions can be found in the notes.

Results

Pigeons required means of 12.4, 5.9, and 5.6 days to reach successive criteria of 80%, 85%, and 90% correct on original training prior to Test 1. Pigeons required means of 3.9, 2.1, and 2.5 days to reach the same successive criteria on reassignment training prior to Test 1. Two-tailed *t* tests were conducted on the number of days required to attain the final criterion and the counterbalancing factors. How the classes were paired with a common response (i.e., people with flowers and cars with chairs *or* people with chairs and cars with flowers) did not significantly affect the total number of days required to meet the 90% criterion in original training [$t(14) = 1.79$]. In addition, which of the classes were reassigned (i.e., people and cars *or* flowers and chairs) did not significantly affect the total number of days required to meet the 90% criterion in reassignment training [$t(14) = .93$]. The direction of button reassignment (i.e., vertical or horizontal) did significantly affect the total number of days the birds needed to meet the 90% criterion in reassignment training [$t(14) = 2.33$]; pigeons that had the buttons reassigned in a horizontal direction learned faster ($M = 7.1$ days) than did pigeons that had the buttons reassigned in a vertical direction ($M = 9.9$ days).

Pigeons maintained a high level of accuracy to the familiar stimuli from the reassigned classes (C1 and C3) on the 1st day of Test 1, as shown by a mean of 89.7% correct. This score significantly exceeded that expected by chance on a one-tailed binomial test ($z = 40.17$, $N = 2,560$). Accuracy to the familiar stimuli from the nonreassigned classes on the 1st day of Test 1 averaged 61.1%. This score was also significantly above chance on the binomial test ($z = 6.15$, $N = 768$).²

Following Test 1, all pigeons were reexposed to the original training and the reassignment training proce-

dures to a criterion of 90% in two reversals. Pigeons required means of 4.5, 1.8, 2.8, and 1.4 days, respectively, to reach criterion in the first original training, first assignment training, second original training, and second reassignment training periods after Test 1.

The mean percentage of correct choice responses on the first 2 days of Test 2A for the four types of stimuli (familiar reassigned, novel reassigned, familiar nonreassigned, and novel nonreassigned) is depicted in the left-most portion of Figure 3. Over the first 2 days of Test 2A, correct responding to the familiar stimuli from the reassigned classes averaged 92.0%. This score significantly exceeded chance on the binomial test ($z = 52.96$, $N = 3,968$). Correct responding to the familiar stimuli from the nonreassigned classes during the first 2 days of Test 2A averaged 61.6% (significantly above chance on the binomial test, $z = 4.59$, $N = 384$). Thus, overall, the differential choice responding to the familiar reassigned and familiar nonreassigned stimuli that was evidenced in Test 1 was maintained in Test 2A.

The pattern of responding to the novel stimuli in the reassigned and nonreassigned classes paralleled that to the familiar stimuli. Over the first 2 days of Test 2A, accuracy to the novel stimuli from the reassigned classes averaged 72.4%, which is significantly above chance on the binomial test ($z = 9.80$, $N = 384$). Responding to the novel stimuli from the nonreassigned classes over the

first 2 days of Test 2A averaged 55.7% correct.³ Although the magnitude of the effect was not numerically large, accuracy to these stimuli was significantly above chance on the binomial test ($z = 2.24$, $N = 384$).

A single reexposure to original and reassignment training to a 90% criterion preceded Test 2B. The birds required means of 3.6 and 1.6 days, respectively, to reach criterion on original and reassignment training. Pigeons maintained high accuracy to the familiar stimuli from the reassigned classes: 92.4% correct over the 4 days of Test 2B, which is significantly above chance ($z = 75.55$, $N = 7,936$). Levels of accuracy to the familiar stimuli from the nonreassigned classes and to all of the novel stimuli declined somewhat from Test 2A to 2B; this decline is not surprising given that all of these trials were nondifferentially reinforced throughout the testing sessions. The pigeons' 4-day mean of 68.2% correct to the novel stimuli from the reassigned classes was still significantly above chance ($z = 10.10$, $N = 768$). So too was the pigeons' 4-day mean of 61.9% correct to the familiar nonreassigned stimuli and the pigeons' 4-day mean of 53.3% correct to the novel nonreassigned stimuli ($z = 1.80$, $N = 768$).

Discussion

This experiment replicated and extended the findings of Wasserman et al. (1992). Connection with a common

Figure 3. Accuracy of choice responding in the four experiments described here. The data represent the first 2 days of testing in Experiment 1 (Test 2A), Experiment 2, and Experiment 3 and the first 4 days of testing in Experiment 4 because each C2, C4, and all novel stimuli were presented once during these testing periods. See the text for an explanation of terms used in the legend.

response in original training joined dissimilar classes of stimuli so that retraining with two of the component classes generalized to the other two classes at levels significantly above chance. In addition, later tests showed above-chance generalization to novel exemplars from each of the component classes, even though the magnitude of the effect for the novel stimuli from the nonreassigned classes was mathematically modest.

