

Common Coding in Pigeons Assessed Through Partial Versus Total Reversals of Many-to-One Conditional and Simple Discriminations

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Common coding of stimuli was examined in pigeons in 3 experiments involving many-to-one mapping of lines and hues onto common events. The common events were shapes in Experiment 1 (involving delayed symbolic matching-to-sample) and food-no-food outcomes in Experiments 2 and 3 (involving simple discriminations). In Phase 2 of Experiments 1 and 2, the hue discriminations were reversed for Group Hue, the line discriminations were reversed for Group Line, and both discriminations were reversed for Group Hue-Line. Line reversals were learned faster by Group Hue-Line than by Group Line, but differences in reversal learning were not found with hues. In Experiment 3, both hue and line discriminations were repeatedly reversed until reversal transfer was stable. Relative to this baseline, significantly poorer performance was found on a line-only reversal. Overall, the results suggest that when a hue and a line are associated with a common event, both may be centrally represented as the hue.

A stimulus class (Goldiamond, 1962) or concept (Kendler, 1961) can be broadly defined as a set of stimuli that control the same response. Stimulus classes may consist of stimuli that are related by their physical similarity (e.g., the concept *giraffe*), in which case one could parsimoniously interpret the common response as occurring because of stimulus generalization. On the other hand, a stimulus class may consist of "arbitrary" stimuli, related to each other through their association with a common event. The present experiments are concerned with stimulus classes involving such arbitrary stimuli.

One indication that pigeons are capable of acquiring an arbitrary stimulus class comes from an experiment involving two independently learned identity matching tasks (i.e., hue matching and shape matching), in which correct matches of one hue and one shape were followed by corn and correct matches of the other hue and the other shape were followed by wheat (Edwards, Jagielo, Zentall, & Hogan, 1982). On test sessions, when the hue samples were presented with shape comparisons and vice versa, the pigeons responded to the comparison associated with the same outcome as the sample (i.e., they showed evidence of forming a stimulus class defined by common outcome expectancy). The orthogonal relation

between hues and shapes precludes explanation of these transfer effects on the basis of differential stimulus similarity.

Stimulus-class formation of the type reported by Edwards et al. (1982) is probably mediated by a Pavlovian process, involving the association of the samples with biologically important outcomes. But if this finding is an instance of a more general process, then one should be able to demonstrate "common coding" in the context of arbitrary associations between nonhedonic stimuli. An example of such common coding was provided in a study by Spradlin, Cotter, and Baxley (1973) using retarded human adolescents. Spradlin et al. initially trained their subjects on a conditional discrimination in which each pair of sample stimuli was associated with a common comparison stimulus (e.g., A-C, B-C). In Phase 2, one member of each sample pair was associated with a new comparison stimulus (e.g., A-D). Finally, in Phase 3, subjects were tested for the presence of an association between the remaining member of each sample pair and the new comparison stimulus (i.e., B-D). Spradlin et al. found that subjects transferred to the new B-D associations at high levels of accuracy. One can conclude that their subjects had acquired a stimulus class ("AB"), through the association of A and B with a common response to C. In Phase 2, pairing A with D resulted in an association between the AB stimulus class and D and thus the association between B and D that was demonstrated in Phase 3.

Using a design analogous to that used by Spradlin et al. (1973), Urcuioli, Zentall, Jackson-Smith, and Steirn (1989, Experiment 2) initially trained pigeons on a many-to-one conditional discrimination involving hue and line samples. In Phase 2, the pigeons were trained on a second task involving the hue samples from Phase 1 and a new pair of comparison stimuli. In Phase 3, the pigeons matched the line samples from Phase 1 to the comparisons from Phase 2. For half the pigeons, the Phase 3 associations were consistent with the

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presumed stimulus classes developed in Phase 1. For the remaining pigeons, the Phase 3 associations were inconsistent with the stimulus classes. Results indicated that when the Phase 3 associations were consistent with the hypothesized stimulus classes, pigeons performed well above chance, whereas when the associations were inconsistent with the stimulus classes, performance levels were well below chance. Thus, under conditions analogous to those reported by Spradlin et al., evidence was found for the formation of stimulus classes in pigeons.

The results reported by Urcuioli et al. (1989) are also consistent with findings reported by Zentall, Urcuioli, Jagielo, and Jackson-Smith (1989), in which—following many-to-one training similar to that used by Urcuioli et al.—delay tests produced similarly sloping retention functions for hue- and line-sample trials, whereas for other mappings (one-to-one and one-to-many) retention functions for hue-sample trials were substantially flatter than for line-sample trials.

An alternative method for demonstrating stimulus class formation in pigeons has been described by Vaughan (1988). In Vaughan's experiment, pigeons were trained to respond to one set of 20 randomly selected slides (1+) and not peck to a second set of 20 (2-). Following acquisition, the contingencies were reversed (i.e., 2+/1-) and then reversed again, repeatedly. After a large number of reversals, the pigeons were able to discriminate the positive from the negative set following presentation of the first few stimuli in each set. Apparently, the pigeons had developed a common code or stimulus class for each of the two stimulus sets.

