A NEW APPROACH TO THE FORMATION OF EQUIVALENCE CLASSES IN PIGEONS

MASAKO JITSUMORI, MARTINA SIEMANN,
MANUELA LEHR, AND JUAN D. DELIUS

CHIBA UNIVERSITY, CHIBA, JAPAN AND
KONSTANZ UNIVERSITY, KONSTANZ, GERMANY

Four pigeons were given simultaneous discrimination training with visual patterns arbitrarily divided into two sets, with the stimuli in one set designated A1, B1, C1, and D1 and those in the other set designated A2, B2, C2, and D2. In sequentially introduced training phases, the pigeons were exposed to a series of reversals to establish AB and then CD equivalences. In subsequent testing sessions, a subset of stimuli from one set served as positive stimuli and those from the other set as negative stimuli on training trials, and transfer of the reinforced relation to other members of the sets was tested with nonreinforced probe trials. The pigeons were trained further on AC and BD equivalences and then were tested for the emergence of untrained AD and BC equivalences. Two of the 4 pigeons exhibited the emergence of one of these untrained equivalences, evidence for the emergence of transitive relations. This finding suggests that the pigeons established three-member functional equivalence classes by incorporating separately trained multiple equivalence relations. Repeated reversal training and probe testing enabled us to explore the formation and expansion of functional equivalence classes in pigeons.

Key words: stimulus equivalence, functional equivalence, discrimination learning, generalization, categorization, conceptualization, pigeons

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Keller and Schoenfeld (1950) defined concepts as generalization within classes and discrimination between classes, and Herrnstein (1990) argued that a true concept should involve more than categorization based on generalization within classes. Specifically, if a concept is involved, the effects of contingencies applied to some stimuli of a given class should propagate to the other members of the same class, more than can be accounted for by perceptual similarities among members of the class (see also Kendler & Kendler, 1968; Lea, 1984). Vaughan (1988) presented pigeons with 40 slides of trees, arbitrarily divided into two sets, and he trained them to discriminate between the sets, one set positive and the other negative. Thus, there should have been no basis for grouping or dividing the stimuli on the basis of their physical similarities or dissimilarities. The reinforcement contingencies for the two sets of stimuli were then reversed. After repeated reversal training, the pigeons generalized the reversals to all the stimuli in each set after they had encountered reversed contingencies with just a few stimuli from the set. This transfer of reversals was said to have demonstrated an acquired functional equivalence among the stimuli of the same set (but see Hayes, 1989).

Classes of stimuli that are functionally equivalent to one another have been distinguished from the formal definition of equivalence proposed by Sidman (1990). Sidman adopted a formal definition of equivalence that describes untrained, emergent relations among stimuli that are found following certain kinds of matching-to-sample training involving conditional discriminations among stimuli that are not physically similar to one another (i.e., symbolic matching to sample). In its minimal form, two conditional discriminations are trained with one set of stimuli in common. For example, subjects are trained to choose Comparison Stimulus B1 in the presence of Sample Stimulus A1 and Comparison Stimulus B2 in the presence of Sample Stimulus A2. In addition, they are trained to choose Comparison Stimulus C1 in the presence of Sample Stimulus B1 and Com-

parison Stimulus C2 in the presence of Sample Stimulus B2. Such training may establish conditional relations between each sample stimulus and its corresponding correct comparison stimulus, in this case, A→B (A1→B1, A2→B2) and B→C (B1→C1, B2→C2). According to Sidman, evidence for formal equivalence among the stimuli involved in A→B and B→C training, requires demonstration of the emergence of reflexive relations (A→A, B→B, C→C), symmetrical relations (B→A, C→B), transitive relations (A→C), as well as equivalence relations (C→A; the untrained conditional relations that incorporate the three defining properties of equivalence). When these relations emerge, the stimuli involved in training are said to constitute two equivalence classes (A1, B1, C1, and A2, B2, C2).

Language-competent humans usually pass all these tests without difficulty, but human adults and young children without fully developed language competencies tend to fail at one or more tests and master the equivalence requirements only after additional ad hoc training (e.g., Sidman, 1992; see also Dougher & Markham, 1996). Among animal species, pigeons have been generally found not to exhibit symmetry and transitivity (D'Amato, Salmon, Loukas, & Tomie, 1985; Lipkens, Kop, & Matthijs, 1988; von Fersen, Emmerton, & Delius, 1992). Although Kuno, Kitadate, and Iwamoto (1994) found that 1 of 4 pigeons exhibited transitivity, they did not find further evidence of transitivity in their more recent studies (H. Kuno, personal communication, 2001). The situation concerning nonhuman primates is controversial. Monkeys showed evidence of transitivity in D'Amato et al.'s (1985) study but not in Sidman et al.'s (1982) study. Yamamoto and Asano (1995) found that a chimpanzee exhibited spontaneous transitivity but only when she had been previously and explicitly trained in the symmetric relation. Tomonaga, Matsuzawa, Fujita, and Yamamoto (1991) found that 1 of 3 chimpanzees spontaneously revealed symmetry, but that it vanished rapidly across testing sessions. Although better evidence of emergent equivalence relations was reported in a sea lion by Schusterman and Kastak (1993, 1998), the overall evidence of formal equivalence in animals, including pigeons, monkeys, and even chimpanzees, has

not been overwhelming (Zentall, 1998). The symbolic matching procedure may not be particularly suitable for animals to generate equivalence relations between the conditionally related sample and comparison stimuli.