Exemplars from the nonreassigned classes should benefit from reassignment training via secondary or mediated generalization. That is, connection with a common response in original training is likely to have created a mediating link between the C1 + C2 and C3 + C4 pairs. This mediating link, then, permitted reassignment training to generalize from C1 to C2 and from C3 to C4. Transfer over this mediating link should not be perfect, however, and performance to the nonreassigned stimuli should be lower than to the reassigned stimuli; there should be a secondary generalization decrement to the C2 and C4 stimuli because correct responding to them is guided only by the mediating connections and not by the C1 and C3 stimuli themselves. In reassignment training with the C1 and C3 stimuli, R1 and R2 images or representations may have been associated with R3 and R4, respectively. In testing, then, the evocation of the R1 and R2 representations to the C2 and C4 stimuli should incline the birds toward making R3 in the presence of C2 stimuli and toward making R4 in the presence of C4 stimuli. Responding should nevertheless be higher to the C1 and C3 stimuli because responding to these stimuli would be guided *both* by the R1 and R2 representations *and* by direct association of the C1 and C3 stimuli with R3 and R4.

The novel stimulus trials in Tests 2A and 2B provide us with measures of primary stimulus generalization decrement. The difference in responding between familiar and novel stimuli in the reassigned and nonreassigned classes provides two separate measures of primary stimulus generalization decrement. The familiar–novel difference throughout Test 2A averaged 19% for the stimuli in the reassigned classes and 7% for stimuli in the nonreassigned classes. The smaller drop in the latter case is probably due to the lower level of accuracy controlled by the familiar stimuli in the nonreassigned classes than by the familiar stimuli in the reassigned classes.

Experiment 1 thus demonstrated reliable transfer of discriminative responding to novel exemplars from classes joined by a common response. Still, accuracy to novel exemplars from the classes that were not given explicit training with the new response was numerically low. We therefore considered changes in our procedure that might yield higher levels of performance to the novel exemplars from the nonreassigned classes. As noted, there are two processes linking the novel stimuli in the nonreassigned classes to those classes directly given reassignment training: primary and secondary stimulus generalization. In Experiment 2, we attempted to strengthen the latter.

EXPERIMENT 2

Our aim in this experiment was to strengthen secondary stimulus generalization. One might strengthen the C1 + C2 and C3 + C4 bonds by giving additional original training and/or training to a higher discrimination criterion. In several experiments involving full or partial reversals of a concurrent discrimination with two S+s and two S–s, Nakagawa (1986, 1992) found evidence for transfer of training between stimuli when the original discrimination was overtrained, but not when it was simply trained to criterion. To strengthen the C1 + C2 and C3 + C4 bonds in Experiment 2, pigeons were trained 3 days past their meeting the 90% criterion, and five reversals of original training and reassignment training were given before the first testing session.

In Experiment 1, there were slight declines in correct responding to test stimuli from Test 2A to 2B. These declines may have been due to the nondifferential reinforcement of responding to those stimuli during testing sessions. For that reason, novel exemplars were introduced in the very first testing session in Experiment 2 and only one testing phase (lasting 4 days) was given to minimize the effects of nondifferential reinforcement on discrimination performance.

Method

Subjects

The subjects were 8 experimentally naive pigeons obtained and maintained as described in Experiment 1.

Apparatus

This and all later experiments were conducted with four 7100/66 Macintosh computers. A distribution amplifier (Model MAC/2 DA2; Extron Electronic, Santa Fe Springs, CA) connected each computer to the pigeon's monitor and to an identical monitor in an adjacent room. Programs were developed in Hypercard (Version 2.3). Pecks to the touch screen (Accutouch, Model 002744-FTM-K1; Elographics, Oak Ridge, TN) were processed by a serial controller board (Model 002210-K1, Elographics). A 15-in. Apple color monitor was located behind the touch screen. Otherwise, the apparatus was just like that used in Experiment 1.

Procedure

Except as described below, Experiment 2 resembled Experiment 1. The period during which the houselight was extinguished following incorrect choice responses was 2 sec on each trial in this and all succeeding experiments. In Experiment 2, five reversals of original training and reassignment training were given before the first testing session. On the first two reversals, training was given to criteria of 80% and 85%, respectively. On the final three reversals, both original training and reassignment training were given until the birds maintained a percentage correct that was above 90% for 3 successive training days.

Novel stimuli were introduced in the first testing session of Experiment 2. Each of four daily sessions comprised 160 test trials. Trials were given in blocks of 24; each block tested nine C1 stimuli and nine C3 stimuli from the original training and reassignment training set, one C2 stimulus and one C4 stimulus from the original training set, and one novel stimulus from each of C1, C2, C3, and C4. Testing continued for 4 days. The C2, C4, and novel stim-

uli were rotated over days so that each stimulus was tested once every 2 days of testing and twice over all 4 days of testing.