A variation of Vaughan's (1988) reversal procedure was described in a study by Nakagawa (1986). Rats were over-trained on two concurrent simple discriminations (e.g., black [B]+, white [W]-, vertical black and white stripes [V]+, horizontal stripes [H]-), after which they received either one of two partial reversals (B+, W-, V-, H+ or B-, W+, V+, H-) or a total reversal (B-, W+, V-, H+). Nakagawa found that rats that received a partial reversal took longer to learn their reversed task than did rats that received a total reversal. If the four associations in original training were independent of one another, one would have expected that the partial-reversal groups would have reversed faster than the total-reversal group because they had only two, rather than four, associations to relearn. Thus, Nakagawa's data suggest instead that the two stimuli associated with the same outcome (i.e., B and V with food and W and H with no food) were commonly coded. Consequently, it was easier for rats to subsequently reverse the class "labels" than to regroup the stimuli into new classes.

Experiment 1

If the many-to-one conditional discrimination used by Urcuioli et al. (1989) produces two stimulus classes (one associated with each comparison stimulus), then the partial- versus total-reversal procedure should produce a pattern of results similar to that reported by Nakagawa (1986). The purpose of Experiment 1, then, was to determine whether pigeons will learn a reversal faster if the correct comparison alternative for both members of a sample "pair" is reversed than if the

correct alternative changes for only one member of each pair. In other words, assuming that common sample-comparison associations establish two stimulus classes during original many-to-one training, will reversal learning be more rapid if the hypothesized stimulus classes remain intact (total reversal), than if those classes are broken up and redefined (partial reversal)? If so, this would provide further evidence that the associations underlying stimulus class formation do not have to involve a biologically important event such as the food (vs. no food) used by Nakagawa (1986) or the different types of food used by Edwards et al. (1982).

Method

Subjects

Subjects were 23 mixed-sex, White Carneaux pigeons, 5-8 yrs old, (retired breeders) obtained from the Palmetto Pigeon Plant (Sumter, South Carolina) and 3 homing pigeons obtained from a local breeder. They had all previously served as subjects in an unrelated experiment. The pigeons were individually caged and were maintained throughout the experiment at 75-80% of their free-feeding body weights. They had free access to water and grit, and the colony room in which the birds were housed was maintained on a 12-hr light-on-12-hr light-off cycle.

Apparatus

The experiment was conducted in a Lehigh Valley Electronics pigeon test chamber with a Model PIP-016 3-key intelligence panel. The compartment in the test chamber measured 37 cm (high) × 30 cm (wide) × 34 cm (deep). Three circular response keys (2.5-cm diameter) were mounted in a horizontal row 10 cm from the top of the panel and were spaced 8.3 cm center-to-center. Behind each pecking key was a 12-stimulus inline projector (Industrial Electronic Engineering with General Electric No. 1820 lamps) that projected red (R) and green (G) hues (Kodak Wratten filters No. 26 and 60, respectively) and three white vertical (V) or horizontal (H) lines (each 13 mm long × 3 mm wide and separated by 3 mm) on the center key, and a white annulus (C; 16-mm outside diameter, 13-mm inside diameter) or a white dot (D; 5-mm diameter) on the side keys. A rear-mounted grain feeder was centered on the intelligence panel midway between the floor and the pecking keys. Reinforcement throughout the experiment consisted of 2-s access to Purina Pigeon Grains. A shielded houselight mounted 7.6 cm above the center key provided general chamber illumination. White noise at 72 dB and an exhaust fan mounted on the outside of the chamber helped to mask extraneous sounds.

Procedure

Pretraining. All pigeons were initially adapted to the operant chamber for three 1-hr sessions and were then trained to eat from the grain feeder. They were then shaped by the method of successive approximations to peck a white field on the center key. Once key pecking was established, the stimulus on the center key was changed randomly following each reinforcement. Stimulus presentations were separated by a 10-s intertrial interval (ITI), with reinforcement presented during the first 2 s of the ITI. Each stimulus (R, G, V, and H) was presented 12 times. Over the next 2 days, the number of pecks required for reinforcement was increased first to 5 and then to 10.

On the next day, on each of 24 trials, the left or right key was lit with either C or D, and a single response resulted in reinforcement.

Phase 1 training. On the day following the end of pretraining, all birds began training on a 0-delay many-to-one matching task with R, G, V, and H samples and C and D comparisons. For all birds, R and V samples were associated with the C comparison, and G and H samples were associated with the D comparison. Each matching trial began with onset of one of the four possible sample stimuli from the center key. Ten pecks to the sample turned it off and immediately produced the two comparison stimuli on the adjacent side keys. A single peck to either side key then turned off both stimuli and initiated a 10-s ITI during which the houselight was lit. If the comparison choice response was correct, it was followed by reinforcement during the first 2 s of the ITI; otherwise, it was followed by the ITI alone.

