*FORMATION OF TRANSITIVITY IN CONDITIONAL
MATCHING TO SAMPLE BY PIGEONS*

HIROMICHI KUNO, TSUTOMU KITADATE, AND TAKASHIGE IWAMOTO

HOKKAIDO UNIVERSITY

Four homing pigeons were trained over 5 months in a zero-delay, "arbitrary" matching-to-sample procedure with sample and comparison stimuli presented on any of three response keys. Birds were also required to complete a fixed-ratio 10 requirement on both sample and comparison stimuli to terminate their presentation. The procedure resulted in the establishment of relations that were not specifically trained and that can be characterized by the property of transitivity in a stimulus equivalence context. This result was in contrast with the findings obtained from most previous research with nonhuman subjects.

Key words: stimulus equivalence, conditional matching to sample, zero-delay matching to sample, transitivity, spatial location, fixed-ratio sample requirements, fixed-ratio comparison requirements, key peck, pigeons

Untrained or derived relations among stimuli trained during a conditional discrimination have been studied in various approaches. One possible standard for classifying these various approaches is based on which relations are trained in the original training. With this approach, three types of paradigms are identified, as illustrated in Figure 1 (A, B, and C). With human subjects, all the various derived relations have been shown, demonstrating the formation of stimulus equivalence (Devany, Hayes, & Nelson, 1986; Lazar, Davis-Lang, & Sanchez, 1984; Mackay & Sidman, 1984; Sidman, 1971). For example, if a verbally competent human subject is trained to pick Stimulus B in the presence of Stimulus A and Stimulus C in the presence of Stimulus B (A-type paradigm), the subject will now show derived symmetry (pick A given B and B given C), derived transitivity (A to C), and reflexivity (A to A, B to B, and C to C). These derived relations have been used as the defining characteristics of a phenomenon known as stimulus equivalence (Sidman, 1971; Sidman & Tailby, 1982). This phenomenon has been shown not only in adults but also in children and in mentally retarded persons.

On the other hand, with nonhuman subjects, although a great deal of effort has been made to investigate stimulus equivalence, the various derived relations have not always been found (D'Amato, Salmon, Loukas, & Tomie, 1985; Holmes, 1979; Kendall, 1983; Lipkens, Kop, & Matthijs, 1988; McIntire, Cleary, & Thompson, 1987; Richards, 1988; Sidman et al., 1982; Sidman & Tailby, 1982), and stimulus equivalence has not yet been demonstrated (Hayes, 1989).

In addition to the three types of paradigms noted above, another possible classificatory standard is based on the kinds of stimuli and reinforcement, required responses, and procedures used (e.g. hedonic or nonhedonic, with reinforcement or without reinforcement, whether requiring stimulus-specific response or not, classical or instrumental conditioning). Using hedonic stimuli, the derived relations have been demonstrated for nonhuman subjects (Edwards, Jagielo, Zentall, & Hogan, 1982; Holland, 1981; Holland & Forbes, 1982; Nakagawa, 1986, 1992; Richards, 1988; Steirn, Jackson-Smith, & Zentall, 1991; Vaughan, 1988; Zentall, Sherburne, & Steirn, 1992; Zentall, Steirn, Sherburne, & Urcuioli, 1991). For example, Stern et al. (1991) trained pigeons in three successive phases using an A-type paradigm. First, they autoshaped pecking of one of two hue stimuli, only one of which was followed by access to food (Phase 1). They then trained the birds on a symbolic zero-delay matching-to-sample (DMTS) task with food and no-food samples and line-orientation comparisons (Phase 2). In the third phase, the

The present study was supported in part by Grant-in-Aid 01510040 from the Ministry of Education, Science and Culture of Japan, to Takashige Iwamoto. Requests for reprints should be addressed to Hiromichi Kuno, Department of Behavioral Science, Faculty of Letters, Hokkaido University, Kita 10, Nishi 7, Kita-ku, Sapporo, 060, Japan, or Takashige Iwamoto, Department of Psychology, Faculty of Letters, Hokkaido University, Kita 10, Nishi 7, Kita-ku, Sapporo, 060, Japan.