Results

The mean numbers of days required to meet criterion on the five successive phases of original training were 7.7, 4.4, 6.1, 4.7, and 3.7, respectively. The mean numbers of days required on successive phases of reassignment training were 3.4, 1.4, 4.1, 3.4, and 3.1, respectively. The pairing of classes in original training (i.e., whether people were joined with flowers and cars were joined with chairs *or* people were joined with chairs and cars were joined with flowers) did not significantly affect the total number of days required to meet the final criterion in original training [$t(6) = 1.45$]. In addition, which of the classes were reassigned (i.e., people and cars *or* flowers and chairs) did not significantly affect the total number of days required to meet final criterion in reassignment training [$t(6) = .25$]. However, whether reassignment of responses took place in a vertical or horizontal direction did affect the total number of days required to meet the final criterion in reassignment training [$t(6) = 3.46$]; the mean number of days required to meet the final criterion in reassignment training was 17.0 for pigeons receiving reassignment in a vertical direction and 13.0 for birds receiving reassignment in a horizontal direction. Thus, as in Experiment 1, the birds that received reassignment of responses to a class in a horizontal direction learned faster than did those that received reassignment in a vertical direction.

Accuracy to the four types of stimuli on the first 2 days of testing is shown in the second panel from the left in Figure 3. Accuracy over the first 2 days of testing to the familiar stimuli from the reassigned classes averaged 94.2% correct, which was significantly above chance ($z = 39.33$, $N = 1,984$). Accuracy to the familiar stimuli from the nonreassigned classes on the first 2 days of testing was 65.2% correct, which was also significantly above chance ($z = 4.04$, $N = 192$).

The pattern of responding to the novel stimuli mirrored that to the familiar stimuli. On the first 2 days of testing, the birds averaged 74.5% correct to the novel stimuli from the reassigned classes, which was significantly above chance ($z = 6.78$, $N = 192$). The birds averaged 58.3% correct to the novel stimuli from the nonreassigned classes over the first 2 days of testing, which was significantly above chance ($z = 2.31$, $N = 192$).⁴

Comparison of the Results of Experiments 1 and 2

Because the objective of Experiment 2 was to strengthen the bond between component classes joined by a common response in original training by incorporating more reversals between original training and reassignment training and by overtraining, a comparison between Test 2A of Experiment 1 and the Testing sessions of Experiment 2 was in order; these testing phases were conducted over the same number of days and both included novel stim-

uli. For statistical analysis, percentage correct was transformed using the following logit function:

$$1/2 \ln p/(100-p).$$

This transformation was necessary to ensure equal variance across conditions; it has been highly recommended for percentage or proportion data (Cohen & Cohen, 1983).

A 2 (reassigned vs. nonreassigned classes) $\times$ 2 (familiar vs. novel stimuli) $\times$ 2 (Experiment 1 vs. Experiment 2) unweighted means analysis of variance (ANOVA) was conducted on the transformed percent correct choice scores for the first 2 days of testing, during which each nonreassigned and novel stimulus was presented once. This analysis yielded a significant main effect of whether the stimuli were reassigned or not [$F(1,22) = 82.35$], confirming the higher accuracy to reassigned than to nonreassigned stimuli. It also yielded a significant main effect of whether the stimuli were familiar or novel [$F(1,22) = 120.59$], confirming the higher accuracy to familiar than to novel stimuli. Finally, the analysis yielded a significant interaction between reassignment and familiarity [$F(1,22) = 31.20$], attesting to the larger drop in accuracy when novel stimuli were shown in the reassigned classes than in the nonreassigned classes. Follow-up analyses revealed a significant main effect of familiarity for the reassigned classes [$F(1,23) = 106.12$] and for the nonreassigned classes [$F(1,23) = 8.04$]. The main effect of experiment (Experiment 1 vs. Experiment 2) was not significant, nor was its interaction with either of the other factors.

Discussion

The goal of this experiment was to increase the strength of the bond between the stimuli that were paired with a common response in original training by increasing the number of alternations between original and reassignment training (from three to five) and by increasing the number of days (from 1 to 3) that the pigeons were required to exceed 90% correct before moving to testing. Analyses conducted on the transformed percent correct data yielded no evidence that the additional training given in Experiment 2 significantly increased the accuracy of performance to the nonreassigned class stimuli over that seen in Experiment 1. All of the mean scores in Experiment 2 were numerically greater than those in Experiment 1 (see Figure 3), but the increases failed to reach statistical significance.

Perhaps of greatest importance was the fact that we again found reliable secondary generalization that extended to novel stimuli at statistically significant levels.

