JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1985, 44, 35-47 NUMBER 1 (JULY)

SYMMETRY AND TRANSITIVITY OF CONDITIONAL RELATIONS IN MONKEYS (CEBUS APELLA) *AND PIGEONS* (COLUMBA LIVIA)

M. R. D'AMATO, DAVID P. SALMON, ERIC LOUKAS, AND ART TOMIE

RUTGERS UNIVERSITY

In Experiment 1 six monkeys were tested with discriminative relations that were backward relative to their training in a 0-second conditional ("symbolic") matching procedure. Although there was some indication of backward associations, the evidence was generally weak, and statistical evaluations did not reach conventional significance levels. Unlike children, who show backward associations to the point of symmetry, monkeys and pigeons display at best only weak and transient backward associations. In Experiment 2 associative transitivity was assessed across two sets of conditional matching tasks. All four monkeys tested demonstrated strong transitivity. In contrast, in Experiment 3 there was no evidence of transitivity in three pigeons tested under conditions closely comparable to those of Experiment 2. These results may identify some key features of interspecies differences and contribute to analyses of serial learning in animals.

Key words: symmetry, transitivity, conditional relations, key press, key peck, monkeys, pigeons

In a conditional or "symbolic" task, the subject associates members of a pair of standard stimuli ("samples"), say A and B, with members of a pair of comparison stimuli, say X and Y, so that when A appears as the sample the subject responds to comparison stimulus X, and when B is the sample the subject responds to Y. An issue of long-standing theoretical significance is whether such associations, which have a decided temporal order, are unidirectional only. Asch and Ebenholtz (1962) argued that when humans learn to associate one stimulus item with another, a backward association is simultaneously formed that is equal in strength to the programmed forward association—their principle of "associative symmetry." Although the issue of whether associations in humans are generally symmetrical (i.e., forward and backward associations equal in strength) seems not to have been resolved, backward associations of substantial strength are often reported (see Houston, 1981).

Early investigators of animal learning also were interested in backward associations, but their maze-apparatus studies often lacked appropriate controls (cf. Hogan & Zentall, 1977). Motivated by Asch and Ebenholtz's principle of associative symmetry, Gray (1966) studied pigeons that were trained with the conditional matching paradigm described above, which is well suited for revealing backward associations. After the animals learned the A-X and B-Y relations, the roles of the samples and comparison stimuli were interchanged to assess the degree to which the X-A and Y-B relations were learned. Two of 3 pigeons showed some evidence of backward association in two 28-trial test sessions (64% correct responses), but their accuracy scores were much higher on a comparable test on forward relations (86%). In a 90-trial backward association test procedure, Rodewald's (1974) 3 pigeons averaged about 66% correct, but there was no control for transfer of general learning factors. Finally, in a careful and detailed investigation also employing pigeons, Hogan and Zentall (1977) found no evidence of backward association when simultaneous

---

This research was supported by NSF Grant 8207146. Preliminary data from Experiments 1 and 2 were described by D'Amato and Salmon (1984), who were responsible for the primate work. The pigeon research was the responsibility of E. Loukas and A. Tomie. Reprints may be obtained from M. R. D'Amato, Department of Psychology, Rutgers University, New Brunswick, New Jersey 08903.

matching was employed; however, with 0-s delay training and testing, some evidence of backward association appeared, but it dissipated quickly after the first 16 test trials. The conclusion suggested by these studies is that when pigeons learn the forward associations of a conditional matching problem, they simultaneously acquire backward associations very weakly, if at all.

More recently Sidman, Rauzin, Lazar, Cunningham, Tailby, and Carrigan (1982) investigated backward association in rhesus monkeys and baboons, also with the conditional matching procedure. They emphasized associative symmetry, which they considered a necessary condition for the establishment of an equivalence relation between a sample and its related comparison stimulus. Actually, it is not clear from their account whether symmetry is required or whether backward associations less pronounced than the forward ones would suffice to demonstrate equivalence. Because it appears that most investigators do not assume an animal necessarily learns a pair of equivalence relations when learning to perform a conditional matching task, we will not discuss this interesting issue further (see Sidman et al., 1982, pp. 23-25); instead, we shall focus on their experimental results. Despite extensive efforts, Sidman et al. could find no evidence of backward association, let alone symmetry, in the behavior of their monkeys and baboons. On the other hand, 4 of 6 young children (54 to 69 months of age) trained with substantially the same stimulus materials and procedures demonstrated backward association to the point of symmetry.

Although the study by Sidman et al. was detailed in scope and incorporated numerous appropriate controls, there was an invariant feature of the procedure that might have put the animal subjects at a disadvantage. In all cases the test comparison stimuli were a vertical and a horizontal line—stimuli that, as compared to colors, primates as well as other animals do not easily discriminate (e.g., Carter & Eckerman, 1975; D'Amato & Fazzaro, 1966). It must be acknowledged that the animals were trained on identity matching with this same pair of stimuli (which proved quite difficult) and that, during testing, performance on the baseline vertical/horizontal line matching task was at a high level of accuracy. Nevertheless, discriminative control in the identity matching task may have depended importantly on the presence of the sample (simultaneous matching was employed) which, with the two comparison stimuli, formed a configural pattern that remained invariant across such retinal transformations as would be caused by rotation of the head. Thus, irrespective of the position of the head, a "vertical" line sample would have the same retinal orientation as a "vertical" line comparison stimulus but would be different from that of a "horizontal" line comparison stimulus (cf. Iversen, Sidman, & Carrigan, 1984). Because colored disks were used as samples in all tests using backward relations, discriminating between the vertical and horizontal lines would not have the benefit of this configural cue. Young children may discriminate vertical and horizontal lines more easily than monkeys do, without the aid of configural cues (cf. Rudel & Teuber, 1963), which would put them at an advantage in the tests for backward association.