Fig. 1. Three types of equivalence paradigms. Each box represents a set of two stimuli. Arrows point from sample to comparison stimuli. For a given sample stimulus, the correct comparison is designated by the same number. The solid arrows represent conditional relations that are explicitly trained to the subject; the broken arrows represent derived relations.

birds were tested on a symbolic DMTS task in which the hue stimuli from Phase 1 were substituted for the Phase 2 food samples. For the positive group, the hue followed by food in Phase 1 was substituted for the food sample and the hue associated with no-food was substituted for the no-food sample; for the negative group, the pairings were reversed so that the sample-comparison pairings were inconsistent with the food-event mediators. Acquisition of the transfer task was significantly more rapid in the positive than in the negative condition. These experiments provide evidence that in pigeons, stimuli paired with events can be substituted for the events themselves; in other words, birds can exhibit derived transitive relations.

Holland (1981) demonstrated derived relations with a B-type paradigm using food aversions established in rats by administering lithium chloride (LiCl) immediately after the presentation of an exteroceptive conditioned stimulus (CS) that previously had been paired with food. In Experiment 1, rats that received first tone-food and then tone-LiCl pairings showed less food consumption in subsequent testing than rats that received only tone-food or tone-LiCl pairings. Additional experiments demonstrated the stimulus specificity of aversions established in this manner. Rats that first received pairings of a CS with LiCl showed greater aversion to the food that had previously been associated with the LiCl-paired CS than to the other food substance. Further, specific aversions were not acquired if rats received CS-shock rather than CS-LiCl pairings.

Arbitrary stimuli that are related to each other through their association with a common event may establish a stimulus class, which is defined as a set of stimuli that control the same response. This type of paradigm can correspond to the C-type paradigm in Figure 1 (Nakagawa, 1986, 1992; Urcuioli, Zentall, Jackson-Smith, & Steirn, 1989; Vaughan, 1988; Zentall et al., 1991). For example, Edwards et al. (1982) trained pigeons on a two-color matching-to-sample task and a two-shape matching-to-sample task. For one sample in each task (e.g., plus sign and red), the outcome on correct trials was corn; for the other samples (e.g., circle and green), the outcome was wheat. When the samples from one task were combined with the comparisons from the other task, birds that received sample-comparison

pairs that had, in original training, been associated with common outcomes (e.g., plus and green) showed superior performance.

Richards (1988) trained pigeons on two matching tasks before a transfer test. On one task, A and B were samples and X and Y were comparisons; on the other task, A and B became comparisons and two novel stimuli served as samples. The transfer test used X and Y samples and A and B comparisons. The birds learned a task that rewarded choosing A after X and B after Y more quickly than a task that rewarded choosing B after X and A after Y. This experimental procedure made it possible to suggest that some backward association, or symmetry, was formed.

Emergence of the derived relations has also been claimed after stimulus-specific responses are trained. For example, McIntire et al. (1987) required the cynomolgus macaques (*Macaca fascicularis*) in their experiment to perform a characteristic response pattern during the samples and also during comparisons that were expected to be members of the same class. In their experiment, a trial was initiated by illumination of the center key (the sample of one class) and then each of two comparison keys with one of six colors. Three of the colors were grouped into one class and the other three into a second class. To respond to a sample and comparison when presented, the subject was required to press and hold the center key continuously for 3.5 s. On the other hand, when responding to sample and comparison of the other class, the subject was required to press eight times (fixed-ratio, or FR, 8). The authors claimed that the resulting conditional discrimination performances of the 2 animals demonstrated derived relations of reflexivity, symmetry, and transitivity (but see Hayes, 1989, and later discussion).