EXPERIMENT 3

Earlier classification research in our laboratory revealed that increasing the number of exemplars in training from 1 to 4 to 12 increased generalization to novel stimuli (Bhatt et al., 1988; Wasserman & Bhatt, 1992). Thus, in

Experiment 3, we increased the number of exemplars per class in the training set from 12 to 24 with the hope of enhancing the magnitude of the transfer effects from familiar to novel stimuli.

Method

Subjects

Eight experimentally naive pigeons served as subjects. The birds were obtained and housed as described in Experiment 1.

Materials

The stimuli used in original training were increased from 12 to 24 for each of the four training classes. The added stimuli were selected from the 2,000 slides used in Experiment 3 of Bhatt et al. (1988) using the criteria described in the present Experiment 1.

Procedure

Shaping and pretraining were as described in Experiment 1. Original and reassignment training were as in Experiment 1 except with 24 exemplars per class rather than 12. In each daily session, each stimulus appeared twice in the 192 trials of original training and each stimulus from C1 and C3 appeared four times in the 192 trials of reassignment training.

There were 4 days of testing that included both familiar and novel stimuli from the four classes. There were 160 trials in each session, with trials blocked as in Experiments 1 and 2. The same set of 12 novel exemplars per class served as the testing set in this experiment, as in Experiments 1 and 2. The stimuli were rotated over test sessions so that half of the novel stimuli in each class appeared on each day of testing.

Results

Pigeons required means of 11.7, 6.9, and 8.0 days to reach criterion on the first, second, and third rounds of original training. The birds required means of 4.6, 3.4, and 3.3 days to reach criterion on the first, second, and third rounds of reassignment training. The pairing of classes in original training (i.e., whether people were paired with flowers and cars were paired with chairs *or* people were paired with chairs and cars were paired with flowers) did not significantly affect the total number of days required to meet the final criterion in original training [$t(6) = .58$]. In addition, which of the classes were reassigned (i.e., people and cars *or* flowers and chairs) did not significantly affect the total number of days required to meet criterion in reassignment training [$t(6) = .60$], nor did whether the reassignment of responses took place in a vertical or horizontal direction [$t(6) = .60$].

Accuracy to the four types of stimuli on the first 2 days of testing is depicted in the second panel from the right in Figure 3. The choice data in testing were similar to those obtained in Experiments 1 and 2. On the first 2 days of testing, the pigeons maintained a high level of differential choice responding to the familiar stimuli from the reassigned classes; accuracy averaged 89.5% correct, which was significantly above chance ($z = 35.15$, $N = 1,984$). In addition, the birds maintained a moderate level of differential choice responding to the familiar stimuli from the nonreassigned classes; accuracy averaged 64.1%

correct over the first 2 days of testing, which was significantly above chance ($z = 3.90$, $N = 192$).

As in the previous experiments, the pattern of response to the novel exemplars mirrored that to the familiar stimuli. Over the first 2 days of Testing, accuracy to the novel stimuli from the reassigned classes averaged 77.6% correct, which was significantly above chance ($z = 7.65$, $N = 192$). Over the first 2 days of testing, accuracy to the novel stimuli from the nonreassigned classes averaged 53.6% correct, which was not significantly above chance ($z = 1.01$, $N = 192$).⁵

Comparison of the Results of Experiments 1 and 3

Wasserman and Bhatt (1992) found that increasing the number of exemplars in a classification task from 1 to 4 to 12 significantly decreased pigeons' speed of learning. A comparison of the speed of learning the original training task to final criterion in Experiment 1 with that in Experiment 3 revealed no significant difference [$t(22) = .63$]. A comparison of Experiment 1 with Experiment 3 on the speed of learning the reassignment task also revealed no significant difference [$t(22) = 1.86$].

We conducted a 2 (reassigned vs. nonreassigned classes) $\times$ 2 (familiar vs. novel) $\times$ 2 (Experiment 1 vs. Experiment 3) unweighted means ANOVA on the logit-transformed mean percent correct choice scores on the first 2 days of testing, during which each familiar stimulus from C2 and C4 and each novel stimulus from all four classes was presented once. This analysis disclosed a significant main effect of reassignment [$F(1,22) = 59.62$] and a significant main effect of familiarity [$F(1,22) = 56.84$]; once again, accuracy to reassigned stimuli exceeded that to nonreassigned stimuli, and accuracy to familiar stimuli exceeded that to novel stimuli. There was also a significant reassignment $\times$ familiarity interaction [$F(1,22) = 13.47$], with a larger familiar–novel disparity for reassigned stimuli than for nonreassigned stimuli. Finally, there was a significant experiment $\times$ reassignment by familiarity interaction [$F(1,22) = 5.32$]. Follow-up analyses on the latter interaction showed a nonsignificant experiment $\times$ familiarity interaction for the nonreassigned stimuli [$F(1,22) = 1.02$], but a significant experiment $\times$ familiarity interaction for the reassigned stimuli [$F(1,22) = 4.40$]. Further examination of the latter interaction showed a significant effect of familiarity in Experiment 1 [$F(1,15) = 64.24$] and in Experiment 3 [$F(1,7) = 8.62$]. Because the F statistic does not allow comparison of the size of effects across experiments, we also calculated the size of the familiarity effect in the two experiments using ω^2 (Dodd & Schultz, 1973). This analysis revealed that familiarity accounted for 59% of the variance in Experiment 1, but only 27% of the variance in Experiment 3. Thus, increasing class set size did reduce the magnitude of the primary stimulus generalization decrement, but only for the reassigned classes, not for the nonreassigned classes. There was no main effect of ex-

periment or any other significant interactions between the experiment factor and the two others.