Whether or not the particular set of comparison stimuli used by Sidman et al. was an important factor in their results, it obviously would be of value to verify their findings under a wider range of conditions.

EXPERIMENT 1

The general strategy of the present experiment was similar to that of the study by Sidman et al. Using four sample/comparison stimulus sets, monkeys were trained on a conditional matching task, and in subsequent test sessions the strength of the backward associations established by the original training was assessed. Zero-second delay, which reduces the likelihood of control by configural factors, and which in one study (Hogan & Zentall, 1977) produced more evidence of backward association than did simultaneous matching, was employed in training and testing.

METHOD

Subjects

Two male (Moe and Roscoe) and four

female (Coco, Dagwood, Fifi, and Olive) monkeys (*Cebus apella*) served as subjects. The four females had extensive past experience with identity matching and with conditional (symbolic) matching. Roscoe had a vast amount of experience with identity matching but virtually none with conditional matching. Moe had some prior experimental experience with simple auditory discriminations but none with visual stimuli. The monkeys were housed in individual cages, with water constantly available. Food (Purina high-protein monkey chow #5045) was restricted to a single feeding, about 1 to 2 hours after an experimental session, adjusted to an amount that maintained each animal at a body weight that promoted effective performance.

Apparatus

Two monkey test chambers were used, described in more detail in previous reports (D'Amato, 1973; Salmon & D'Amato, 1981). The front wall of each chamber contained four inline (IEE Model 1071) projectors located at the four corners of a 12-cm square, with a fifth projector at the center. Each projector was fitted with a transparent key that served as the response mechanism. Only the center and top two projectors were used, the sample stimulus appearing on the former and the comparison stimuli on the latter. A microswitch, used to initiate a trial, was located below the projector array and below it was a recessed dipper well that was illuminated during intertrial intervals. Noyes banana pellets (190 mg) served as reinforcers and were delivered to a cup located on the right wall.

Illumination of the chamber was provided by an overhead houselight, a 25-W soft-white bulb located behind a translucent shield. The houselight could be dimmed by adding a 500-ohm resistor in series with the bulb, reducing the illumination from 3 ft-ca. (measured on the floor of the chamber) to about 0.1 ft-ca. Stimulus presentation, programming of trial events, and data recording were controlled by a PDP 8/e computer and a Commodore disk unit.

The stimuli consisted of a red disk that illuminated a circular area on the projectors approximately 25 mm in diameter, and five forms: circle, equilateral triangle with point down, vertical line, plus (vertical line superimposed on horizontal line), and a dot. All forms appeared as white figures on a black background and, except for the circle and dot, were composed of white lines, approximately 1.5 by 17 mm. The circle, 17 mm in diameter, was also composed of a 1.5-mm line, and the solid dot was 6 mm in diameter.

Procedure

Task 1: Training. The 4 female subjects entered the present experiment directly from an unrelated study in which they received very extensive training on the conditional matching tasks that comprised Task 1 of the present study (Table 1). As the training parameters were appropriate for the present experiment, these subjects required no additional training prior to the backward association tests.

Roscoe and Moe were trained on conditional matching with the samples and comparison stimuli shown in Table 1, first with simultaneous and then with 0-s delay matching. Training continued until they performed accurately with the parameters described below. The total number of training trials that preceded the first backward association test was approximately 3400 for Roscoe and 1300 for Moe.

All 6 monkeys were exposed to the same four stimuli during Task 1. The stimuli that served as samples for Coco and Dagwood (triangle and dot) functioned as comparison stimuli for Fifi and Olive, and those that were comparison stimuli for the first 2 subjects served as samples for the latter 2; in all cases, however, the same two stimuli were conditionally paired (e.g., triangle and red). Moe was assigned the same samples and comparison stimuli as were Coco and Dagwood but the conditional relations were reversed; Roscoe was the corresponding control for Fifi and Olive.

The sequence of events on a terminal training or backward association test trial was as follows. Trial onset was initiated by pressing the microswitch 10 times, which resulted in a 0.4-s tone that signaled presentation of the sample stimulus on the center projector. The duration of the sample was normally 1 s, except for Coco and Fifi during Task 1 testing, when it was 0.3 s, the duration that was used during their previous training. Both of these values are well above that necessary to support accurate performance levels in identity matching (D'Amato & Worsham, 1972). Termination of the sample was followed immediately by presentation of the comparison stimuli on the upper two projectors. A single depression of the projector response key on which the correct comparison stimulus appeared resulted in termination of the stimulus display, delivery of a food pellet, and entry into the 20-s intertrial interval, during which the houselight was dimmed and the dipper well was illuminated. Depression of the projector key displaying the incorrect comparison stimulus terminated the stimulus display and began a 60-s timeout period signaled by the dim houselight alone, which was followed by the intertrial interval. Training sessions usually consisted of 24 trials, each sample stimulus appearing 12 times in a quasirandom order; 48-trial sessions were presented occasionally. Throughout all phases of the experiment the subjects received one session per day, usually six sessions per week.

Backward association tests. During the backward association (BA) tests, the roles of samples and comparison stimuli were interchanged. In the positive backward-association (BA+) tests, the conditional relations were consistent with the backward associations that might have been formed during training. Referring to Coco in Table 1, when red appeared as the sample in the BA+ test, pressing the key on which the triangle appeared was correct and reinforced; when vertical line was the sample, pressing the key on which the dot appeared was correct and reinforced; incorrect responses resulted in the usual timeout. In the negative backward-association tests (BA−), the reverse relationships held. Dot was the correct comparison stimulus when red appeared as sample, and triangle was correct when the sample stimulus was vertical line.