With appropriate variations of the symbolic matching procedure, it is well documented with pigeons that physically unrelated visual stimuli become substitutable or exchangeable for one another when they share a common association with another stimulus, response, or reinforcer (Zentall, 1998; see also Hall, 1996). Employing many-to-one matching-to-sample procedures, Urcuioli, Zentall, and their colleagues examined a stimulus grouping effect that they called *common coding* (for reviews, see Roberts, 1996; Urcuioli, 1996; Zentall, 1996; see also Neiman & Zentall, 2000). In several of their experiments, pigeons were first trained on the A→C and B→C conditional relations. One comparison stimulus, say C1, was correct following Sample Stimuli A1 and B1, and a second comparison stimulus, C2, was correct following the other two samples, A2 and B2; thus, A1→C1, B1→C1, A2→C2, and B2→C2 relations were trained. New comparison stimuli were then associated with one of the samples of each pair (i.e., A1→D1 and A2→D2). On transfer tests, evidence for the development of emergent B1→D1 and B2→D2 relations suggested that the pigeons had learned that the samples were members of two separate functional equivalence classes: (A1, B1) and (A2, B2). Similarly, Wasserman and his colleagues demonstrated the formation of functional equivalence classes established by common responses or response outcomes (Astley & Wasserman, 1998, 1999; Bhatt & Wasserman, 1989; Bhatt, Wasserman, Reynolds, & Knauss, 1988; Wasserman, Devolder, & Coppage, 1992).

In the present study, we focused on the emergence of untrained functional equivalence relations in pigeons using a variation of the multiple reversal design used by Vaughan (1988; see also Sidman, Wynne, Maguire, & Barnes, 1989, in brain-damaged humans) rather than the conditional discrimination design used by Zentall (1996) and Wasserman et al. (1992). The method was a modification of Vaughan's that was developed by Delius and colleagues to analyze the associations among a small number of artificial stim-

uli (Delius, Ameling, Lea, & Staddon, 1995, and Siemann & Delius, 1998, in pigeons; von Fersen & Delius, 2000, in dolphins). Pigeons were first trained on two-key forced-choice discriminations involving A1+A2−, B1+B2−, A1+B2−, and B1+A2− pairs; the plus indicates food reward and the minus indicates timeout, contingent upon choice of the respective stimuli. The pigeons were then trained with the reversed A1−A2+, B1−B2+, A1−B2+, and B1−A2+ pairs, and then again with the rereversed A1+A2−, B1+B2−, A1+B2−, and B1+A2− pairs, and so forth, many times. Notice that across repeated reversal sessions, whenever A1 signaled reward, B1 did so too, and vice versa. Similarly, whenever A2 signaled reward, B2 did so too, and vice versa. Thus, the repeated reversal training could have established symmetric A1→B1 and B1→A1 relations in Set 1 as well as symmetric A2→B2 and B2→A2 relations in Set 2. If the pigeons learned these symmetric relations, we concluded that the pigeons had formed A↔B equivalence.

Delius et al. (1995) and Siemann and Delius (1998) trained and tested functional equivalence using only two stimuli per set. In the present study, more than two equivalence relations were trained among the members of the same class in successive training phases to explore the emergence of untrained transitive relations. More specifically, we trained pigeons to learn four, rather than two, equivalence relations in the hope that the larger number of stimuli in a set would facilitate the development of functional equivalence classes. That is, in addition to being trained for A↔B functional equivalence, the pigeons were also trained for C↔D, A↔C, and B↔D equivalences. To assess the formation of four-member functional equivalence classes, Set 1 (A1, B1, C1, D1) and Set 2 (A2, B2, C2, D2), we first tested the pigeons for the existence of the trained equivalences and then examined whether untrained A↔D and B↔C equivalences would emerge transitively from the trained equivalences. Tests for each of these functional equivalences involved testing for symmetry, as will be fully described later.

METHOD

Subjects

Four experimentally naive homing pigeons (*Columba livia*) of local stock were maintained at 90% of their free-feeding weights. They were housed in individual cages (40 cm by 40 cm by 45 cm) in a well-ventilated room that was kept on a 12:12 hr light/dark cycle. Water was freely available. Grit was freely available except during the experimental sessions.

Apparatus

During experimental sessions, conditioning platforms were attached to the outside of each pigeon's home cage (Figure 1; see Xia, Delius, & Siemann, 1996, for details). Each pigeon had access to its own platform, which contained two response keys that could be reached through a cage opening through which the pigeons normally ate. The two clear pecking keys (2.5 cm in diameter) were located side by side. The centers of the keys were 5 cm apart. Directly under each key was a matrix (1.3 cm by 1.8 cm) of light-emitting diodes. Dispensers affixed to the panel could deliver food reward (two to four grains of millet) onto each key. A microcomputer system (Compaq 386) controlled the experimental events and collected data.