Training sessions consisted of 96 trials each and were conducted 6 days a week. Sessions were counterbalanced for number of each sample and position of the correct comparison response. Trial types were randomly presented with the constraints that on no more than 3 consecutive trials could (a) a particular sample stimulus appear, (b) the position of the correct comparison be the same, or (c) a particular comparison be correct. Each pigeon was trained on the many-to-one matching task to a criterion of 2 consecutive sessions at 90% correct or better accuracy, with at least 20 correct choices (83% correct) on each of the four sample trial types. All birds were then overtrained for an additional 20 sessions.

Phase 2 transfer. As birds completed Phase 1, they were assigned to one of three groups, Group Hue ($n = 8$), Group Line ($n = 10$), or Group Hue-Line ($n = 8$). In assigning the birds to groups, an attempt was made to equate the groups for slow and fast learners. In addition, 1 homing pigeon was assigned to each group. For birds in Group Hue, the hue-sample (but not the line-sample) associations were reversed. For these birds, the C comparison was now correct after the G sample, and the D comparison was correct after the R sample. For birds in Group Line, the line-sample associations were reversed; the C comparison was now correct after H, and the D comparison was correct after V. For birds assigned to Group Hue-Line, both hue- and line-sample associations were reversed. These reversal contingencies, together with the training conditions, are summarized in Table 1. In all other respects, the procedure used during Phase 2 was the same as that during Phase 1. Phase 2 continued until birds reached an independent performance criterion of 90% correct for two consecutive sessions on each of the two sample dimensions.

Results

Pigeons acquired the Phase 1 many-to-one matching task to a criterion of 90% correct overall in an average of 31.1 sessions. The three Phase 2 groups did not differ significantly in the rate at which they learned in Phase 1 ($F < 1$). However, the hue-sample portion of the task was acquired significantly faster (mean = 15.9 sessions), than the line-sample portion (mean = 38.9 sessions), $F(1, 25) = 23.38, p < .01$.

Acquisition of the Phase 2 reversal by each partial reversal group (Hue and Line) was compared with acquisition of the corresponding hue- and line-sample reversals, respectively, in Group Hue-Line. These data are summarized in Figure 1. Analyses of variance (ANOVAs) performed on the sessions-to-80%-correct and sessions-to-criterion (two consecutive sessions at 90% correct or better) data for the line-sample reversal indicated that this reversal was learned significantly faster by Group Hue-Line than by Group Line, $F(1, 16) = 4.53$ and 5.02, respectively, both $ps < .05$. Group Hue-Line reached

Table 1
Design of Experiment 1

Phase 1	Phase 2		
	All groups	Group Hue	Group Line
R-C	R-D	R-C	R-D
G-D	G-C	G-D	G-C
V-C	V-C	V-D	V-D
H-D	H-D	H-C	H-C

Note. The first letter of each pair represents the sample (R = red; G = green; V = vertical; H = horizontal) and the second letter represents the correct comparison (C = circle; D = dot).

criterion on the line-sample reversal in an average of 34.4 sessions, compared with 61.9 sessions for Group Line.

ANOVAs performed on the corresponding hue-sample data indicated that the hue-sample reversal was not learned significantly faster by Group Hue-Line than by Group Hue, $F(1, 14) = 3.15$ (sessions to 80% correct) and $F < 1$ (sessions to criterion). Group Hue-Line reached criterion on the hue-sample reversal in an average of 23.8 sessions, compared with 21.1 sessions for Group Hue.

As in Phase 1, the hue-sample associations were learned faster than the line-sample associations in Phase 2. This difference was apparent both for the within-subject comparison in Group Hue-Line (the hue-sample reversal was completed in an average of 23.8 sessions, compared with 34.4 sessions for the line samples), $F(1, 7) = 6.69, p < .05$, and for the between-group comparison involving Groups Hue and Line (Group Hue reached criterion in an average of 21.1 sessions, whereas Group Line reached criterion in an average of 61.9 sessions), $F(1, 17) = 11.47, p < .01$.