All subjects were exposed to both BA+ and BA− tests. Half received the BA+ test first, half the BA− test first (see Table 1). After the first test, 5 subjects were returned to the original conditional matching task for 9 or 10 baseline training sessions. This additional baseline training was followed by the second BA test. Fifi, the lead monkey in the study, did not receive the second test (BA−) until she finished testing on the second conditional matching task (see below). All BA tests were limited to one 24-trial session, except in the cases of Coco and Fifi, each of which received two; for these 2 monkeys the data analysis is based on the first test session only.

Task 2: Training and testing. In preparation for Experiment 2, Coco, Dagwood, Fifi, and Olive were trained on a second conditional matching task in which the samples were the comparison stimuli of the first matching task (Table 1). The numbers of training sessions received by the 4 subjects were 26, 11, 38, and 104, respectively. All subjects averaged 90% correct responses or better over the last 10 sessions of training. The terminal training parameters were the same as in the first matching task—that is, 1-s presentation of the standard stimulus, 0-s delay, and 24-trial sessions. Dagwood's rapid acquistion of Task 2 is probably due to the fact that between completion of testing on Task 1 and training on Task 2, she received extensive training on a closely related conditional matching problem. The other 3 subjects had no intervening training.

Upon completion of training on Task 2, 2 subjects were given a BA+ test and 2 a BA− test. After 9 to 13 additional baseline training sessions, the second test, BA− for the first 2 subjects and BA+ for the second 2, was given. The BA tests consisted of one 24-trial session for Dagwood and Olive, two for Coco and Dagwood. As in Task 1, only the first test session entered the data analyses.

RESULTS

Task 1

Over the three baseline sessions that immediately preceded the first BA test on Task 1, the 6 subjects averaged 95.1% correct responses (range: 90.3 to 97.2%); the corresponding value for the three sessions that preceded the second BA test was 94.2% (range: 86.1 to 100%).

Table 1

Stimulus Assignments for Conditional Matching Tasks 1 and 2

Subject	*Task 1* *Samples*	*Task 1* *Comparison Stimuli*	*Task 2* *Samples*	*Task 2* *Comparison Stimuli*
Coco	Triangle →	Red	* Red →	Plus
	Dot →	V. Line	V. Line →	Circle
Dagwood	* Triangle →	Red	Red →	Circle
	Dot →	V. Line	V. Line →	Plus
Fifi	* Red →	Triangle	Triangle →	Plus
	V. Line e]	Dot	Dot →	Circle
Olive	Red →	Triangle	* Triangle →	Circle
	V. Line →	Dot	Dot →	Plus
Moe	Triangle →	V. Line		
	Dot →	Red		
Roscoe	* Red →	Dot		
	V. Line →	Triangle		

*Received BA+ test first.

Figure 1 presents the BA tests for the first 12 trials only, which presumably were less influenced by the reinforcement contingencies than the results based on all 24 trials. All subjects but Olive performed better on the BA+ than on the BA− test. Across subjects, the mean percentage of correct responses was 66.7 on the BA+ tests, 41.7% on the BA−. However a two-tailed correlated *t* test, based on the difference in numbers of correct responses on BA+ and BA− tests, fell short of accepted significance levels [$t(5) = 2.29$, $.05 < p < .10$]. The results for all 24 test trials were very similar, with mean values of 66.0% versus 38.2% correct on the BA+ and BA− tests, respectively. The same type of statistical analysis led to a comparable result [$t(5) = 2.15$, $.05 < p < .10$].

Somewhat stronger evidence of backward association was found in the first two test trials, performance on the BA+ and BA− tests being 83.3% and 41.7% correct, respectively. However, the difference all but vanished on Trials 3 and 4, for which the corresponding values were 66.7% and 59.3%.

Strong stimulus preferences were in evidence during the BA tests. Olive, for example, pressed the same comparison stimulus, vertical line, on all 24 trials of the BA+ and BA− tests. Moe pressed the triangle on 23 trials of both BA tests. To determine whether the degree of backward association displayed by a subject was related to the strength of its stimulus preference, each subject was ranked with regard to both variables (using Trials 1 to 12). The differences between numbers of correct responses on the two BA tests (BA+ minus BA−) provided the basis of the first ranking. For the second, on each BA test the percentage of responses to the comparison stimulus responded to less frequently was subtracted from the percentage of responses to the other comparison stimulus; the two difference scores available for each subject were added together to form a composite measure of stimulus preference. A rank order (Spearman) correlation coefficient applied to the ranks was statistically significant (rho = −.90, $p < .05$).

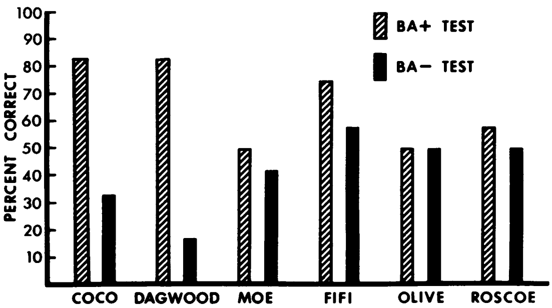

Fig. 1. Percentage of correct responses on the first 12 trials of the positive (BA+) and negative (BA−) backward-association tests of Task 1 of Experiment 1.

Task 2

The mean percentage of correct responses over the three sessions preceding the first BA test of Task 2 was 93.7 (range: 86.1 to 94.4%); for the three sessions preceding the second BA test it was 95.1% (range: 88.9 to 98.6%).

Figure 2 presents the BA test results on the second conditional matching task, again for the first 12 trials. Three of the 4 monkeys performed better on the BA+ than on the BA− test. However, Fifi's sharply differing results all but eliminated an overall performance difference. The mean percentages of correct responses on the BA+ and BA− tests were 47.9 versus 39.6, respectively, for the first 12 trials, and 44.8% versus 46.9% for all 24 trials. For Trials 1 and 2 the corresponding values were 50.0% and 37.5%.