Discussion

This experiment replicated most of the results of the previous experiments in that it documented transfer between stimuli bound together by a common response and generalization to novel exemplars from the reassigned class.

The effects of increasing the number of exemplars per class were mixed, however. Whereas Wasserman and Bhatt (1992) found that increasing the number of exemplars per class from 1 to 4 to 12 reduced the speed of learning a four-choice classification task, we found no such slowing of learning by increasing the number of exemplars per class from 12 in Experiment 1 to 24 in Experiment 3. That increase did reduce the amount of generalization decrement between familiar and novel stimuli in the reassigned classes; however, it did not reduce the amount of primary stimulus generalization decrement in the nonreassigned classes.

It is not clear why an increase in the number of exemplars per class should increase generalization to novel exemplars only for the reassigned classes. Recent experiments (Astley & Wasserman, 1998b) also using 24 exemplars per class in training revealed equivalent generalization from familiar to novel exemplars for *all* classes of stimuli. These more recent experiments used delay or probability of reinforcement as potential binding cues in the first phase of the experiment rather than association with a common response. The results of the Astley and Wasserman (1998b) experiments suggest that there may have been unique factors present in Experiment 3 (including random variation) that produced different effects among reassigned compared with nonreassigned stimuli.

EXPERIMENT 4

Figure 2, discussed earlier, depicts the processes that may account for the results that we have observed in the

three prior experiments. Reassignment training may affect novel exemplars through primary stimulus generalization, and it may affect familiar exemplars from the nonreassigned classes through secondary stimulus generalization. As a further examination of transfer along these different associative pathways, we next examined reassignment training with *novel* exemplars rather than with the *familiar* exemplars previously seen in original training.

In Experiment 4, reassignment training was given with novel stimuli from C1 and C3 before transfer tests with familiar and novel stimuli from C1, C2, C3, and C4. Figure 4 depicts the hypothesized sources of associative transfer in this experiment. The novel stimuli used in reassignment training are depicted as C1'' and C3''. Note that we expect transfer via primary stimulus generalization from C1'' and C3'' exemplars to both familiar (C1 and C3) and novel (C1' and C3') stimuli from the reassigned classes. We expect transfer over two links to familiar stimuli from C2 and C4 as well. One link is primary stimulus generalization from the reassigned C1'' and C3'' stimuli to the familiar C1 and C3 stimuli; the second link is secondary stimulus generalization from the familiar C1 and C3 stimuli to the familiar C2 and C4 stimuli. Finally, we expect transfer to the novel C2 and C4 stimuli (C2' and C4') via three links. The two links described above for transfer to the familiar C2 and C4 stimuli apply to the novel stimuli from those classes; in addition, the C2' and C4' stimuli should be affected by primary stimulus generalization from the familiar C2 and C4 stimuli. Because transfer via each of these links entails stimulus generalization decrement, we expect the highest transfer performance to the familiar C1 and C3 stimuli and to the C1' and C3' stimuli; we expect approximately equal levels of performance to familiar and novel stimuli from C1 and C3 because primary stimulus generalization alone produces transfer to both. We expect somewhat lower levels of performance to the familiar C2 and C4 stimuli. And, we expect the lowest performance to the novel C2 and C4 stimuli. Indeed, given the substan-

Figure 4. The processes hypothesized to be responsible for transfer among stimuli in Experiment 4. The symbols C1, C2, C3, and C4 represent stimuli in the perceptual classes *people*, *flowers*, *cars*, and *chairs* that were used in original training; the symbols C1'' and C3'' represent stimuli that were novel at the time of their introduction in reassignment training; and the symbols C1', C2', C3', and C4' represent completely novel stimuli.

tial levels of primary and secondary stimulus generalization decrement observed in our earlier studies, there is reason to expect that performance to the novel C2 and C4 stimuli might not exceed chance levels.

Method

Subjects

The subjects were 4 experimentally naive pigeons and 4 other pigeons that had previously served in object recognition experiments with black-and-white line drawings as stimuli. There were no statistically significant differences between the birds that were experimentally naive and those with previous experience except on one measure, described below. The birds were obtained and housed as described in Experiment 1.