Stimuli

The stimuli consisted of eight patterns of 13 or 14 lit diodes from a square 5×5 matrix (see Figure 1). The stimuli were arbitrarily divided into two sets that were referred to as Set 1 and Set 2. Set 1 consisted of Patterns 1 to 4, and Set 2 consisted of Patterns 5 to 8 for 2 pigeons; the sets were reversed for the other 2 pigeons. The allocation of the patterns to the stimuli designated A1, B1, C1, D1 in Set 1 and A2, B2, C2, D2 in Set 2 was balanced as nearly as possible across pigeons. The stimuli were judged to be roughly comparable in terms of similarity by the authors as well as by two other observers who were not informed about the purpose of the experiment.

Procedure

The pigeons were trained to peck the keys with an autoshaping procedure (Brown & Jenkins, 1968). A pattern composed of a central cluster of five illuminated diodes (not illustrated and not used subsequently) was used as the stimulus. Within a block of 40 trials, the stimulus appeared equally often under the left and right keys. As soon as the
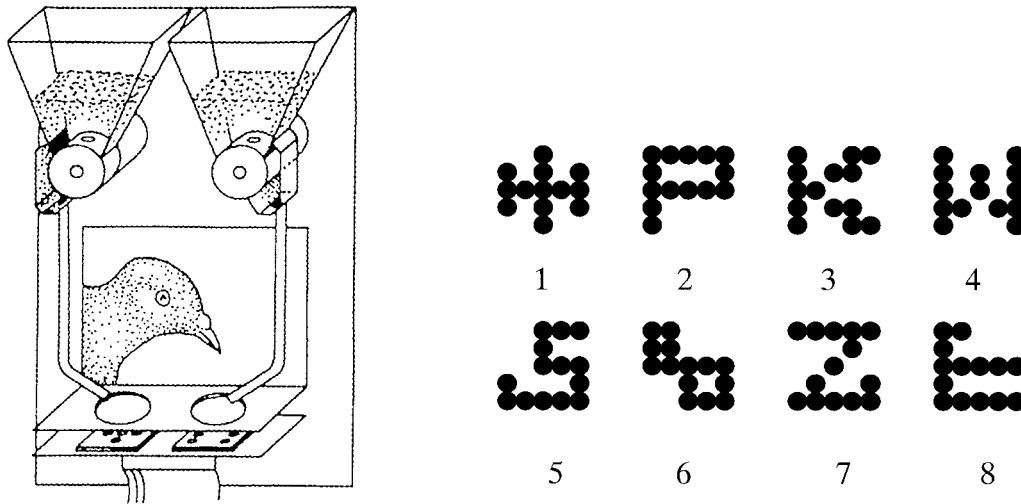
Fig. 1. Left: sketch of the conditioning panels (from Xia, Delius, & Siemann, 1996). During the experimental sessions, they replaced the food troughs of the home cages. Right: the light-emitting diode matrix patterns used as stimuli.

pigeons pecked the keys regularly, the training started.

$A \leftrightarrow B$ *training*. Figure 2 shows the sequentially introduced training and testing phases. The first training phase was designed to train $A \leftrightarrow B$ equivalence, that is, $A1 \leftrightarrow B1$ and $A2 \leftrightarrow B2$. With the stimulus pairs $A1+A2-$, $B1+B2-$, $A1+B2-$, and $B1+A2-$, the pigeons were trained to choose A1 or B1 in Set 1 over A2 or B2 in Set 2. Each trial began with the presentation of one of the stimulus

pairs under the two keys. The presentation order of the eight stimulus configurations (including control for position) was randomized within each of the eight-trial series in a block of 80 trials, with the restriction that the positive patterns could not appear on the same key more than three times in succession within and across consecutive series. Three pecks on one of the keys turned off the stimuli. Choice of the positive stimulus initiated a 2-s reward period, with millet grains delivered
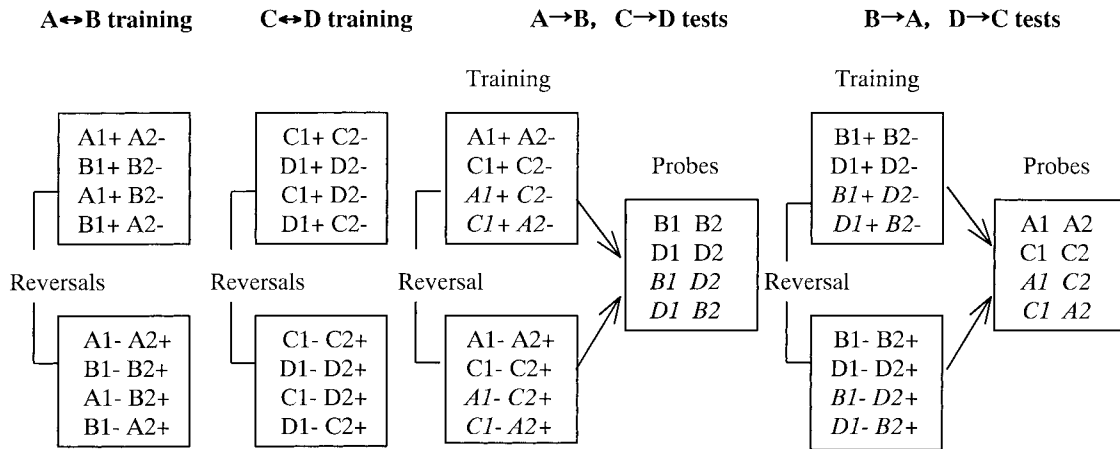
A↔B training   **C↔D training**   **A→B, C→D tests**   **B→A, D→C tests**