Comparison-stimulus preferences were somewhat reduced in the BA tests of Task 2; the mean difference in percentage of responses to the preferred and nonpreferred comparison stimuli was 41.9 in Task 2, whereas in Task 1 the corresponding value for the same 4 subjects was 50.1%.

With human subjects, the strength of backward association often increases with increasing practice on the original task (e.g., Levy & Nevill, 1974). In many instances our monkeys were very highly trained on the referent matching task, so that the failure to obtain strong evidence of backward association probably was not due to this variable. Moreover, after Roscoe's two BA tests, he was returned to Task 1 for an additional 34 sessions (816 trials) and then was given a BA− and a BA+ test, separated by 9 baseline training sessions. He scored 42% correct responses on the 24 trials of the BA− test and 46% on the BA+ test, the difference in percentages being about the same as observed during the first pair of BA tests (50% vs. 58%, respectively).

Backward association in the conditional matching paradigm could be masked by irrelevant associations. Investigators typically focus on the relations or features that concern them, but animals learn much more in experiments than the targets of our interest (Premack, 1983), such as the locations at which certain classes of stimuli appear, characteristics of the stimulus sequences, the general stimulus context of the experimental space, and so on. Applied to the present situation, it is possible that the monkeys strongly associated the samples with the center key on which they invariably appeared, and the comparison stimuli with the two upper keys on which they were presented. During the backward association tests these relations were unavoidably reversed, which could have been a source of disruption sufficient to mask backward associations of modest strength.

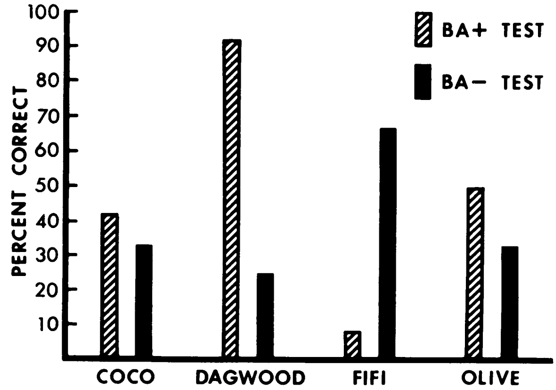

Fig. 2. Percentage of correct responses on the first 12 trials of the positive (BA+) and negative (BA−) backward-association tests of Task 2 of Experiment 1.

As a preliminary assessment of the influence of this potential source of disruption, Roscoe was retrained on the familiar conditional matching task, with the modification that the stimuli were presented on the two lower projectors only. On half the trials the sample stimulus appeared on the lower right projector, and on half, the lower left; of course, on all trials the comparison stimuli were presented on the lower right and left projectors. Thus, samples and comparison stimuli could not be differentiated in terms of the projectors on which they appeared. After Roscoe mastered this new procedure, he was given a BA+ and a BA− test, separated by eight baseline sessions. Although neither position nor stimulus preferences were apparent during the test sessions, there was no evidence of backward association. The percentages of correct responses on the first 12 test trials were 50.0 and 66.7 for the BA+ and BA− tests, respectively; for all 24 trials the corresponding values were 50.5% and 45.8%.

DISCUSSION

Of the 10 available comparisons between performance on positive and negative backward-association tests, eight were in favor of BA+, one favored BA−, and one revealed no difference (Figures 1 and 2). It might appear from this result, as well as from the *t* values obtained in Task 1, that at least some of the monkeys acquired backward associations to a measurable degree. The significant negative correlation obtained between the amount of comparison-stimulus preference and the degree to which BA+ performance exceeded BA− performance, raises the possibility that even stronger evidence for backward association might have been forthcoming had comparison-stimulus preferences been less marked. Although this might well be the case, the very fact that strong stimulus preferences emerged toward stimuli with which the monkeys had extensive and approximately equal experience suggests that backward association did not constitute a strong source of control.

Dagwood's performance in Tasks 1 and 2, which among the individual animals provided the strongest evidence of backward association, might have been based at least partly on an alternative source of control. Table 1 shows that, for Dagwood, in Task 2 the vertical line sample was paired with the plus comparison stimulus and the red disk sample was paired with the circle comparison stimulus, these relations being reversed in the case of Coco. Given the extensive past experience that these subjects had with identity matching, their BA test behavior might be expected to be controlled in part by the similarity of samples and comparison stimuli. This would obviously work to the advantage of Dagwood but to the detriment of Coco and could thus account for Dagwood's strong showing in Task 2, as well as the fact that Coco's performance on both BA tests was below 50%. It might also account for Fifi's "atypical" performance in Task 2. Although Olive, who had the opposite training relations, did not show the expected enhanced performance on the BA+ test, her rather strong stimulus preference on the BA+ test (67%) might have been a mitigating factor.

There was only partial balancing of the training relations in Task 1, so it is conceivable that similarity relations between the samples and their related comparison stimuli played a role there as well. More importance could be attached to the performance of Coco and Dagwood in Task 1 if Moe, who was exposed to the same samples and comparison stimuli but in the reverse conditional relations, also produced strong evidence of backward association.

Our conclusion is that if monkeys form backward associations under the conditions used in our experiment, those associations tend to be weak and easily swamped by competing sources of control. Thus our results, in conjunction with those of Sidman et al. (1982) and the data from relevant pigeon studies, suggest that a sharp difference exists between humans and other species (monkeys, baboons, and pigeons) in the degree to which associations occur bidirectionally. Young children tested under reasonably comparable conditions often display backward associations to the point of symmetry. In contrast, most of the animals tested thus far have shown, at best, weak and transient backward associations. Their associations seem to be largely limited to the forward direction.

EXPERIMENT 2

The question addressed by the present study is whether monkeys are capable of demonstrating transitivity across two sets of conditional relations. As shown in Table 1, Coco was trained in Task 1 with triangle/dot as samples and red/vertical line as the related comparison stimuli; in Task 2 the latter pair served as the samples and the comparison stimuli were plus/circle. When tested with triangle/dot and plus/circle as samples and comparison stimuli, respectively, transitivity would be in evidence if Coco pressed the plus key when triangle was the sample stimulus and the circle key when the sample was dot.