Kendall (1983) studied equivalence relations in pigeons, using two conditional position discriminations in which each sample stimulus corresponded with a particular key location or with a particular left or right visual display. The A stimuli were two lights mounted on a small panel near the top of the side wall, the B stimuli were projected on the front wall, and the C stimuli were projected on the side wall of the test chamber. Kendall found that 2 subjects performed the AC conditional discrimination after learning the AB and BC conditional discriminations. No pigeon performed

the BC conditional discrimination after learning the AB and AC training conditional discriminations; nor did pigeons perform the AC conditional discrimination after learning the AB and CB conditional discriminations. As pointed out by Lipkens et al. (1988), however, an objection can be raised to Kendall's procedure, namely that the new conditional relations that were observed were implicitly taught by chaining the two conditional discriminations trained earlier.

Although it may be difficult to demonstrate the derived relations in nonhumans without using hedonic stimuli or stimulus-specific responses, D'Amato et al. (1985) demonstrated some of the derived relations comparing two performances on positive and negative test trials as follows. They compared two performances on 24 trials of a positive transitivity test, in which the reinforcement contingencies were congruent with the behavior expected from an animal whose behavior was controlled by associative transitivity, with those of a negative transitivity test, in which the reinforcement contingencies were incongruent with the behavior expected from that controlled by associative transitivity. They argued that all 4 monkeys used in their experiment demonstrated strong transitivity, whereas pigeons did not.

Without using hedonic stimuli, differential responses, or differential reinforcement in test trials, Sidman et al. (1982) reported that the acquisition of symmetrical relations was not evident in monkeys or baboons. Pigeons also showed none of these equivalence relations (D'Amato et al., 1985; Lipkens et al., 1988).

The present experiment was carried out to elucidate whether transitive relations, one of the characteristics of stimulus equivalence, can be demonstrated in pigeons without hedonic stimuli, differential responses, or differential reinforcement (with a probe test). To remedy some deficiencies of earlier experiments that did not demonstrate some properties of equivalence and to allow a more sensitive detection of transitivity, the following seven changes were introduced in our experiment: (a) The sample was presented in a random location among three keys, not only in a particular location of a center key. (b) Ten pecks were required to terminate comparisons as well as samples. (c) The length of the training sessions prior to the test sessions was extended enough to produce

Fig. 2. A schematic diagram of a series of events in our matching-to-sample training trial. The series branched away at the choice stage depending on whether correct comparisons or incorrect comparisons were chosen. The rectangles indicate the different states of the schedule. The circles represent the stimulus/response keys, and the figures represent the stimuli presented.

stable and robust performance. (d) Matching to sample with a 0-s delay was employed instead of simultaneous matching to sample. (e) Intermittent reinforcement sessions, including 24 nonreinforcement trials per session, were introduced immediately before test sessions to reduce deterioration of performance due to novel situations. (f) Two kinds of associations, that is, Stimulus A to B and Stimulus B to C, were concurrently presented in the same training sessions to minimize forgetting. Thus, four kinds of conditional relations were presented at the same time. (g) Heterogeneous associations (shape-color) between the sample and the comparison were employed instead of homo-

geneous associations (shape-shape/color-color) in probe trials.

METHOD

Subjects

Four experimentally naive homing pigeons (P1, P2, P3, P4), about 3 years of age, served as subjects. They were maintained at approximately 80% of their free-feeding weights throughout the experiment. They were housed in individual home cages with water continuously available. The birds were trained for one session per day, 7 days a week.

Apparatus

Two identical standard experimental chambers with three keys (BRS/LVE, SEC-022) were used. Each chamber was 37 cm high, 35 cm wide, 31 cm deep. One wall of the chamber contained three stimulus/response keys, a houselight, and an aperture (5 cm by 6 cm) to provide access to mixed pigeon grain. The keys were 2.5 cm in diameter and were aligned horizontally above the chamber floor with a center-to-center distance of 16.5 cm, 9 cm from the vertical edges of the panel and 25.5 cm above the floor. Each key required a minimum force of about 0.15 N to be activated. An in-line projector (BRS/LVE, IC-900-696 Extra Film Patterns) behind each key displayed the stimuli, either red or green patches filling the key or a white triangle, circle, cross, or vertical line on a black background. A NEC PC 9801 VX personal computer controlled sequences of stimuli and experimental procedures and recorded events of interest.