Discussion

The finding that reversal of the line-sample associations was faster for Group Hue-Line than for Group Line is evidence for the common coding of samples associated with the

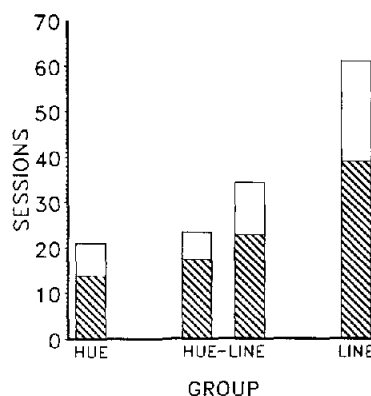


Figure 1. Experiment 1: Sessions to 80% correct (lined bars) and sessions to criterion (open bars) on Phase 2 reversals for the hue-sample conditional discrimination for Group Hue, the line-sample discrimination for Group Line, and both the hue- and the line-sample discriminations for Group Hue-Line.

same comparison stimulus. For example, if we assume that R and V samples were both coded as "sample A" and G and H samples were both coded as "sample B," then the pigeons found it easier to reverse the sample-class-comparison association than to relearn which samples belonged to those classes. Of course, this interpretation also predicts that there should be a difference in the rate at which Group Hue-Line and Group Hue reversed their hue-sample associations, but none was found.

This dissociation between sample dimensions might be explained, however, in the following way. Assume that stimuli can have both unlearned and learned representations. An unlearned representation is one that is elicited by the stimulus without learning and should be isomorphic with the stimulus (e.g., an R sample would produce a "red" representation; a V sample, a "vertical" representation). A learned representation is one that is established through experience. The learned representation might be arbitrary (e.g., R and V samples might both evoke an arbitrary representation "A"), or it could involve the unlearned representation of another stimulus. For example, in the many-to-one task, a V sample might produce a "red" representation, because both V and R samples were associated with the C comparison. Such a learned representation, as depicted in Table 2, would result in appropriate performance. Furthermore, because there is evidence that conditional discriminations involving hue samples (and thus hue representations) are learned faster and are remembered better than those involving line representations (Carter & Eckerman, 1975; Farthing, Wagner, Gilmour, & Waxman, 1977; Urcuioli & Zentall, 1986), the coding of line samples as hues may actually result in facilitated performance.

Table 2
Hypothesized Unlearned and Learned Sample, Sample-Representation, and Comparison Associations in Phases 1 and 2 of Experiment 1

Group	Task	Result
Phase 1		
All	Unlearned r	R-r-C
	Unlearned v	V-v-C
	Learned r	V-r-C
Phase 2		
Hue-Line	Learn new r-D association	R-r-D V-r-D
Line	Abandon old V-r association and Learn new V-D association	R-r-C V-v-D
	or Learn new V-g association	V-g-D
	Hue	Learn new r-D association and Abandon old V-r association

Note. Uppercase letters represent stimuli (R = red; V = vertical; C = circle; D = dot) and lowercase letters represent elicited representations (r = representation of red; g = representation of green; v = representation of vertical).

If the pigeons in the present experiment commonly coded samples using hue representations, then during reversal training with lines they could have acquired (a) a new comparison association to their already established hue representation (e.g., match D to "r"), (b) a new comparison association to the line representation itself (match D to "v"), or (c) a new learned representation of the line samples (e.g., V could now be represented as "g"). In the case of Group Hue-Line, it would have been more efficient to use their existing hue representation because this would have been appropriate for both the hue and line samples. In the case of Group Line, however, the old hue-representation-comparison associations still would have been appropriate for the hue samples, thus for the line samples, reverting to the line representations or acquiring new learned representations would seem more efficient.

If the above analysis is correct, to preserve those hue-sample associations, pigeons should learn the line-sample reversals by (a) abandoning the line-sample-hue-representation associations learned in Phase 1 and (b) reversing the remaining line-representation-comparison associations. Having to reverse the line-sample-comparison associations should put Group Line at a disadvantage because, as noted above, acquisition is slower when samples (and presumably their unlearned representations) are lines than when they are hues (Carter & Eckerman, 1975).

According to the model presented in Table 2, the reversals in Phase 2 should have been easier for Group Hue than for Group Line because these birds could have learned new hue-representation-comparison associations, as could Group Hue-Line. Birds in Group Hue would also have to abandon their line-sample-hue-representation associations, while retaining the unlearned line-representations of line samples and the line-representation-comparison associations, learned in Phase 1 (see Table 2).

A prediction that follows from the model presented in Table 2 is that Group Hue should show some disruption of performance on the unchanged line-sample portion of the Phase 2 task, if hue representations mediate line-sample associations. This disruption should occur because, as the birds in Group Hue begin to associate the hue representations with new comparisons, errors on line-sample trials should result. Furthermore, this level of disruption should be greater than whatever general performance disruption might be found for Group Line on the unchanged hue-sample portion of the Phase 2 task.

An ANOVA was performed on the change in performance on the unchanged sample-dimension portion of the task for Groups Hue and Line. Baseline performance on an average of the last two sessions of Phase 1 was compared with performance on the first session of Phase 2. Overall, performance on trials with hue samples was significantly better than that with line samples, $F(1, 16) = 23.64, p < .01$, but more importantly, the interaction between group and phase (last sessions of Phase 1 vs. first session of Phase 2) was also significant, $F(1, 16) = 5.15, p < .05$. As predicted by the model, the drop in performance on the unchanged line-sample trials by Group Hue (7.1% correct) was greater than the drop in performance on the unchanged hue-sample trials

by Group Line (0.6% correct). Thus, the hypothesis that hues and lines can be commonly coded as hue representations is supported, not only by the relative asymmetry in line versus hue reversal learning presented in Figure 1, but also by the degree of initial performance disruption on the unchanged components of the tasks.