Materials

An additional set of 24 stimuli per class was selected to serve as the reassignment set. In addition, 12 stimuli per class were selected to be added to the novel test stimuli in order to expand that set from 12 to 24 exemplars per class. The stimuli were selected in the same manner as those in Experiment 1. Thus, the original training, reassignment training, and testing sets each included 24 exemplars per class.

Procedure

Shaping and pretraining for the naive birds were as described for Experiment 1. The non-naive birds were given 1 to 2 days on the pretraining procedure before beginning the experiment.

Original training was conducted as it was in Experiment 3, but reassignment training was conducted with the set of 24 novel exemplars per class from C1 and C2 described above. There were 192 trials per session; trials were blocked as in the earlier experiments.

There were 172 trials in each testing session. The first 16 trials in each testing session included only C1 and C3 stimuli from reassignment training. Thereafter, each block of 26 trials included nine stimuli each from the C1 and C3 sets used in reassignment training, one stimulus from each of the four class sets used in original training, and one novel stimulus from each of the four classes. The original training and novel stimuli were rotated over the 4 days of testing so that one fourth appeared on test trials each day; thus, each stimulus was presented only once during the 4 days of testing. For purposes of comparison, the 12 novel stimuli from each of the four classes that were presented during the first 2 days of testing were identical to the novel testing stimuli in the previous three experiments; the remaining 12 novel stimuli from each of the four classes were presented during the second 2 days of testing.

Results

The pigeons required means of 8.4, 3.0, and 5.1 days to reach criterion on the first, second, and third rounds of original training. The birds required means of 3.4, 2.2, and 2.6 days to reach criterion on the first, second, and third rounds of reassignment training. Two-tailed t tests were conducted of the relationship between the number of days required for acquisition and the counterbalancing factors. How the classes were paired with a common response (i.e., whether people were paired with flowers and cars were paired with chairs *or* whether people were paired with chairs and cars were paired with flowers) did not significantly affect the total number of days required to meet the final criterion in original training [$t(6) = 1.99$]. In addition, which of the classes were reassigned (i.e., people and cars *or* flowers and chairs) did not significantly

affect the total number of days required to meet the final criterion in reassignment training [$t(6) = .96$]. Finally, the direction of reassignment of the correct buttons (i.e., whether vertical or horizontal) did not significantly affect the total number of days required to meet the final criterion in reassignment training [$t(6) = .46$].

The right-most panel in Figure 3 depicts the results of the choice tests over all 4 days of testing. Because the pool of novel testing stimuli was expanded in this experiment, all 4 days of testing were required for the pigeons to be tested once on each novel stimulus. The 24 novel stimuli that were differentially reinforced on choice trials in reassignment training and in testing are called "reassigned/novel-in-choice training stimuli." The reassigned-class stimuli that were used in original training are called "reassigned/familiar, withheld-in-choice training stimuli." Finally, the reassigned-class stimuli that were completely novel until the testing sessions are called "reassigned/novel-in-testing stimuli."

Over all 4 days of testing, the pigeons maintained a mean of 91.5% correct to the reassigned/novel-in-choice training stimuli. This level was significantly above chance on the binomial test ($z = 50.13$, $N = 3,648$). The experimentally naive birds and those with previous experience differed significantly on accuracy to the reassigned/novel-in-choice training stimuli [$t(6) = 3.51$]. The accuracy of the birds with prior experience ($M = 93.1\%$) was higher than the accuracy of the birds with no prior experience ($M = 89.8\%$). As noted, the experimentally naive and experienced birds did not differ on any other behavioral measures.

The 4-day means for the reassigned/familiar, withheld-in-choice training stimuli and the reassigned/novel-in-testing stimuli were 76.0% (significantly above chance, $z = 10.18$, $N = 384$) and 74.5% correct (significantly above chance, $z = 9.60$, $N = 384$), respectively.

Over all 4 days of testing, accuracy to the familiar stimuli from the nonreassigned classes averaged 56.2%, which was significantly above chance ($z = 2.44$, $N = 384$). Accuracy to the novel stimuli from the nonreassigned classes averaged 55.2%, which was also significantly above chance ($z = 2.04$, $N = 384$).

Comparison of the Results of Experiments 3 and 4

We compared the results of Experiments 3 and 4 to evaluate the effectiveness of reassignment training with familiar stimuli versus novel stimuli. Both experiments included the same set of 24 exemplars in each of the four classes in original training and both used the same set of 12 exemplars per class in the first 2 days of testing.