Procedure

The experiment was divided into four parts: preliminary training, conditional discrimination training, intermittent-reinforcement conditional discrimination training, and the transitivity test.

Preliminary training. The subjects were first trained to approach and eat from the illuminated hopper, and were then taught to peck the keys by the method of successive approximations until they had learned to peck on all keys with all illuminations used in the experiment. The sequence of training for each key position and stimuli presented was counter-balanced among the subjects. In the next phase, the birds were required to peck on each key 10 (FR 10) times to get 3-s access to mixed

grain. This procedure lasted until each subject had received 20 reinforcements on each key for each stimulus.

Conditional discrimination training. The sequence of events within a trial in this phase is shown in Figure 2. A trial began with the illumination of the houselight followed 3 s later by the presentation of the sample stimulus on one of three keys, randomly selected. When the pigeon pecked the sample key 10 times, the sample stimulus disappeared immediately and two comparison stimuli appeared on the remaining two keys. If the pigeon selected (pecked 10 times) the comparison stimulus arbitrarily related to the preceding sample stimulus, both comparison stimuli were removed immediately and, at the same time, a food magazine containing mixed grain appeared in the aperture for 3 s. A 10-s intertrial interval (ITI) followed. When the pigeon selected (pecked 10 times) the comparison stimulus not related to the preceding sample stimulus, both comparison stimuli were removed, the houselight was turned off immediately, and a blackout period continued for 5 s without reinforcement, followed by the 10-s ITI. Incorrectly completed trials were always repeated until a correct selection was made (correction method). The arbitrary relations among stimuli used in the present experiment are shown in Figure 3. For example, when the sample stimulus was a circle (vertical line), the correct comparison was a triangle (cross); when the sample stimulus was a triangle (cross), the correct comparison was red (green). The explicitly taught relations are indicated by solid arrows in Figure 3. The four types of trials were presented at random within the sessions. A session consisted of 72 trials (excluding correction trials), but if the 72 trials were not completed within 4 hr, the session ended. This training phase consisted of 110 sessions (including sessions terminated by the 4-hr limit).

Intermittent-reinforcement conditional discrimination training. In this phase, intermittent-reinforcement conditional discrimination training sessions were introduced to maintain the performance for the upcoming test sessions. Twenty-four nonreinforcement trials were included per session. The experimental procedure was the same as that for conditional discrimination training except that (a) no reinforcement was available in 24 trials per session (72 trials) even if the pigeons selected

Fig. 3. A transitivity paradigm. Each box represents a set of two stimuli. Arrows point from sample to comparison stimuli. For a given sample stimulus, the correct comparison is designated by the same number. The solid arrows (A1B1, A2B2, B1C1, and B2C2) represent conditional relations that were explicitly taught to the subject; the broken arrows (A1C1 and A2C2) represent emergent transitive relations.

the correct comparison stimulus, and (b) no correction trial was available on those 24 trials even if the pigeons selected the incorrect comparison stimulus. The 24 nonreinforcement trials were randomly assigned to trials within the session. This training phase consisted of 56 sessions for Bird P2 (because of lower performance), and 49, 53, and 48 sessions for Birds P1, P3, and P4, respectively.

Transitivity test. During transitivity testing, nonreinforcement trials in the prior training sessions were replaced by another type of trial in which pigeons were, for the first time, required to select a comparison stimulus (either red or green) after the sample stimulus was a triangle or a cross. Again, no reinforcement was given on these trials, and no correction procedure was used. These untaught relations are represented by broken arrows in Figure 3. A transitivity test session consisted of 48 baseline trials (12 each of the four previously trained trial types) and 24 test trials (12 each of the two possible trial types). Five test sessions were carried out on 5 consecutive days for Birds P1 and P4. For Birds P2 and P3, however, test sessions were carried out with two baseline sessions intervening between each test, with this sequence continuing until five test sessions had been conducted after the second session, because there was an abrupt deterioration of performance on probe test trials in the second session. If pigeons selected red (or green) following samples of triangle (or cross), transitivity was confirmed.