Experiment 2

If the evidence for common coding found in Experiment 1 with many-to-one conditional discriminations is a general phenomenon, then one should be able to find evidence for similar processes in simpler tasks in which a many-to-one mapping exists. For example, can common coding be demonstrated when pigeons are trained with two successive simple discriminations, each involving a different stimulus dimension (e.g., R+G- and V+H-)? Will it take longer to reverse one discrimination alone (e.g., V-H+, while R+G- remains as during training) than to reverse that discrimination in the context of reversing the other discrimination (i.e., V-H+ and R-G+)? In Phase 1 of Experiment 2, we trained pigeons to associate, for example, R and V stimuli with food and G and H stimuli with the absence of food. In Phase 2, either both discriminations were reversed (Group Hue-Line) or only one was reversed (Groups Hue and Line). On the basis of the results of Experiment 1, it was expected that it would take longer for Group Line than Group Hue-Line to reverse lines.

A second purpose of Experiment 2 was to determine whether the absence of a significant difference between Group Hue and Group Hue-Line on the hue reversal could be replicated. If so, such a finding would be consistent with the common hue coding explanation offered in Experiment 1 (see Table 2).

Method

Subjects

The subjects were 16 mixed-sex, White Carneaux pigeons, 5-8 yrs old, obtained from the Palmetto Pigeon Plant. They all had experience with a task unrelated to the task used in this experiment. The pigeons were housed and maintained as described in Experiment 1.

Apparatus

The apparatus was similar to that used in Experiment 1, with the following exceptions: The three response keys (3.2 cm [wide] and 2.5 cm [high]) on the intelligence panel were separated by 0.8 cm, and only the center key was used.

Procedure

Pretraining. All pigeons were adapted to the operant chamber, magazine trained, and then trained to peck a white center key, as in Experiment 1.

Phase 1 training. All birds then began training on a four-component multiple schedule of reinforcement in which the first response after 6 s in the presence of either of two stimuli (S+s) was reinforced with 2-s access to Purina Pigeon Grains (i.e., a fixed interval [FI] 6-s schedule), whereas responses were extinguished in the presence

of either of the other two stimuli (S-s, presented for a fixed duration of 6 s). The birds were randomly assigned to one of four counterbalanced groups (R+G- V+H-, R+G- H+V-, G+R- V+H-, and G+R- H+V-). Each session consisted of 96 trials, 24 with each stimulus. Stimulus presentations were separated by 10-s ITIs during which the houselight was illuminated. The stimuli were presented randomly with the constraint that no more than 3 consecutive trials could be either positive or negative. Discrimination ratios (DRs) were calculated for overall responding by dividing the number of responses made to both S+ stimuli by the total responses made to all four stimuli. DRs were also calculated separately for each stimulus dimension (hue and line) by dividing hue S+ responses by total responses to both hue stimuli and line S+ responses by total responses to both line stimuli. Only those pecks made during the first 6 s of each S+ trial entered into the calculation of the DRs.

Each pigeon was trained to a criterion of 2 consecutive sessions at a DR of 0.90 or better accuracy on both the hue and the line discriminations. All birds were then overtrained for an additional 20 sessions.

Phase 2 transfer. As birds completed Phase 1, they were assigned to one of three groups, Group Hue ($n = 4$), Group Line ($n = 6$), and Group Hue-Line ($n = 6$). In assigning the birds to groups, an attempt was made to equate the groups for mean sessions to criterion in Phase 1. For birds in Group Hue, the hue discrimination was reversed. For birds in Group Line, the line discrimination was reversed. For birds in Group Hue-Line, both discriminations were reversed. In all other respects, Phase 2 sessions were the same as those in Phase 1. Phase 2 continued until each bird reached criterion (see Phase 1) on each of the two discriminations.

Results and Discussion

Phase 1 Training

Pigeons reached the overall acquisition criterion in an average of 5.1 sessions. An ANOVA performed on the acquisition scores for the three Phase 2 groups indicated that they did not differ significantly in the number of sessions required to reach criterion in Phase 1 ($F < 1$). However, the birds learned the hue discrimination significantly faster (mean = 4.4 sessions) than the line discrimination (mean = 5.0 sessions), $F(1, 15) = 7.98, p < .05$.