A repeated-measures ANOVA comparing the reassigned/familiar, withheld-in-choice training stimuli and the reassigned/novel-in-testing stimuli in Experiment 4 revealed no reliable difference [$F(1,7) = .42$]. Thus, accuracy to the reassigned/familiar, withheld-in-choice training stimuli was averaged with accuracy to the reassigned/novel-in-testing stimuli for inclusion in the analyses described below; this combining was done so that the anal-

ysis might compare transfer from stimuli directly given choice training in the reassignment training phase (i.e., the reassigned familiar stimuli in Experiment 3 and the reassigned/novel-in-choice training stimuli in Experiment 4) with the same-class stimuli that were not shown during the reassignment training phase (i.e., the reassigned novel stimuli in Experiment 3 and the reassigned/familiar, withheld-in-choice training stimuli and the reassigned/novel-in-testing stimuli in Experiment 4). A 2 (choice trained vs. not choice trained) $\times$ 2 (Experiment 3 vs. Experiment 4) repeated measures ANOVA was conducted on the logit-transformed choice accuracy scores to the reassigned-class stimuli during the first 2 days of testing. This analysis yielded a significant effect of choice training [$F(1,15) = 26.59$], but no significant effect of experiment or any significant interaction. The reliable effect of choice training indicates that accuracy was reliably higher to the stimuli that were given in choice training than it was to different stimuli from the same classes. The lack of a reliable experiment effect or interaction involving this factor suggests similar levels of transfer from novel to familiar stimuli in Experiment 4 and from familiar to novel stimuli in Experiment 3.

As mentioned earlier, processes that might reasonably affect the familiar nonreassigned stimuli in Experiment 4 are not equivalent to those that might affect their counterparts in the earlier experiments. Specifically, the familiar nonreassigned stimuli in Experiment 4 should experience both primary and secondary stimulus generalization decrement, whereas the familiar nonreassigned stimuli in the other experiments should experience only secondary stimulus generalization decrement. The stimuli in Experiment 3 that experienced both primary and secondary stimulus generalization decrement were the nonreassigned novel stimuli. A one-way ANOVA comparing accuracy with the nonreassigned novel stimuli from Experiment 3 with the nonreassigned familiar stimuli of Experiment 4 revealed no significant difference [$F(1,14) = 2.55$] in the logit-transformed percent correct scores across experiments. Unfortunately, comparison of the nonreassigned novel stimuli of Experiment 3 with the nonreassigned familiar stimuli of Experiment 4 involves comparison of measures close to the performance floor of 50%, and the finding of no difference is of limited utility.

Discussion

This experiment showed that transfer of training via primary and secondary stimulus generalization does not depend on reassignment training being conducted with the same stimuli that were shown in original training. Here, when reassignment training was done with novel stimuli from two of the classes joined in original training, approximately equal levels of transfer were observed to the stimuli from original training and to completely novel stimuli from the reassigned classes. The presumed basis for this transfer is primary stimulus generalization; that is, the pigeons responded to the reassigned-class test stimuli as

they did to those given differential training because the stimuli resembled one another.

GENERAL DISCUSSION

These four experiments replicate and extend the findings of Wasserman et al. (1992). Here, we again found that association with a common response linked perceptually distinct stimuli so that they were treated in the same way in later testing sessions. In three of the four experiments reported here, these effects also transferred to novel stimuli at levels that were significantly above chance. Although the latter effects were small in magnitude, they were reliable and demonstrable even when many features of the training procedure were varied.

Two features of the results of the present series of experiments remain puzzling. We noted earlier that we could not explain why performance to the novel nonreassigned-class stimuli was reliably above chance in all experiments except Experiment 3. In addition, it is odd that we obtained evidence that the direction of button reassignment (i.e., whether responses were reassigned in a vertical or horizontal direction) made a difference in Experiments 1 and 2, but not in Experiments 3 and 4. Response generalization can explain the direction of reassignment effect; it is easy to imagine that responses to keys in the same horizontal plane might be more similar to one another than are responses to keys in the same vertical plane. If this is the case, however, the effect should have been seen in all four experiments, and it was not. We have no explanation for this difference between experiments.

How might we account for the main results of our experiments? Earlier in this paper and elsewhere (Wasserman & Astley, 1994) we have provided an account of superordinate conceptualization in terms of secondary, or mediated, generalization. Urcuioli (1996) has applied this account to similar results obtained with a matching-to-sample procedure.

In his classic 1943 book, Hull postulated that an overt behavior that was conditioned to two stimuli might mediate transfer of responding between them. In support of this notion, Hull cited a study by Shipley (1935) in which an eyeblink was conditioned to a light. Trials were later given with a shock to the finger, which evoked both an eyeblink and retraction of the finger. Then in testing sessions, the light was again presented; it now elicited finger retraction. "The interpretation is that the light evoked the lid closure, and the proprioceptive stimulation produced by this act (or some other less conspicuous act conditioned at the same time) evoked the finger retraction" (Hull, 1943, p. 192). The notion of mediated generalization has received extensive consideration over the years, and salient discussions of the issue have been published by Osgood (1953), Underwood (1966), and Kendler and Kendler (1975).