RESULTS

Training

The conditional discrimination phase was divided into 3 blocks. Figure 4 shows the mean percentage correct in the last 10 sessions in each phase over the three blocks and the sessions, with intermittent reinforcement, for each subject. Figure 4 also shows that except for Bird P4, performance was better in trials containing color comparison stimuli (S-C trials) than in trials consisting of only shape stimuli (S-S trials). The mean percentage correct in the final, intermittent reinforcement, training phase reached 93.0%, 80.6%, 87.0%, and 86.5% for P1, P2, P3, and P4, respectively.

Test

Figure 5 shows day-by-day percentage correct in test sessions (test trials and baseline trials) for each bird and the intervening sessions for P2 and P3. Choice of the comparison consistent with transitivity across all test trials for P1 and P4 was statistically significant above the chance level ($z = 2.74, p < .01$; $z = 2.92, p < .01$, respectively). Accuracy for P2 and P3 was not significantly above the chance level ($z = 1.46, p > .05$; $z = 1.28, p > .05$, respectively). It was noted, however, that P2 showed very high evidence of transitivity in the first test session, in which the transitivity-appropriate response was made on 20 of 24 test trials [$\Pr(x|x \geq 20, x \leq 4) = .002 < .01$]. Performances on test (probe) trials for the 4 birds were lower than performances on the baseline trials in every case but one.

DISCUSSION

First of all, our procedure with the improvements mentioned above succeeded in providing evidence of the formation of transitivity for 1 bird (P4) and some evidence of the formation of transitivity for 2 other birds (P1 and P2). P2 showed very high transitivity-consistent performance in the first test session but not thereafter. P3, however, showed little evidence of transitivity, although it made 16 of 24 choices consistent with transitivity in the

Fig. 4. Mean percentages of correct responses in four training phases. Open circles, open triangles, filled circles, and filled triangles represent mean percentages of correct responses in Conditional Relations A1B1, A2B2, B1C1, and B2C2, respectively. Points above FFCDT, MFCDT, and LFCDT show data from the first, middle, and last blocks (1 block = $\frac{1}{3}$ training sessions) of conditional discrimination training. Points above IRCDT show data from the condition in which correct matching-to-sample performance was reinforced intermittently.

Fig. 5. Day-by-day accuracy for the reinforced trials (baseline trials) and for the nonreinforced trials (probe trials) for each session in the five transitivity test sessions for each bird. For P2 and P3, accuracy for the intervening sessions (I) was added. Bars represent percentage correct on baseline trials (B) and test trials (T). Bars that represent percentage correct in probe trials consist of three bars, which represent percentage correct on overall probe trials (left), A1C1 probe trials (center), and A2C2 probe trials (right). Horizontal dotted line represents the chance level.

PERCENT CORRECT

SESSIONS

first test session. Taken in aggregate, the 4 pigeons selected the choice consistent with transitivity on 69% (66 of 96) of the trials in the first test. These results are in contrast with the lack of transitivity obtained in some non-human animal research (D'Amato *et al.*, 1985; Gray, 1966; Hogan & Zentall, 1977; Holmes, 1979; Rodewald, 1974; Sidman *et al.*, 1982). Because these results were inconsistent across subjects, however, it seems that the establishment of transitivity in pigeons might be weaker than in humans.

Although the advantages brought by the specific changes selected in our procedures (*i.e.*, the changes mentioned in the Introduction) remain to be analyzed, some evaluation of possible advantages may be offered. Iversen, Sidman, and Carrigan (1986) carried out an experiment in which the sample was first presented only on the center key, and was then allowed to appear on any one of the three keys, with the comparisons on the remaining two. The change from a fixed to a variable sample and comparison locations caused the line orientations (horizontal and vertical lines) used as controlling stimuli to lose control over the animals' responses. Consequently, the authors argued that an accurate description of controlling stimuli in a matching-to-sample procedure might require specifying the locations of stimuli and that failure to give an accurate description might have generated unwarranted conclusions about a subject's performance or abilities (*e.g.*, Cumming & Berryman, 1965; Farthing & Opuda, 1974; Sidman *et al.*, 1982).