Training   Training

A1+ A2−	C1+ C2−	A1+ A2−		B1+ B2−	
B1+ B2−	D1+ D2−	C1+ C2−	Probes	D1+ D2−	Probes
A1+ B2−	C1+ D2−	*A1+ C2−*		*B1+ D2−*	
B1+ A2−	D1+ C2−	*C1+ A2−*	B1 B2	*D1+ B2−*	A1 A2
			D1 D2		C1 C2

Reversals   Reversals   Reversal   *B1 D2*   Reversal   *A1 C2*
                                                          D1 B2   *C1 A2*

A1− A2+	C1− C2+	A1− A2+	B1− B2+
B1− B2+	D1− D2+	C1− C2+	D1− D2+
A1− B2+	C1− D2+	*A1− C2+*	*B1− D2+*
B1− A2+	D1− C2+	*C1− A2+*	*D1− B2+*

Fig. 2. Overview of the stimulus pairs used for the A↔B training, the C↔D training, and the A↔B and C↔D testing. Rewarded and penalized stimuli during training trials are indicated by + and −. The numbers 1 and 2 refer to the two stimulus sets, each consisting of four stimuli (A, B, C, and D). Novel stimulus pairs used during the testing stage are printed in italics. Across successive trials, the stimuli appeared equally often under the left and right keys. The arrows specify which probe pairs followed which training pairs during the testing stage.

to the corresponding dark key. Choice of the negative stimulus produced a 3-s timeout, during which all diodes of the stimulus matrices were lit. After a 2-s intertrial interval with darkened matrices, the next trial began. Following an incorrect choice, the same trial was repeated until the pigeon responded correctly. These correction trials were not taken into account for trial counts and performance scores.

A session consisted of one or more blocks of 80 trials and continued until the pigeon achieved 80% correct or better in a single block. If the pigeon did not reach this 80% criterion, its daily session was terminated after approximately 12 blocks. The training continued until the pigeons reached this criterion in two successive sessions; in addition, the mean accuracy over the whole second session had to be 80% correct or better. Thus, the pigeons had to complete at least two training sessions before reaching this double criterion. On the following day, contingencies of reinforcement were reversed (A1−A2+, B1−B2+, A1−B2+, B1−A2+). Performance during the first few trials immediately after reversal was expected to be close to 0% correct, and training under this new condition continued until the pigeons again reached the criterion described above. The contingencies of reinforcement were then reversed again, and so on. Reversals were repeated until 80% or more correct responses were observed during the first block following each of three successive reversals.

C↔D training. The pigeons were given a series of reversals to establish the C↔D equivalence relations (i.e., C1↔D1 and C2↔D2). Procedural details were as in the previous training phase except that the stimuli were now C1, C2, D1, and D2 (see Figure 2).

Maintenance training. Following C↔D training, the pigeons were given 32 additional training sessions. These were arranged in sets of either two A↔B training sessions, each with the opposite contingencies, followed by two C↔D training sessions, each with the opposite contingencies, or the reverse. The order in which the 4 pigeons were trained on these eight four-session sets was randomly determined. As in the previous training phases, a session terminated when the pigeons made 80% or more correct choices in a block of 80 trials.

A↔B and C↔D tests. Testing sessions were designed to determine whether the pigeons learned the A↔B and C↔D equivalences. Probe trials were inserted among training trials to determine whether the contingencies of reinforcement that were used in training would control pigeons' choice of test stimuli when they were included within the same session. Therefore, although responding was not reinforced on probe trials, the choices were scored as correct or incorrect according to the contingencies that were in effect for the training stimuli. The test for A↔B equivalence consisted of the A→B test and B→A test, between which the training and test roles of the stimulus pairs were exchanged symmetrically (see Figure 2). Similarly, the test for C↔D equivalence consisted of C→D and D→C tests.

To conduct A→B and C→D tests simultaneously in the same testing session, A1A2 and C1C2 and, in addition, *A1C2* and *C1A2* appeared as training pairs (see Figure 2). The stimuli in italics had not previously been presented in pairs during training. The stimulus pairs in probe trials were B1B2, D1D2, *B1D2*, and *D1B2*. For B→A and D→C tests, B1B2, D1D2, *B1D2*, and *D1B2* served in training trials and A1A2, C1C2, *A1C2*, and *C1A2* served in probe trials. The testing order was balanced across pigeons. The novel pairings of the stimuli were presented as a test to determine whether the equivalences had been learned, regardless of the specific stimulus pairings that were used previously during the training phases. Because the novel pairings used as probe pairs in one test were used as training pairs in the other test, two of the four probe pairs were not truly novel, depending on the order of testing.