Phase 2 Transfer

As in Experiment 1, sessions-to-criterion scores for each partial-reversal group (Group Hue and Group Line) were compared with the corresponding scores for Group Hue-Line. Once again, these analyses indicated that Group Line took significantly longer to reverse its discrimination to a 0.80 DR and to criterion (mean = 5.5 and 8.2 sessions, respectively) than Group Hue-Line (mean = 4.0 and 6.3 sessions, respectively), $F(1, 10) = 5.00$ and 4.99, respectively, both $ps < .05$. By contrast, Group Hue reversed its hue discrimination to a 0.80 DR and to criterion (mean = 4.0 and 5.8 sessions, respectively) as rapidly as Group Hue-Line (mean = 3.8 and 6.0 sessions, respectively; both $Fs < 1$). These data are summarized in Figure 2.

Direct comparison of the hue and line reversals in Phase 2 indicated that the former was learned faster than the latter, as demonstrated by the significant between-groups difference

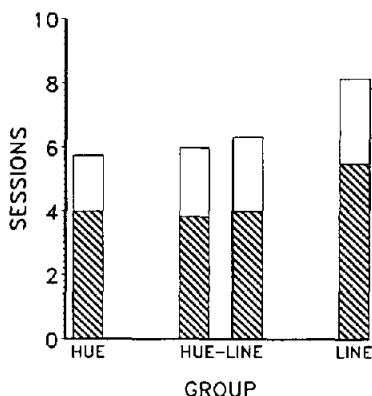


Figure 2. Experiment 2: Sessions to 0.80 discrimination ratio (lined bars) and sessions to criterion (open bars) on Phase 2 reversals for the hue discrimination for Group Hue, the line discrimination for Group Line, and both the hue and the line discriminations for Group Hue-Line.

between Group Hue (mean = 5.8 sessions) and Group Line (mean = 8.2 sessions), $F(1, 8) = 6.38$, $p < .05$. The corresponding within-subject comparison for Group Hue-Line, however, showed comparable rates of reversal learning (hue = 6.0 sessions, line = 6.3 sessions; $F < 1$).

The Phase 2 transfer results of Experiment 2 support those of Experiment 1. Pigeons learned to reverse the simple vertical- versus horizontal-line discriminations faster when they also had to learn to reverse the red- versus green-hue discriminations. On the other hand, they did not learn to reverse the simple red- versus green-hue discriminations faster when they also had to learn to reverse the vertical- versus horizontal-line discriminations.

An analysis performed on the change-in-performance data (from the end of Phase 1 to the first session of Phase 2) on the unchanged portion of the task for Groups Hue and Line indicated that the drop in performance for the unchanged line-sample trials was not greater than that for the unchanged hue-sample trials ($F < 1$). In fact, overall, there was not a significant drop in performance on the unchanged portion of the task for these two groups. The failure to replicate this aspect of the transfer results from Experiment 1 may be related either to the very rapid acquisition and reversal of this simple discrimination task or perhaps to the relatively greater amount of overtraining provided in Phase 1 of the present experiment.

Experiment 3

The purpose of Experiment 3 was to assess common coding by testing for greater performance disruption on a line-alone reversal following multiple reversals of both hue and line. This procedure is analogous to that used by Vaughan (1988).

Method

Subjects and Apparatus

The subjects were selected from those used in Experiment 2. They were the 4 birds from Group Hue and 4 birds randomly selected from

each of Groups Line and Hue-Line. They were housed and maintained as in Experiment 1. The apparatus was the same as that used in Experiment 2.

Procedure

Phase 1. Following completion of Phase 2 of Experiment 2, the birds in Groups Hue and Line were either returned to the discriminations they were trained on ($n = 2$ from each group) or reversed on the dimension not yet reversed ($n = 2$ from each group), while the birds in Group Hue-Line were reversed on either hues ($n = 2$) or lines ($n = 2$). Thus, all birds experienced at least one partial reversal. Each bird then received multiple, simultaneous, hue and line reversals. Birds were trained to an acquisition criterion of 0.90 or greater DR for two consecutive sessions for both hues and lines and were then reversed on both dimensions. Each bird was trained for a minimum of six hue-line reversals and to a stability criterion that involved two components: (a) the difference between the best and worst line-reversal DR on the first session of the last three hue-line reversals was no greater than 0.10 (to provide a stable line-reversal baseline) and (b) the difference between the line and hue DRs on the first session of the last reversal was not greater than 0.10 (if birds were commonly coding hues and lines, performance levels should be comparable on the two dimensions).

Phase 2. Following acquisition of the reversal on which stability criterion was attained, each pigeon was transferred to a line-only reversal and was trained to criterion.

Results and Discussion

The birds averaged 9.7 reversals to reach the stability criterion. One bird was dropped because of an injury.

For each bird, baseline performance was calculated by averaging first-session performance on the line reversal over the last three hue-line reversals. One bird showed a strong preference for the vertical line (i.e., learned the V+H- discriminations much faster than the H+V- discriminations). This bias resulted in highly variable performance from reversal to reversal, but stability was reached on odd and even reversals. For this bird, the baseline was calculated 2, 4, and 6 reversals back from the test reversal.