Such an outcome, which we will refer to as "associative" transitivity, is by no means inevitable and may be indicative of a cognitive capacity not equally represented in all animals. For example, one plausible interpretation of associative transitivity is that, during the test trials, the sample elicits a representation of the original correct comparison stimulus, which then serves as the covert or surrogate sample. Clearly, a cognitive capacity of this sort goes beyond the learning mechanisms required for acquisition of conditional matching tasks.

Sidman et al. (1982) found no sign of associative transitivity in two rhesus monkeys. However, vertical/horizontal lines were used as the test comparison stimuli, and as pointed out earlier, this may have been a complicating factor. We know of no other published work on associative transitivity with monkeys. There have been studies of "inferential" transitivity using monkeys and apes, but we will defer their consideration until later.

METHOD

Subjects and Apparatus

Coco, Dagwood, Fifi, and Olive, who participated in Experiment 1, served as subjects. The maintenance conditions were the same as in the previous study, as were the apparatus and the discriminative stimuli.

Procedure

Initial baseline training. The two sets of conditional relations across which transitivity was assessed were Tasks 1 and 2 of Experiment 1 (Table 1). The present study began immediately after the previous one, and it was necessary only to ensure that the subjects performed with comparable accuracy on both conditional matching tasks. This was accomplished by presenting Tasks 1 and 2 on alternate sessions until each subject maintained a high level of performance on both, which required 19, 18, 21, and 44 sessions for Coco, Dagwood, Fifi, and Olive, respectively.

The parameters employed during baseline sessions and the transitivity tests were the same as those of Experiment 1: use of the center and upper projectors only; 1-s sample duration; 0-s delay matching; 24-trial sessions, one session per day.

Transitivity tests. There were two types of transitivity tests, positive (T+) and negative (T−). On T+ tests, the reinforcement contingencies were congruent with the behavior expected from an animal that was controlled by associative transitivity. For example, in the case of Coco described above, pressing a key that presented a plus stimulus was reinforced when the sample was the triangle, whereas such responses resulted in a timeout when the dot served as sample; pressing a key on which the circle appeared was reinforced when the dot was the sample stimulus. These reinforcement relations were reversed on T− tests, responses on plus being reinforced when the dot, rather than the triangle, was the sample. If, without explicit training, monkeys are capable of associative transitivity, they should perform at a much higher level of accuracy on T+ than on T− tests.

Two subjects received three transitivity tests in the sequence T+/T−/T+; for the other 2 subjects the sequence was T−/T+/T−. Adjacent tests were separated by a total of 7 to 10 baseline sessions on Tasks 1 and 2, which alternated daily. All tests were preceded by a Task 2 baseline session. (Coco and Fifi received two additional nontransitivity tests that will not be discussed here [see D'Amato & Salmon, 1984].)

RESULTS

Baseline sessions. Performances were quite accurate during the baseline sessions preceding each transitivity test. Mean percentage correct on the last three sessions before the first test was 98.3 for Task 1 and 92.0 for Task 2. The corresponding values for the baseline sessions preceding the second and the third tests were 97.2% versus 96.2% and 97.9% versus 97.2%, respectively.

Transitivity tests. The results from the 24 trials of each transitivity test appear in Figure 3. All subjects demonstrated associative transitivity to a marked degree. On three of the T+ tests, not a single error was made and the lowest performance on these tests was 75% correct. In contrast, the highest level achieved on the T− tests was only 29% (Coco). For each subject a single T+ and a single T− score was formed by averaging the two results obtained with the same transitivity test. The

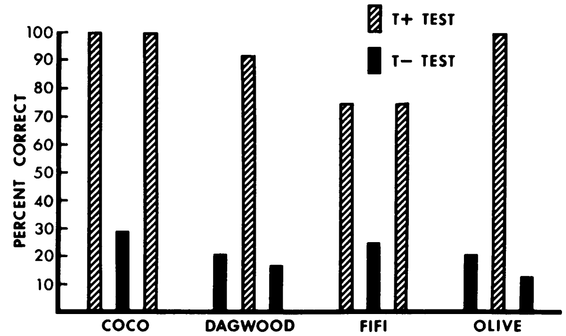

Fig. 3. Percentage of correct responses on the 24 trials of the positive (T+) and negative (T−) transitivity tests of Experiment 2.

difference between the means of the subjects' performance on the T+ and T− tests (91.7% vs. 22.4%) was highly significant [$t(3) = 9.92$, $p < .01$)].

The results from the first 12 trials of each test were equally striking. In this case the T+ and T− means were 90.6% and 11.5%, respectively. A correlated *t* test was again highly significant [$t(3) = 24.04$, $p < .001$].

DISCUSSION

Unlike the equivocal results obtained in Experiment 1 regarding associative symmetry, all 4 monkeys in the present study clearly demonstrated associative transitivity. Olive, who in the previous experiment displayed stong stimulus preferences, had no such problem in the transitivity tests, indeed making no errors on the T+ test.

It will be noted in Table 1 that Coco and Dagwood formed a counterbalanced pair in terms of the training conditional relations that linked the standard stimuli of Task 1 (triangle/dot) to the comparison stimuli of Task 2 (plus/circle). If performance on the transitivity tests were importantly influenced by stimulus similarity, as apparently was sometimes the case in Experiment 1, Dagwood should have produced more evidence of transitivity than Coco; not only were the triangle and circle, explicit stimuli in the transitivity tests, similar forms, there was in addition a significant similarity between the plus comparison stimulus and the potential surrogate sample, vertical line. In fact, however, Coco showed somewhat more evidence of transitivity than did Dagwood. On the other hand, one could possibly attribute the difference between Fifi's and Olive's performance to this factor, but only with regard to the explicit stimuli. (All of Fifi's correct responses on the T− test and 8 of the 12 errors committed on the T+ tests were on trials in which vertical line served as sample.) The important point is that associative transitivity seems to be such a robust phenomenon in monkeys that it overwhelms such potentially competing sources of control as stimulus similarity and test sequence.