Sacks, Kamil, and Mack (1972) found that by requiring a greater fixed-ratio sample requirement, the speed of acquisition and transfer in a matching-to-sample procedure was enhanced, and the performance was improved when a delayed matching procedure was introduced. Moreover, requiring the equivalent response to both sample and comparison might allow Stimulus B presented as comparison in a particular trial and Stimulus B presented as sample in another trial to resemble each other, and enable Stimulus B to mediate between Stimulus A and Stimulus C.

To show transitivity, the subject must associate the sample stimulus with the correct comparison stimulus in the absence of an explicit mediating stimulus. Hogan and Zentall (1977) reported that when the sample stimulus remained present with the comparison stimuli

(simultaneous matching to sample), no evidence of learning of backward associations was found. On the other hand, when the sample stimulus was removed on presentation of the comparison stimuli (0-s delayed matching to sample), evidence of backward associations was found, although only over the first few transfer trials.

Carter and Eckerman (1975) carried out an experiment using four kinds of discrimination tasks: a matching task with colors alone as sample and comparison stimuli (color matching), a matching task with shapes alone as sample and comparison stimuli (line matching), and symbolic matching tasks involving shapes and colors as sample and comparison stimuli (color symbolic matching and line symbolic matching). The results demonstrated that symbolic matching was learned more slowly than color matching and that line matching was learned more slowly than color matching. Their analysis treated this difference as resulting from the difficulties of the specific component discriminations rather than from an essential difference between shapes and colors. Although our recommendation for shape-color matching in test trials does not derive directly from their analysis, it is likely that shape-color matching in test trials might be more appropriate than shape-shape matching. Moreover, Hogan and Zentall (1977) reported that pigeons demonstrated strong color preferences in a matching-to-sample procedure with colors alone. For these reasons, heterogeneous configurations of sample and comparison stimuli (*i.e.*, circle sample/red comparison and vertical line sample/green comparison) in the present transitivity tests may have been advantageous.

It has been argued that nonhuman animals have a strong tendency to avoid novel stimuli (Cumming & Berryman, 1965; Zentall, Edwards, Moore, & Hogan, 1981; Zentall & Hogan, 1974, 1976, 1978). For example, Zentall *et al.* (1981) argued that by presenting novel stimuli, they might have masked the extent to which transfer effects in matching to sample were demonstrated because pigeons tended to avoid pecking the novel stimuli. Farthing and Opuda (1974) tried to reduce the effect of novel-stimulus avoidance by reinforcing responses to the novel color presented by itself prior to the test. In general, both a novel stimulus and a novel situation may make it difficult to inter-

pret the results of experiments. Nevertheless, most studies (except for that of Lipkens et al., 1988) on equivalence classes in nonhuman animals have used procedures in which probe test sessions immediately followed continuous-reinforcement sessions. The same kind of problems mentioned above remained to be resolved in our procedure; that is, unreinforced trials in the probe test sessions were unfamiliar to the birds used in the preceding continuous-reinforcement procedure. To reduce the effect of nonreinforcement in probe test trials, intermittent-reinforcement conditional discrimination was introduced.

Another possible advantage of our procedure is that the number of trials used in our study was larger than that used in earlier studies on transitivity. For example, Lipkens et al. (1988) conducted only five or six or, at most, 29 training sessions prior to the test sessions. On the other hand, the birds used in our experiment were exposed to many more training sessions.