Each test session began with an 80-trial block of training trials and continued until the 80% correct criterion was reached within a block of 80 trials. This was immediately followed by a test block that consisted of 128 training trials and 32 randomly inserted probe trials (four repeats of eight different probe trials including control for left–right position). On probe trials, choice responses were not reinforced but led directly to an intertrial interval. For each type of test, two successive sessions were given, between which the contingencies of reinforcement for training pairs were reversed. Therefore, if the pi-
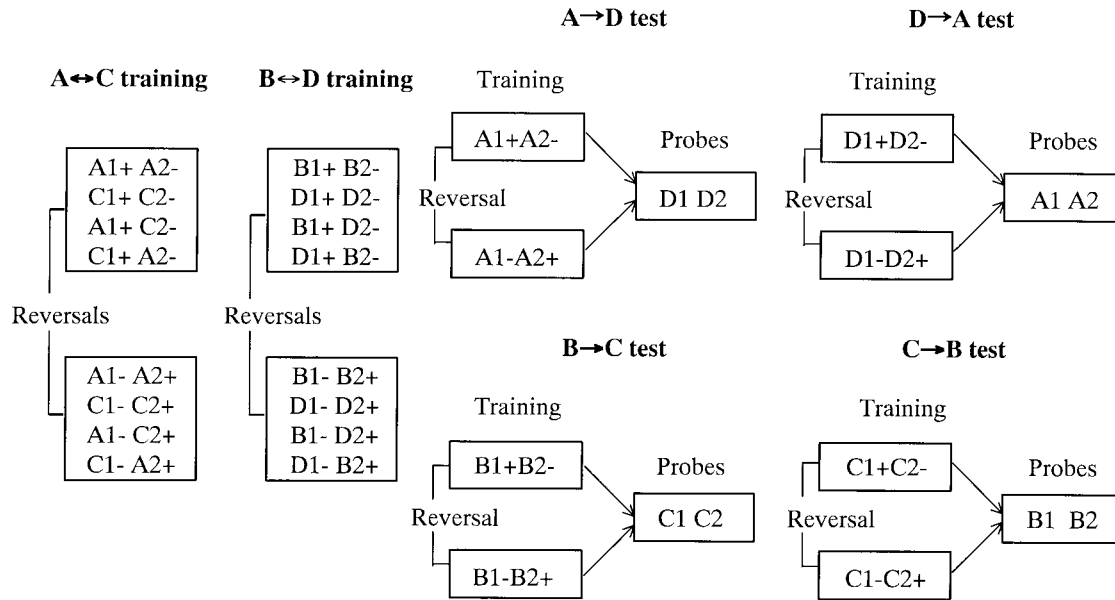
Fig. 3.   Overview of stimulus pairs used for the A↔C training, the B↔D training, and the A↔D and B↔C testing. See Figure 2 for details. Note that no novel pairs were presented.

geons chose test stimuli according to the contingencies that were most recently valid in the session in which these test stimuli appeared as training stimuli, then the test performance would be near 100% correct in one testing session and 0% correct in the other testing session. Thus, the mean test performance over the two testing sessions would be about 50% correct. If they chose test stimuli by chance, it would also be about 50% correct. Alternatively, it would be near 100% correct if they responded to the test stimuli according to the contingencies that were in effect for the training stimuli in each testing session. The contingencies of reinforcement for the training stimuli in the first of two successive testing sessions were balanced across pigeons. A total of four test sessions was given: two successive sessions for A→B and C→D tests and two successive sessions for B→A and D→C tests.

A↔C, B↔D training. The pigeons were then given A↔C training and B↔D training (Figure 3). Two pigeons received A↔C training first, and the others received B↔D training first. Because the training pairs had already been used repeatedly during the earlier tests, a single reversal was considered sufficient for each of these training phases. The

pigeons received a total of four sessions with the A↔C and B↔D training pairs, along with four additional sessions given by using the A↔B and C↔D training pairs identical to those used in the first and second training phases. The training order was randomized across pigeons. As before, a training session terminated after the pigeon reached the 80% correct criterion in a block of 80 trials.

A↔D, B↔C tests. This test phase assessed whether the four-member equivalence classes were formed. More specifically, the emergence of A→D, D→A, B→C, and C→B relations was tested, none of which had been trained explicitly in the previous training phases. For the A→D test, for example, the training and probe pairs were A1A2 and D1D2, respectively (Figure 3). The reinforcement allocation of the training pair was reversed between two successive test sessions. A total of eight test sessions occurred, two successive sessions for each of A→D, D→A, B→C, and C→B tests. The test order was balanced across pigeons. As before, each test session began with one or more blocks of training trials. Immediately after the 80% correct criterion was reached in a block of 80 trials, a test block consisting of 60 training trials and 20 randomly inserted probe trials was given.

RESULTS

Acquisition

Bird 3 completed A↔B training after 17 reversals and C↔D training after nine reversals. The remaining 3 pigeons continued to perform poorly immediately after the contingencies were reversed. Their A↔B training was terminated after 20 reversals, and their C↔D training was terminated after 15 reversals. During the next phase of training, in which A↔B training and C↔D training were given in an alternating fashion across sessions, 1 additional pigeon (Bird 4) showed spontaneous reversal performances. Mean percentages of correct responses during the first blocks on the last four reversals for each A↔B and C↔D training were 49% and 45% for Bird 1, 38% and 43% for Bird 2, 76% and 79% for Bird 3, and 88% and 83% for Bird 4, respectively.