For each bird, baseline performance on the line reversal was then compared with performance on the line-only test reversal, using a repeated-measures ANOVA. Initial analyses indicated that the magnitude of this difference depended neither on the birds' group assignment in Experiment 2 nor on whether or not the multiple reversals involved the original discriminations acquired during Phase 1 of Experiment 2. Thus, the data were pooled over these conditions. A one-way repeated measures ANOVA indicated that performance on the first session of line-only test reversal was significantly worse (mean DR = 0.62) than baseline, first-session, line-reversal performance (mean DR = 0.68), $F(1, 10) = 6.65$, $p < .05$. Furthermore, there was a significant drop in performance on the unreversed hue discrimination from the last session prior to the line-only reversal (mean DR = 0.94) to the first line-only reversal session (mean DR = 0.87), $F(1, 10) = 5.72$, $p < .05$.

The results of Experiment 3 suggest that the two pairs of hue-line stimuli that were consistently associated with common outcomes were commonly coded. When, during the test

reversal, the two pairs of hue-line stimuli were no longer followed by their previous common outcomes, significant disruption of first session transfer performance was found, relative to baseline, as well as significant disruption of performance of the unreversed discrimination.

General Discussion

The results of Experiments 1, 2, and 3 support the contention that when pigeons associate two initial stimuli with the same event (a comparison stimulus in Experiment 1, a food or no-food outcome in Experiments 2 and 3), those initial stimuli may be similarly represented or commonly coded. Furthermore, the results of Experiments 1 and 2 suggest that the common code may involve an "unlearned" representation of the stimulus that is easier to associate with comparison or outcome, or is easier to remember (e.g., the hue), and that the pigeon learns to use this representation to code the stimulus that is relatively more difficult to discriminate, code, and remember (e.g., the line).

The results of Experiment 3 indicate that the multiple-reversal procedure, developed by Vaughan (1988) to assess stimulus class formation, can be used with stimulus classes that have as few as two members. With only two stimuli per class, evidence for stimulus class formation requires establishing a stable reversal baseline and then testing with a partial reversal.

Although there are various ways in which pigeons may learn to code one stimulus in terms of the unlearned representation of another easier-to-code stimulus, simple conditioning may be the most parsimonious explanation. The presence of a vertical-line stimulus, for example, should typically elicit a vertical-line representation. On some trials, however, such a stimulus may produce an erroneous representation (e.g., a horizontal line or a red or green hue). If the task is such that the same correct (comparison) response is preceded by either a vertical or a red stimulus, then miscoding vertical as red will be reinforced, whereas miscoding vertical as either horizontal or green will be extinguished. Furthermore, because hues tend to be more memorable than lines (Carter & Eckerman, 1975; Farthing et al., 1977; Urcuioli & Zentall, 1986), if such a miscoded red representation were to occur, then it would more likely be present at the time of reinforcement than a correctly coded vertical representation. Thus, a simple reinforcement mechanism can account for the dominance of the learned red representation over the unlearned vertical representation.

In Experiments 1 and 2, the presence of a significant difference in rate of line-discrimination reversal between Groups Line and Hue-Line, together with the absence of a difference in rate of hue-discrimination reversal between Groups Hue and Hue-Line, is consistent with the hue-representation model presented in Table 2. According to this model, it is hypothesized that Group Line acquired their Phase 2 associations by abandoning their learned line-sample-hue-representation associations and either learning new line-representation-comparison associations or new line-sample-hue-representation associations, whereas Group Hue acquired their Phase 2 associations by learning new hue-representa-

tion-comparison associations and abandoning their learned line-sample-hue-representation associations in favor of their (presumably still available) unlearned line-sample-line-representations.

An alternative explanation for faster reversal of the line discrimination by Group Hue-Line than by Group Line is based on the difference in detectability of change in reinforcement across phases, between these two groups (see e.g., Sheffield's [1949] discussion of generalization decrement as an explanation of the partial reinforcement extinction effect). For birds in Group Hue-Line, there is a larger, and thus probably a more easily detected, change in the conditions of reinforcement from Phase 1 to Phase 2 than for either Group Line or Group Hue. For Group Hue-Line, responding on the basis of original training results in no reinforcement. On the other hand, for Groups Hue and Line, responding on the basis of original training still results in reinforcement on half of the trials. Could differential probability of reinforcement in Phase 2 of Experiments 1 and 2 have resulted in differential transfer effects? The finding that Group Hue-Line did not reverse its hue discrimination any faster than Group Hue, however, is inconsistent with this generalization decrement account. But more definitive data regarding this issue could be obtained by training birds on a matching task in which the four samples used in Experiment 1 are mapped onto four different comparisons (thus precluding common coding as the basis for common associations). Then in Phase 2, only those associations involving, for example, line samples would be reversed for some birds, whereas all associations would be reversed for others. From a generalization decrement view, one would predict faster line-reversal learning in the latter condition than in the former. By contrast, if common coding were responsible for the differences between Groups Line and Hue-Line seen here, then there should be no difference in the rate of reversal learning.