As mentioned before, McIntire et al. (1987) required cynomolgus macaques to make two different kinds of responses to six colors categorized into two groups of three in their conditional discrimination training. These two differential response patterns (they called this a "naming system") resulted in the demonstration of high conditional discrimination performance based on reflexivity, symmetry, and transitivity in the test sessions. Therefore, they concluded that the equivalence classes had been established and that these findings indicated the potential importance of differential response topographies in the ontogeny of equivalence classes and the formation of reflexivity, symmetry, and transitivity. Moreover, they suggested that the formation of equivalence classes (and hence the formation of reflexivity, symmetry, and transitivity) might have arisen from the use of a functional naming system. On the other hand, although the present authors did not use differential response patterns or a naming system, transitivity was demonstrated. Therefore, specific training with such differential response patterns may not be essential, at least for the development of transitivity; thus, the formation of equivalence classes in nonhuman animals may have no direct relation to human language.

The fact that performances on test trials were below those on baseline trials in the tran-

sitivity tests might be due to limitations on the birds' ability to exhibit transitive relations or to general deterioration in performance because of novelty or unfamiliarity of stimulus configurations on the transitivity tests.

In summary, we demonstrated a weak transitive property in a conditional discrimination in pigeons. These stimulus-stimulus relations were found even though no mediating response had been trained. However, further studies to evaluate the extent to which our results are valid are encouraged. In the first place, in the present study, only 2 pigeons showed consistent weak transitivity, and only with a particular configuration of stimuli. In the second place, the transitive relation alone was investigated with an A-type paradigm only (see Figure 1). Therefore, both the transitive relations in other paradigms and symmetrical relations in all paradigms remain to be investigated. Moreover, the necessity of the suggested improvements in our training procedure remains to be determined. For example, is the procedure of presenting sample and comparison stimuli in random locations necessary? Are FR 10 sample and comparison requirements efficient? Are as many as 10,000 conditional discrimination training trials necessary? Are training sessions involving trials without reinforcement prior to the test necessary? Would our findings also hold for other animal species? Both the exact nature of the relation between language and equivalence (Saunders, 1989) and investigation of the establishment of other properties such as symmetry and reflexivity still remain to be clarified.

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.
- Cumming, W. W., & Berryman, R. (1965). The complex discriminated operant: Studies of matching-to-sample and related problems. In D. I. Mostofsky (Ed.), *Stimulus generalization* (pp. 284-330). Stanford, CA: Stanford University Press.
- D'Amato, M. R., Salmon, D. P., Loukas, E., & Tomie, A. (1985). Symmetry and transitivity of conditional relations in monkeys (*Cebus apella*) and pigeons (*Columba livia*). *Journal of the Experimental Analysis of Behavior*, 44, 35-47.
- Devany, J. M., Hayes, S. C., & Nelson, R. O. (1986). Equivalence class formation in language-able and language-disabled children. *Journal of the Experimental Analysis of Behavior*, 46, 243-257.