Why then did Sidman et al. (1982) find no evidence of transitivity in their experiment with rhesus monkeys (2 subjects were run but data were presented only for 1)? Apart from differences in procedures between our study and theirs (Experiment 4), the use of a horizontal and a vertical line as the test comparison stimuli might have been a factor. In the present terminology, their Task 1 (Experiment 4) employed red/green as samples and +/X as comparison stimuli; in Task 2 the corresponding pairs of stimuli were +/X and horizontal/vertical lines. The animals had a great deal of difficulty learning Task 2 and might finally have done so on the basis of configural factors that incorporated the sample stimuli. In the absence of such factors, the discriminability of the line comparison stimuli during the transitivity tests might once again have become poor and therefore not subject to strong control by associative transitivity. (In a previous experiment, the two subjects had learned to match horizontal/vertical line samples to red/green comparison stimuli, and trials of this nature were included in the baseline trials among which were interspersed the test probes. Thus the transitivity tests were also BA tests.)

Associative transitivity is to be distinguished from inferential transitivity, a topic much explored with children. If a subject learns the relationships A>B and B>C, inferential transitivity is displayed if the subject is then capable of inferring that A>C (e.g., Bryant & Trabasso, 1971). Investigators of animal behavior have for some time been interested in whether nonhuman primates are capable of inferential transitivity (e.g., Menzel & Draper, 1965), and in recent years the issue has been addressed more directly in squirrel monkeys (McGonigle & Chalmers, 1977) and in chimpanzees (Gillan, 1981). As pointed out elsewhere (D'Amato & Salmon, 1984), the presently available data do not seem conclusively to demonstrate inferential transitivity in nonhuman primates, not even in apes (cf. Breslow, 1981; McGonigle & Chalmers, 1977).

On the other hand, associative transitivity appears from the present results to be a robust phenomenon in monkeys, and from the perspective of cross-species comparisons, it would be of interest to assess the degree to which associative transitivity is represented in nonprimates. The next experiment was devoted to this issue.

EXPERIMENT 3

As we knew of no reports of transitivity in nonprimates, we undertook a study with pigeons as subjects, applying training and testing procedures that were reasonably similar to those of Experiment 2.

METHOD

Subjects

Four male White Carneaux pigeons, about 3 years of age, began the experiment. One bird died before testing began. The subjects had considerable previous experience with a 0-s identity matching task employing two samples and with a conditional (symbolic) matching problem that was relevant for the present study. The subjects were housed in individual cages with water and grit continuously available. Throughout the experiment they were maintained at 75% of their free-feeding weights by supplemental feedings of mixed grain.

Apparatus

Two pigeon conditioning chambers were used, measuring 35 by 35 by 30 cm. Three in-line projectors (IEE #7835) were mounted on the front wall, 20 cm above the floor of the chamber; the side projectors were separated from the center unit by 35 cm. Each projector was fitted with a transparent key, which served to detect pecks. A food hopper was located below the center key, 3 cm above the floor. Ambient illumination was provided by two bulbs (Syl 120) mounted behind a strip of translucent plastic that ran the length of the panel at its top edge, above the keys. An exhaust fan provided ventilation and a source of masking noise. Stimulus presentation, programming of trial events, and data recording were controlled by Commodore microcomputers (Model 2001).

Except for small differences in size, the stimuli were the same as those employed in Experiment 2; they included a red disk that illuminated a circular area on the response keys 29 mm in diameter, and five forms: circle, triangle, vertical line, plus, and dot. As projected, the forms appeared as white lines, approximately 2 mm by 17 mm, on a black background. The diameters of the circle and dot were 17 and 7 mm, respectively.

PROCEDURE

Training: Task 1. The first conditional matching task, which employed the same samples and comparison stimuli as shown in Table 1, was acquired as part of an unrelated study, the same as that in which Coco, Dagwood, Fifi, and Olive had participated prior to Experiment 1. The 4 birds received between 123 and 126 sessions of 48 trials each on Task 1; the terminal sessions were conducted with 0-s delay. By the end of this training, all subjects were performing at accuracies of at least 90% on Task 1. The stimulus assignments for Tasks 1 and 2 were the same for Subjects P1, P2, P3, and P4 as those for Fifi, Olive, Dagwood, and Coco, respectively (Table 1).

A typical trial began with the houselight illuminated and a white disk (observing stimulus) presented on the center projector. After the first response on the center key, the white disk was replaced by one of the samples. Ten additional responses on the center key caused the key to go dark and the correct and incorrect comparison stimuli to appear on the outer projectors (0-s delay matching). A single peck at the correct comparison stimulus was followed by extinction of the houselight and comparison stimuli and delivery of the reinforcer, 4-s access to the grain hopper. Pecking the incorrect comparison stimulus had the same consequences except for omission of the reinforcer. Trials were separated by a 30-s intertrial interval at the end of which the houselight and center key were illuminated, signaling the next trial.

Each training and baseline session consisted of 48 trials. The sequence of samples was arranged in a quasirandom order subject to the restrictions that in each block of 24 trials each sample occur an equal number of times and no more than three times in succession.

Task 2. The procedures described above and the stimuli of Table 1 were used in Task 2 training, which began with simultaneous matching until the subjects were performing at high levels of accuracy, when 0-s delay was introduced. Birds P1, P2, P3, and P4 required a total of 73, 57, 72, and 57 sessions, respectively, to complete Task 2 training. The mean percentages of correct responses on the last two sessions of 0-s delay training were 92, 94, 91, and 97, in that order.