Testing

The percentage correct scores on probe trials were averaged over two successive test sessions, between which the contingencies of reinforcement for training pairs were reversed. As described earlier, the average score would be 100% correct if the reinforced relation for the training stimuli propagated to the test stimuli on probe trials. It would be 50% correct if the pigeons chose the test stimuli by chance or according to the contingencies that were applied when the corresponding stimulus pair had last served as a reinforced training pair. The square diagrams in Figure 4 represent the findings of the equivalence tests for each of the 4 pigeons. The data obtained with the novel pairings of the stimuli are not included. Thus, the scores for A→B, B→A, C→D, and D→C are those that arose solely from the B1B2, A1A2, D1D2, and C1C2 probe pairs, respectively. The mean percentage correct score for the novel pairings of these stimuli (*B1D2* and *D1B2* in the A→B and C→D tests, and *A1C2* and *C1A2* in the B→A and D→C tests) is shown below the square diagram for each pigeon.

Heavy arrows represent relations that yielded 75% or more correct choices. This criterion was adopted because a binomial test revealed that 75% correct choices is significantly ($p < .05$) above chance (50%). Thin arrows are those that did not meet the 75% correct criterion and statistical significance. If the 75% correct criterion was fulfilled in both directions between members of the set, we considered equivalence to be satisfied. The most remarkable finding was that Birds 3 and 4, which had eventually performed well with reversals during training, exhibited the emergence of the untrained A↔D equivalence, as indicated by superior performances on the A→D and D→A tests. They also passed the A→B and B→A tests for the trained A↔B equivalence. Although the B↔D relations were not tested, it is apparent that the emergent A↔D equivalence shown by these 2 pigeons reflects transitivity of the kind "if A↔B and B↔D, then A↔D." On the other hand, the pigeons did not fully pass the test for the untrained B↔C equivalence and did not even pass the test for the trained C↔D equivalence. Training for C↔D as well as A↔C equivalence relations might not have been sufficient for these pigeons to relate C to the other members of the class. All in all, we may conclude that they had formed the (A, B, D) equivalence classes. Notice, however, that C was not completely disconnected from members of the class, because Bird 3 passed the B→C test and Bird 4 passed the C→D test. Specifically, the emergent B→C relation exhibited by Bird 3 suggests that C was conditionally related not only to B but also to A of the same class.

Birds 1 and 2, which had had difficulty with reversals during training, failed the tests for the untrained equivalences. Only the D→A test performance of Bird 1 was better than the 75% correct criterion. Because this pigeon also passed the tests for A↔B equivalence, we may conclude that D was conditionally related to the members of the (A, B) equivalence class. Because Bird 2 passed only the B→A test, we have to conclude that this pigeon had not learned any of the equivalence relations.