- 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., & Opuda, M. J. (1974). Transfer to matching-to-sample in pigeons. *Journal of the Experimental Analysis of Behavior*, 21, 199-213.
- Gray, L. (1966). Backward association in pigeons. *Psychonomic Science*, 4, 333-334.
- Hayes, S. C. (1989). Nonhumans have not yet shown stimulus equivalence. *Journal of the Experimental Analysis of Behavior*, 51, 385-392.
- Hogan, D. E., & Zentall, T. R. (1977). Backward associations in the pigeon. *American Journal of Psychology*, 90, 3-15.
- Holland, P. C. (1981). Acquisition of representation-mediated conditioned food aversions. *Learning and Motivation*, 12, 1-18.
- Holland, P. C., & Forbes, D. T. (1982). Control of conditional discrimination performance by CS-evoked event representations. *Animal Learning & Behavior*, 10, 249-256.
- Holmes, P. W. (1979). Transfer of matching performance in pigeons. *Journal of the Experimental Analysis of Behavior*, 31, 103-114.
- Iversen, I. H., Sidman, M., & Carrigan, P. (1986). Stimulus definition in conditional discriminations. *Journal of the Experimental Analysis of Behavior*, 45, 297-304.
- Kendall, S. B. (1983). Tests for mediated transfer in pigeons. *Psychological Record*, 33, 245-256.
- Lazar, R. M., Davis-Lang, D., & Sanchez, L. (1984). The formation of visual stimulus equivalences in children. *Journal of the Experimental Analysis of Behavior*, 41, 251-266.
- Lipkens, R., Kop, P. F. M., & Matthijs, W. (1988). A test of symmetry and transitivity in the conditional discrimination performances of pigeons. *Journal of the Experimental Analysis of Behavior*, 49, 395-409.
- Mackay, H. A., & Sidman, M. (1984). Teaching new behavior via equivalence relations. In P. H. Brooks, R. Sperber, & C. McCauley (Eds.), *Learning and cognition in the mentally retarded* (pp. 493-513). Hillsdale, NJ: Erlbaum.
- McIntire, K. D., Cleary, J., & Thompson, T. (1987). Conditional relations by monkeys: Reflexivity, symmetry, and transitivity. *Journal of the Experimental Analysis of Behavior*, 47, 279-285.
- Nakagawa, E. (1986). Overtraining, extinction and shift learning in a concurrent discrimination in rats. *The Quarterly Journal of Experimental Psychology*, 38, 313-326.
- Nakagawa, E. (1992). Effects of overtraining on reversal learning by rats in concurrent and single discriminations. *The Quarterly Journal of Experimental Psychology*, 44, 37-56.
- Richards, P. W. (1988). The question of bidirectional associations in pigeons' learning of conditional discrimination task. *Bulletin of the Psychonomic Society*, 26, 577-579.
- Rodewald, H. K. (1974). Symbolic matching-to-sample by pigeons. *Psychological Reports*, 34, 987-990.
- Sacks, R. A., Kamil, A. C., & Mack, R. P. (1972). The effects of fixed-ratio sample requirements on matching to sample in pigeons. *Psychonomic Science*, 26, 291-293.
- Saunders, K. J. (1989). Naming in conditional discrimination and stimulus equivalence. *Journal of the Experimental Analysis of Behavior*, 51, 379-384.
- Sidman, M. (1971). Reading and auditory-visual equivalences. *Journal of Speech and Hearing Research*, 14, 5-13.
- Sidman, M., Rauzin, R., Lazar, R., Cunningham, S., Tailby, W., & Carrigan, P. (1982). A search for symmetry in the conditional discriminations of rhesus monkeys, baboons, and children. *Journal of the Experimental Analysis of Behavior*, 37, 23-44.
- Sidman, M., & Tailby, W. (1982). Conditional discrimination vs. matching to sample: An expansion of the testing paradigm. *Journal of the Experimental Analysis of Behavior*, 37, 5-22.
- Steirn, J. N., Jackson-Smith, P., & Zentall, T. R. (1991). Mediation use of internal representations of food and no-food events by pigeons. *Learning and Motivation*, 22, 353-365.
- Urcioli, 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. (1988). Formation of equivalence sets in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 14, 36-42.
- Zentall, T. R., Edwards, C. A., Moore, B. S., & Hogan, D. E. (1981). Identity: The basis for both matching and oddity learning in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 7, 70-86.
- Zentall, T. R., & Hogan, D. E. (1974). Abstract concept learning in the pigeon. *Journal of Experimental Psychology*, 102, 393-398.
- Zentall, T. R., & Hogan, D. E. (1976). Pigeons can learn identity or difference, or both. *Science*, 191, 408-409.
- Zentall, T. R., & Hogan, D. E. (1978). Same/different concept learning in the pigeon: The effect of negative instances and prior adaptation to transfer stimuli. *Journal of the Experimental Analysis of Behavior*, 30, 177-186.
- Zentall, T. R., Sherburne, L. M., & Steirn, J. N. (1992). Development of excitatory backward associations during the establishment of forward associations in a delayed conditional discrimination by pigeons. *Animal Learning & Behavior*, 20, 199-206.
- Zentall, T. R., Steirn, J. N., Sherburne, L. M., & Urcioli, P. J. (1991). Common coding in pigeons assessed through partial versus total reversals of many-to-one conditional and simple discriminations. *Journal of Experimental Psychology: Animal Behavior Processes*, 17, 194-201.

Received March 30, 1992

Final acceptance June 13, 1994