Tasks 1 and 2 were then alternated on successive sessions until the subjects maintained high accuracy levels on both. This required a total of 71, 30, and 43 sessions for Subjects P1, P2, and P3, respectively. Bird P4 died after completing 46 sessions of this phase.

Transitivity tests. The transitivity tests closely followed the procedures used in Experiment 2. Two subjects were assigned to the sequence T+/T−/T+ and 2 to T−/T+/T−. Subject P3 had been assigned to the latter sequence, but because of the death of P4, it was reassigned to T+/T−/T+, which we thought might improve the chances of obtaining evidence of transitivity. All transitivity test sessions were based on 24 trials, and successive tests were separated by 10 baseline sessions in which Tasks 1 and 2 alternated on successive sessions. Each test was preceded by a Test 2 baseline session. During training and testing, the birds were usually run 6 days a week, one session per day.

RESULTS AND DISCUSSION

Baseline sessions. Performances of the 3 birds on the baseline sessions preceding each transitivity test were highly accurate and similar to those obtained with the monkeys. Mean percentage correct on the last three sessions before the first test was 96.3 for Task 1 and 93.5 for Task 2. The corresponding values for the baseline sessions preceding the second and third transitivity tests were 96.5% versus 91.9% and 96.1% versus 93.0%, respectively.

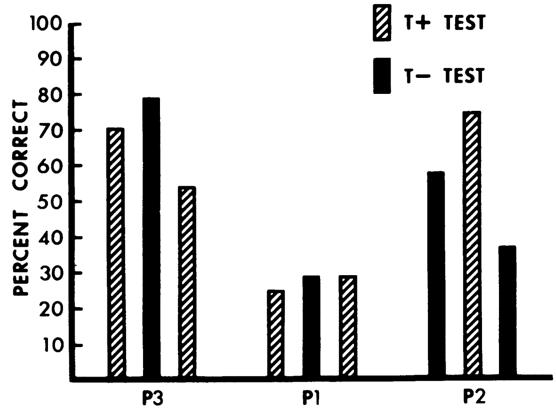

Fig. 4. Percentage of correct responses on the 24 trials of the positive (T+) and negative (T−) transitivity tests of Experiment 3.

Transitivity tests. The results from the 24 trials of each transitivity test are presented in Figure 4. Unlike the results obtained with the monkeys, there was no indication of associative transitivity in the pigeons' data. Bird P2 responded at a higher level of accuracy on the T+ than on the T− tests, but the other 2 birds performed more accurately on the negative transitivity tests. The mean percentages of correct responses for the 3 birds on the T+ and T− tests were 54.9 and 52.1, respectively. The corresponding values for the first 12 test trials were 53.5% and 55.6%; for Trials 1 to 4 they were 37.5% and 41.7%.

Performance on the test sessions was examined for the degree of stimulus or position (right or left key) preference exhibited by each bird. A position preference was defined as 18 or more responses on the right or left key during a single test session; 18 or more responses on the plus or circle comparison stimulus during a test session defined a stimulus preference. The two-tailed binomial probability level of each preference assessment is .022. There was a total of 18 such assessments, three for position and three for stimulus preference for each subject. Over the nine position assessments, there were only two significant preferences, both on the first transitivity test—one for the right key (P2) and one for the left (P3). A significant stimulus preference emerged on three occasions, once on the second transitivity test (P1) and twice on the third (P2 and P3). Thus, even though position and stimulus preferences are not independent of each other, it does not appear that such preferences played an important role in the pigeons' failure to display associative transitivity.

GENERAL DISCUSSION

The failure to find strong evidence of backward association in Experiment 1 is consistent with previous studies using monkeys and pigeons in similar paradigms. Why animals show so little inclination in this direction whereas young children demonstrate backward associations in essentially the same situation virtually to the point of symmetry (Sidman et al., 1982) is a question of some importance. Asch and Ebenholtz (1962) point out: "Associative symmetry permits the transition in recall from one term to another in more than one way. In this respect association resembles other cognitive processes" (p. 162). An interesting speculation is that, because of selective advantages conferred by forming associations in a backward direction, the association process became increasingly bidirectional over evolution, approaching symmetry in humans. By this account, however, one would expect a clearly demonstrable degree of backward association in animals, particularly primates.

Backward association is to be distinguished from backward conditioning. The former arises in the context of two stimuli neither of which is an unconditioned (or previously conditioned) stimulus: It is immaterial which stimulus precedes which in the acquistion phase, and the conditioned response bears no special relation to either stimulus. In contrast, the stimuli involved in the latter have a distinctly different status that dictates their temporal order. The conditioned response is closely related to the unconditioned stimulus, and the question at issue is whether conditioning occurs when the normal order of the stimuli is reversed. Backward conditioning seems to occur to some degree under special circumstances (for a recent review, see Spetch, Wilkie, & Pinel, 1981). Whether the capacity for backward conditioning is an evolutionary precursor of the capacity for backward association is an issue for future research.

The marked difference in the results obtained with monkeys and pigeons on the transitivity tests of Experiments 2 and 3 may indicate a corresponding difference in the ability of the two species to utilize implicit or surrogate stimuli, the process of representation as it is sometimes referred to (Terrace, 1984). The simplest way to describe, in ordinary discourse, the monkeys' behavior on the positive transitivity (T+) tests is that, although the subjects had not been explicitly trained on the test stimuli, they immediately knew which sample went with which comparison stimulus. It seems that the only basis for this directed behavior is mediation by the stimulus that served as the bridging comparison stimulus/sample element. Thus, when Coco was presented with the triangle as sample on the T+ test, because of the previous Task 1 training, this stimulus evoked a representation of red, which was its correlated stimulus. Presumably, red then functioned as the surrogate sample, serving to direct Coco's response to the plus comparison stimulus in accordance with the relations of Task 2. It is possible that the use of 0-s delay matching facilitated this process, inasmuch as the explicit sample was no longer present when the comparison stimuli appeared. Whatever the nature of the mediating process, judging from the results of Experiments 2 and 3, it apparently operates much more strongly in monkeys than in pigeons.