Only Birds 3 and 4 performed well with the novel pairings of the stimuli in the A↔B, C↔D tests; the mean percentage of correct choices was 84% (range, 81% to 94%) for Bird 3 and 84% (range, 81% to 87%) for Bird 4. The accuracy with these pairs was in fact better than that with the familiar C1C2 and D1D2 test pairs that appeared in the same test sessions. Because all novel pairs involved A or B, the acquired A↔B equivalence could
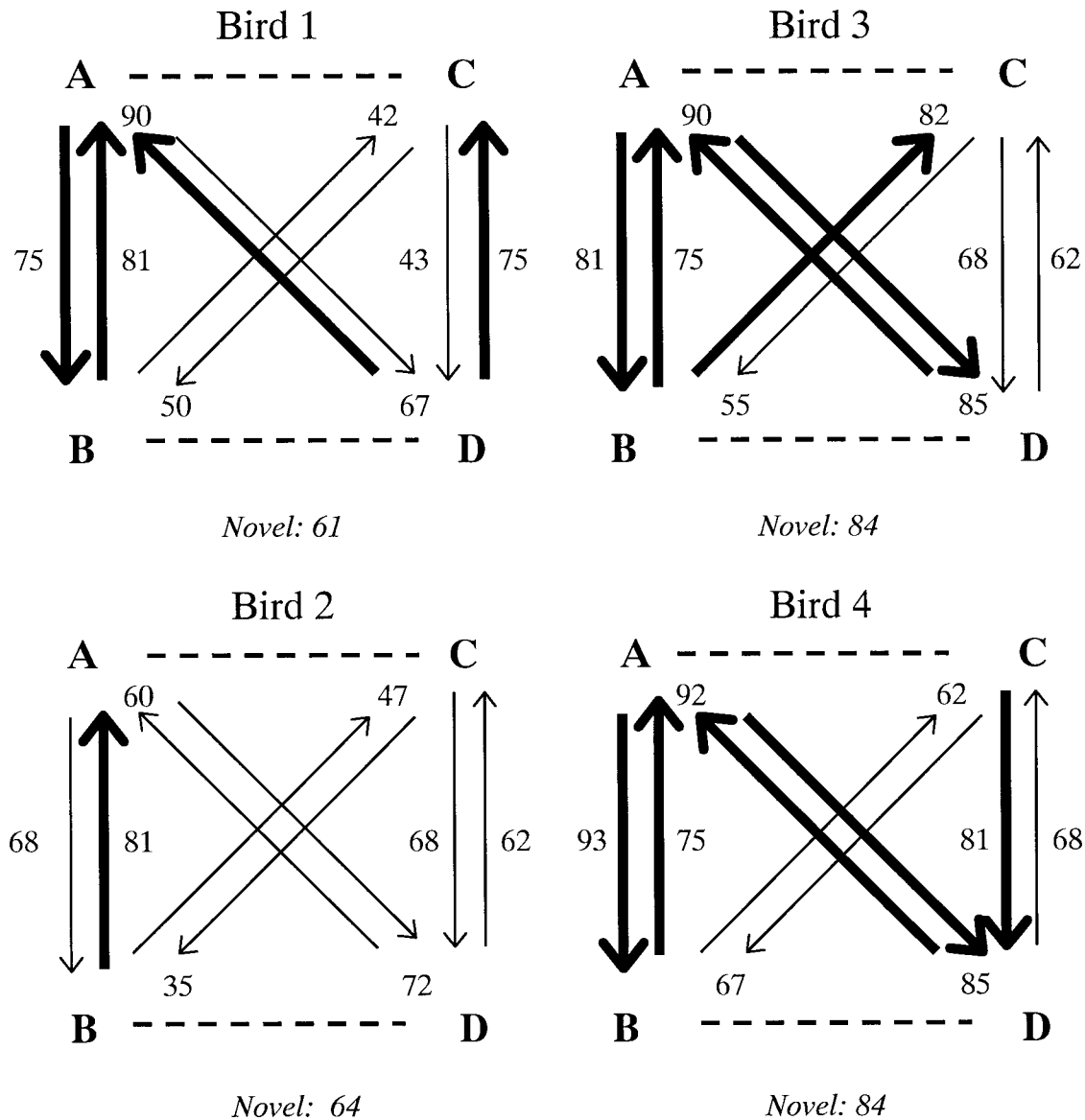
Fig. 4. The test results for each pigeon. Heavy arrows represent the stimulus relations that tested as having been learned. Thin arrows represent the stimulus relations that tested as not having been learned. The numbers by the arrows are the test percentage correct scores. Broken lines represent the equivalences that were trained but not tested. The mean percentage of correct choices with novel pairings is located below the square diagram of each pigeon.

have facilitated performances with these pairs. That is, the acquired A↔B equivalence was not restricted to the particular pairings of these stimuli used for training. On the other hand, although Bird 1 performed accurately with the A1A2 and B1B2 test pairs during the A↔B equivalence test, this equivalence relation did not transfer to the *A1C2, C1A2,* *B1D2,* and *D1B2* pairs that had not been used in training. In this sense, Bird 1 might not have learned that A and B of the same set were truly equivalent.

None of the pigeons passed the tests for the trained C↔D relation. The counterbalanced assignment of stimuli within each set across pigeons ensured that this finding

could not have been due to the particular stimuli used as C and D. The pigeons generally required fewer training trials to reach the 80% criterion in a single block of each session during the C↔D training than A↔B training. It is likely that idiosyncratic learning might have facilitated within-session performance more efficiently during the C↔D training that was carried out after completion of A↔B training. The finding that even Birds 3 and 4, which had successfully reversed their choices within the first block after reversal, failed to pass the equivalence test suggests that the reversal training was not sufficient for the pigeons to discard idiosyncratic learning and to fully learn the C↔D equivalence. Another possibility is that pigeons are unable to learn more than two separate equivalence classes with the present procedure. The pigeons might have had difficulty in learning the (C1, D1) (C2, D2) equivalence classes in addition to the already established (A1, B1) (A2, B2) classes, and managed to respond correctly to the C↔D training pairs only by relying on the reinforcement contingencies within each individual session.

DISCUSSION

The most important finding of the present study was that an untrained A↔D equivalence did emerge transitively in 2 of the 4 pigeons based on explicitly trained A↔B and B↔D equivalences. Thus, these 2 pigeons established the (A, B, D) functional equivalence classes. We can conclude that pigeons trained with the repeated reversal procedure incorporate separately trained multiple equivalences into a larger functional equivalence class consisting of stimuli that are not differentially similar to one another.

The repeated reversal procedure used in the present study has some advantages over the many-to-one matching-to-sample procedure used by Zentall, Urcuioli, and colleagues (e.g., Urcuioli, 1996; Zentall, 1998). They trained pigeons with A→C and B→C conditional relations to establish the functional equivalence relation between the two samples, A and B, both of which were conditionally related to the same comparison, C. One of the two samples, say A, was then conditionally related to a new comparison, D, to examine whether the new A→D conditional

relation would transfer to the other sample, B, through the acquired A→B equivalence. The emergence of the untrained B→D conditional relation revealed the formation of (A, B) functional equivalence classes. The studies by Zentall and Urcuioli thus examined the formation of an acquired equivalence relation between two stimuli that were conditionally related to a common comparison stimulus. An analogous argument can be made for the studies by Wasserman and colleagues, which demonstrated the formation of functional equivalence classes established by common responses or response outcomes (e.g., Astley & Wasserman, 1998; Wasserman et al., 1992).