Although an overt response was central to Hull's (1943) conceptualization, secondary generalization may not re-

quire overt mediating behavior. Research concerning "coding," cited earlier, has shown that animals may transform events into stimulus codes that guide later behavior. Hall (1996) reviewed evidence suggesting that associatively evoked central representations of stimuli (what he calls "images") can form further associative links.

We do not know what the nature of the mediator might be in our study; incipient responses or central representations of those responses might be the crucial link. Nevertheless, the model depicted in Figure 5 illustrates the general process that might account for the linking of perceptually distinct classes by association with a common response. For simplicity of explanation, only the C1 and C2 classes will be discussed. In this scheme, original training produces associations of C1 with R1 and of C2 with R1; these associations endow the C1 and C2 stimuli with the ability to evoke an incipient response (r1) and/or the stimulus (proprioceptive) consequences of that response (s1). In reassignment training, both C1 stimuli and r1 → s1 cues become associated with R3. When the C2 stimuli are introduced in testing with R3 and R4 as possible responses, the C2 stimuli evoke the r1 → s1 cues that have preceded reinforcement of R3 in the past. According to the mediational model, because of the r1 → s1 link, pigeons will tend to make R3 to C2 stimuli even though R3 has never been reinforced in the presence of C2 stimuli. Again, we do not know whether incipient responses might be crucial to our results or whether the central representation of those responses is the real mediator, but the general approach is the same in either case.

Urcuioli (1996) has pointed out that one way to test the mediational account of equivalence in matching-to-sample is to change the order of training. The change in our procedure that is equivalent to that proposed by Ur-

cuioli would be to change the order of original training and reassignment training (and not to alternate them as we did here). If reassignment training were given before original training, then the r1 → s1 links depicted in Figure 5 would not be present prior to the reinforcement of R3 in reassignment training. This order of training should produce chance performance in testing, because the r1 → s1 cues would not prompt choice of R3 in the presence of the C2 stimuli. Future research will compare performance of subjects receiving original training before reassignment training with performance of those receiving reassignment training before original training as a test of our mediational model.

Another avenue of research that we are pursuing is to explore other events (in addition to association with a common response) that might serve to join perceptually different classes together into a superordinate category. Preliminary results of these studies indicate that pigeons strongly generalize a choice response from members of one perceptual class to another when the classes have been associated with a common delay or probability of reinforcement. In contrast to the small but measureable generalization observed in the present study to the novel nonreassigned stimuli (averaging 56% correct across all four experiments), these later studies (Astley & Wasserman, 1998b) have revealed much higher generalization (averaging 67% correct). We are thus very confident that even a double dose of generalization decrement—both primary and secondary (see Figure 2)—is not enough to eradicate evidence of superordinate categorization behavior in pigeons.

A related manipulation that might produce a similarly strong link between perceptual classes involves varying the number of pellets given as reinforcement. This manipulation is presently under study in our laboratory, but we have no preliminary data to report.

Other possible treatments, however, such as association with a common location or context, might provide a less salient link between the component classes. Our plans for the future include exploring these questions and others concerning the creation and generality of nonsimilarity-based categories.

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Figure 5. The processes hypothesized to be responsible for transfer between familiar reassigned and familiar nonreassigned stimuli in Experiments 1-3. The uppercase letters stand for observable stimuli and responses, and the lowercase letters stand for hypothesized internal stimuli and responses.

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NOTES

1. One additional subject was dropped from the experiment because it was unable to meet the criterion of 85% correct in original training even after 57 days of training. It was replaced by a pigeon that was successful in attaining all of the training criteria.
2. Accuracy to the familiar stimuli from the reassigned classes averaged over both days of Test 1 was 89.1%, and accuracy to the familiar stimuli from the nonreassigned classes was 60.9%.
3. Over all 4 days of Test 2A, the pigeons averaged 92.1% correct to the familiar stimuli from the reassigned classes and 62.4% correct to the familiar stimuli from the nonreassigned classes. Responding to the novel stimuli from the reassigned classes averaged 72.7% correct over the 4 days of Test 2A and accuracy to the novel stimuli from the nonreassigned classes averaged 55.5% correct.
4. Over all four testing sessions, accuracy to the familiar reassigned class stimuli averaged 94.6% correct and that to the familiar nonreassigned class stimuli averaged 64.1% correct. The 4-day average percent correct to the novel reassigned class stimuli was 69.8% and that to the novel nonreassigned class stimuli was 54.1%.
5. Accuracy to the familiar stimuli from the reassigned classes averaged 89.5% correct and to the familiar stimuli from the nonreassigned classes it averaged 58.1% correct over all 4 days of testing. Accuracy to the novel stimuli from the reassigned classes averaged 74.2% correct, and accuracy to the novel stimuli from the nonreassigned classes averaged 52.3% correct over the 4 days of testing.

(Manuscript received October 16, 1997;
revision accepted for publication February 6, 1998.)