Although the asymmetry in reversal effects found in Experiments 1 and 2 tends to discredit a generalization decrement account, the asymmetry itself may be an artifact associated with differences in the rate at which hue versus line associations were learned. Because the hue associations were learned faster than the line associations, and because birds were trained to criterion on both discriminations, birds were overtrained on the hue associations while they were still acquiring the line associations. Could such overtraining have been responsible for the equally rapid rates of hue reversal learning for Groups Hue and Hue-Line? Although it provides a possible explanation, differential overtraining seems rather implausible because all birds received an additional 20 sessions of training after they had reached criterion on the more slowly learned line discrimination. Thus, associations on both dimensions were overtrained, so an appeal to the degree of overtraining would be required to explain the results of Experiment 1. But even degree of overtraining would not account for the reversal asymmetry in Experiment 2. In that experiment, the difference in the rate of Phase 1 acquisition between hues and lines was very small (less than one session), so the degree of overtraining was comparable for both dimensions. Thus, it seems unlikely that differential overtraining can account for the overall pattern of results.

The results of the present experiment, together with our earlier work (Urcuioli et al., 1989) and that of Vaughan (1988), support the notion that "functional equivalence" (Shipley, 1935) or "stimulus classes" (Spradlin & Saunders, 1986) can be established in pigeons. Although this phenomenon does not meet the more rigorous criteria of equivalence described by Sidman (1986), and thus may differ in important ways from that described in the human literature, the apparent development of new, derived relations between stimuli may well involve similar underlying processes.

References

- Carter, D. E., & Eckerman, D. A. (1975). Symbolic matching by pigeons: Rate of learning complex discriminations predicted from simple discriminations. *Science*, *187*, 662-664.
- Edwards, C. A., Jagielo, J. A., Zentall, T. R., & Hogan, D. E. (1982). Acquired equivalence and distinctiveness in matching to sample by pigeons: Mediation by reinforcer-specific expectancies. *Journal of Experimental Psychology: Animal Behavior Processes*, *8*, 244-259.
- Farthing, G. W., Wagner, J. M., Gilmour, S., & Waxman, H. M. (1977). Short-term memory and information processing in pigeons. *Learning and Motivation*, *8*, 520-532.
- Goldiamond, I. (1962). Perception. In A. J. Bachrach (Ed.), *Experimental foundations of clinical psychology* (pp. 280-340). New York: Basic Books.
- Kendler, T. S. (1961). Concept formation. *Annual review of psychology* (pp. 447-473). Palo Alto, CA: Annual Reviews.
- Nakagawa, E. (1986). Overtraining, extinction, and shift learning in a concurrent discrimination in rats. *Quarterly Journal of Experimental Psychology*, *38*, 313-326.
- Sheffield, V. F. (1949). Extinction as a function of partial reinforcement and distribution of practice. *Journal of Experimental Psychology*, *39*, 511-526.
- Shipley, W. C. (1935). Indirect conditioning. *Journal of General Psychology*, *12*, 337-357.
- Sidman, M. (1986). Functional analysis of emergent verbal classes. In T. Thompson & M. D. Zeiler (Eds.), *Analysis and integration of behavioral units* (pp. 213-245). Hillsdale, NJ: Erlbaum.
- Spradlin, J. E., Cotter, V. W., & Baxley, N. (1973). Establishing a conditional discrimination without direct training: A study of transfer with retarded adolescents. *American Journal of Mental Deficiency*, *77*, 556-566.
- Spradlin, J. E., & Saunders, R. R. (1986). The development of stimulus classes using match-to-sample procedures: Sample classification versus comparison classification. *Analysis and Intervention in Developmental Disabilities*, *6*, 41-58.
- Urcuioli, P. J., & Zentall, T. R. (1986). Retrospective coding in pigeons' delayed matching-to-sample. *Journal of Experimental Psychology: Animal Behavior Processes*, *12*, 69-77.
- Urcuioli, P. J., Zentall, T. R., Jackson-Smith, P., & Steirn, J. N. (1989). Evidence for common coding in many-to-one matching: Retention, intertrial interference, and transfer. *Journal of Experimental Psychology: Animal Behavior Processes*, *15*, 264-273.
- Vaughan, W., Jr. (1988). Formation of equivalence sets in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, *14*, 36-42.
- Zentall, T. R., Urcuioli, P. J., Jagielo, J. A., & Jackson-Smith, P. (1989). Interaction of sample dimension and sample-comparison mapping on pigeons' performance of delayed conditional discriminations. *Animal Learning and Behavior*, *17*, 172-178.

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