The finding with 2 of the 4 pigeons that the separately trained (A, B) and (B, D) functional equivalence classes were merged into a larger (A, B, D) class revealed expansion of functional equivalence classes by pigeons. This was not the case in the studies by Zentall and Urcuioli (e.g., Urcuioli, 1996; Zentall 1998), Wasserman et al. (1992), and Vaughan (1988). In the present study, the equivalence classes were established through the behavioral functions that the members had in common, but there were no overt responses or mediators on probe trials to assist the emergence of transitive relations. Another advantage of the present study is that the relations that were trained or tested involved symmetry between class members that were to be functionally equivalent. As far as we know, there have been no studies that demonstrate the formation of equivalence classes in animals of the sort revealed in the present study.

Using standard symbolic matching-to-sample procedures, there has been no strong evidence for the formation of formal equivalence in animals, including nonhuman primates. Specifically, under these conditions, animals show little evidence for the emergence of symmetrical relations (e.g., if A→B, then B→A). Perhaps, language-competent humans interpret A→B as also implying B→A, to the extent that this in fact is often a source of erroneous deductions (Rips, 1994, p. 181). Young children, language-deficient humans, and animals seem not to be so disposed.

The three properties—reflexivity, symmetry, transitivity—are formal requirements that

determine whether the stimuli are also equivalent in a logico-mathematical sense (e.g., Lipkens et al., 1988). For the formation of equivalence classes in the matching paradigm, the stimuli should be interchangeable with respect to their sample and comparison functions. During matching training, however, the contingencies do not necessarily require subjects to treat the stimuli that have different functions as equivalent. The contingencies of reinforcement in symbolic matching to sample specify only "if X then Y" conditional relations. This may be the reason why animals and language-deficient humans generally fail to learn equivalence relations in the matching paradigm (see Hall, 1996, for a discussion of equivalence formation from the perspective of associative learning theory).

Another obstacle to the emergence of symmetry may be that performance on test trials requires subjects to emit untrained choice behavior. For example, the subjects trained with red and green colors as samples and vertical and horizontal lines as comparisons may learn to choose a particular line stimulus when a color stimulus is presented as a sample. Symmetry tests require subjects to emit untrained choice responses with respect to the color stimuli when a line stimulus appears as a sample. The emergence of symmetry and the emergence of untrained choice behavior are separate issues that are inevitably confounded in this matching-to-sample paradigm. In addition, symmetry tests require a change in the spatial and temporal locations at which samples and comparisons appear, which may hinder the emergence of symmetry in animals (see Iversen, Sidman, & Carrigan, 1986; Lionello & Urcuioli, 1998). It is possible that standard symbolic matching is not suitable for demonstrating emergent symmetrical relations in animals.

The symmetry property examined in the present study should be distinguished from the emergent symmetrical relation of the sort defined by Sidman (1992). The repeated reversal training used in the present experiment inevitably means that symmetry between the stimuli is trained. The supraordinate contingency is best described as members of each stimulus set "go together." If, on a given session, responses to one member of a set are reinforced, then responses to all the members of that set are reinforced. Nevertheless, in the present experiment, the stimuli in the same set were not always trained to be equivalent but in some cases were only conditionally related. Further research may be needed for more precise control of the response strategies used by pigeons in this experimental paradigm.

We close by briefly mentioning the results of an experiment reported by Delius, Jitsumori, and Siemann (2000) and Jitsumori and Delius (2001). A design analogous to the present one was used, but stimuli that were selected to be similar within each set and to be dissimilar between the two sets were used. It allowed equivalence class formation to be aided by stimulus generalization and, indeed, all 5 pigeons passed the tests demonstrating the formation of four-member equivalence classes: (A1, B1, C1, D1) and (A2, B2, C2, D2). Then we attempted to add to each class two additional and quite dissimilar stimuli, X and Y, by training the pigeons on A↔X and then D↔Y equivalences. Subsequent testing revealed that the D↔Y equivalence had been successfully learned by 4 of the 5 pigeons and that, furthermore, they had established the generalized equivalence class: (A, B, C, D, Y). In 1 of these 4 pigeons, Stimulus X was additionally but only weakly related to the members of the class. Only that pigeon demonstrated the emergent X→Y relation during X↔Y equivalence tests. That is, the new disparate stimuli were conditionally related through familiar members of the set that were physically similar to one another. Generalized equivalence classes, consisting of some stimuli that are perceptually similar and other stimuli that are perceptually disparate, have been repeatedly documented in experiments with humans (e.g., Fields, Adams, Buffington, Yang, & Verhave, 1996; Fields, Reeve, Adams, Brown, & Verhave, 1997). These findings, along with the findings in the present study, demonstrate the potential of the multiple-reversal procedure for investigating the formation and expansion of generalized equivalence classes in nonhuman subjects.

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