Of course, further research is necessary to verify the results of Experiment 3 under a wider range of conditions. We tried to make the pigeon study as comparable as possible to the monkey experiment, but differences are inevitable in such comparative research. The monkeys, for example, all had been extensively trained on various identity matching tasks, whereas the pigeons had extensive previous training with only one identity matching task. However, all of the subjects had participated in a common experiment that preceded the present research, so with respect to recent experimental experience, the monkeys and pigeons were on reasonably comparable footing.

The results of Experiments 2 and 3 may be applicable to recent investigations of serial learning in animals. Straub and Terrace (1981) trained pigeons to peck four colors in a specific sequence, symbolized as ABCD. Birds were then tested for transfer to two- and three-element subsets of the four colors—for example, AC, BC, ACD. If the results of our transitivity tests are any indication of an animal's ability to develop and employ ordered representations of external stimuli, one would expect that the pigeons would not do well at "filling in" the missing stimuli. In fact, the pigeons performed very well on the AC, AD, and CD tests, but they responded below chance levels on the BC test. On the three-element tests, they did best on ABD and worst on BCD, none of the results being up to baseline levels for the complete ABCD sequence. As pointed out by the authors, many of the transfer data could be accounted for by the rules "start at A" and "respond to D last." The birds need not have developed an ordered representation of the sequence of colors. An intriguing question is whether, given the results of Experiment 2, monkeys would show virtually complete transfer to the two- and three-element subsets—whether, in other words, the transitivity tests of Experiments 2 and 3 are diagnostic of serial learning capacity in animals.

REFERENCES

Asch, S. E., & Ebenholtz, S. M. (1962). The principle of associative symmetry. *Proceedings of the American Philosophical Society,* **106,** 135-163.

Breslow, L. (1981). Reevaluation of the literature on the development of transitive inferences. *Psychological Bulletin,* **89,** 325-351.

Bryant, P. E., & Trabasso, T. (1971). Transitive inferences and memory in young children. *Nature,* **232,** 456-458.

Carter, D. E., & Eckerman, D. A. (1975). Symbolic matching by pigeons: Rate of learning complex discriminations predicted from simple discriminations. *Science,* **187,** 662-664.

D'Amato, M. R. (1973). Delayed matching and short-term memory in monkeys. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in theory and research* (Vol. 7, pp. 227-269). New York: Academic Press.

D'Amato, M. R., & Fazzaro, J. (1966). Attention and cue-producing behavior in the monkey. *Journal of the Experimental Analysis of Behavior,* **9,** 469-473.

D'Amato, M. R., & Salmon, D. P. (1984). Cognitive processes in cebus monkeys. In H. L. Roitblat, T. G. Bever, & H. S. Terrace (Eds.), *Animal cognition* (pp. 149-168). Hillsdale, NJ: Erlbaum.

D'Amato, M. R., & Worsham, R. W. (1972). Delayed matching in the capuchin monkey with brief sample durations. *Learning and Motivation,* **3,** 304-312.

Gillan, D. J. (1981). Reasoning in the chimpanzee: II. Transitive inference. *Journal of Experimental Psychology: Animal Behavior Processes,* **7,** 150-164.

Gray, L. (1966). Backward association in pigeons. *Psychonomic Science,* **4,** 333-334.

Hogan, D. E., & Zentall, T. R. (1977). Backward associations in the pigeon. *American Journal of Psychology,* **90,** 3-15.

Houston, J. P. (1981). *Fundamentals of learning and memory* (2nd ed.). New York: Academic Press.

Iversen, I., Sidman, M., & Carrigan, P. (1984, April). *Defining the stimuli in conditional discriminations.* Paper presented at the meeting of the Eastern Psychological Association, Baltimore, MD.

Levy, C. M., & Nevill, D. D. (1974). B-A learning as a function of degree of A-B learning. *Journal of Experimental Psychology,* **102,** 327-329.

McGonigle, B. O., & Chalmers, M. (1977). Are monkeys logical? *Nature,* **267,** 694-696.

Menzel, E. W., Jr., & Draper, W. A. (1965). Primate selection of food by size: Visible versus invisible rewards. *Journal of Comparative and Physiological Psychology,* **59,** 231-239.

Premack, D. (1983). The abstract code as a translation device. *Behavioral and Brain Sciences,* **6,** 158-167.

Rodewald, H. K. (1974). Symbolic matching-to-sample by pigeons. *Psychological Reports,* **34,** 987-990.

Rudel, R. G., & Teuber, H.-L. (1963). Discrimination of direction of line in children. *Journal of Comparative and Physiological Psychology,* **56,** 892-898.

Salmon, D. P., & D'Amato, M. R. (1981). Note on delay-interval illumination effects on retention in monkeys (*Cebus apella*). *Journal of the Experimental Analysis of Behavior,* **36,** 381-385.

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.

Spetch, M. L., Wilkie, D. M., & Pinel, J. P. J. (1981). Backward conditioning: A reevaluation of the empirical evidence. *Psychological Bulletin,* **89,** 163-175.

Straub, R. O., & Terrace, H. S. (1981). Generalization of serial learning in the pigeon. *Animal Learning & Behavior,* **9,** 454-468.

Terrace, H. S. (1984). Animal cognition. In H. L. Roitblat, T. G. Bever, & H. S. Terrace (Eds.), *Animal cognition* (pp. 7-28). Hillsdale, NJ: Erlbaum.

Received June 27, 1984
Final acceptance May 19, 1985