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TESTS FOR CONTROL BY EXCLUSION AND NEGATIVE STIMULUS RELATIONS OF ARBITRARY MATCHING TO SAMPLE IN A "SYMMETRY-EMERGENT" CHIMPANZEE

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In the present experiments, controlling relations in arbitrary matching-to-sample performance were tested in a 9-year-old female chimpanzee who showed statistically significant emergence of symmetry in previous two-choice conditional discrimination experiments. In Experiment 1, a novel (undefined) sample stimulus was followed by a pair of trained (defined) and undefined comparison stimuli to assess the control by exclusion in arbitrary matching. The chimpanzee selected the undefined shape comparison, excluding the defined one, in color-sample-to-shape-comparison probe trials, although stimulus preferences were relatively stronger than control by exclusion in shape-sample trials. An additional test for control by relations of the sample to the positive comparison (S+ control) showed that her behavior was also under the control of relations of the sample to the positive comparison. In Experiment 2, a defined sample was followed by a pair of negatively defined and undefined comparisons to test control by the relations of the sample to the negative comparison. (S− control). The subject selected undefined comparisons in both color-shape and shape-color test trials. These results clearly indicate that the conditional discrimination behavior of this "symmetry-emergent" chimpanzee was under both S+ and S− control. Furthermore, her performance was also under control by exclusion in color-shape arbitrary matching, unlike other chimpanzees who showed no evidence of symmetry but only S+ control of arbitrary matching.

Key words: conditional discrimination, controlling relations, exclusion, S− control, S+ control, stimulus equivalence, screen touch, chimpanzee

In humans, it is well known that not only the relations between sample and positive comparison stimuli but also those between sample and negative comparison stimuli may exert control of conditional discriminations such as matching to sample (M. Dixon & Dixon, 1978; Stromer & Stromer, 1989). Figure 1 illustrates the possible controlling relations of two-choice conditional discrimination behavior. For example, the subject was trained to select stimulus B1 out of the set of comparisons, B1 and B2, in the presence of the sample A1, and to select comparison B2 in the presence of sample A2. In this case, control by the relations between the sample and the positive comparison (S+ control) can be described as follows: If A1, then select B1; if A2, then select B2. Similarly, control by the relations between the sample and the negative comparison (S− control) can be described as follows: If A1, then do *not* select B2; if A2, then do *not* select B1.

A third type of controlling relation also can be formulated. This is a variation, or more general form, of S− control, called *control by exclusion* (L. Dixon, 1977; McIlvane et al., 1987; Stromer, 1986). For example, when the subject has learned the stimulus relations noted above (if A1, then B1; if A2, then B2), he or she could select the novel stimulus N2 out of the set of comparisons, N2 and B2, in the presence of another novel sample N1. Control by exclusion generally can be described as follows: If *not* A1, then do *not* select B1; if *not* A2, then do *not* select B2.

In two-choice conditional discriminations, control by exclusion logically refers to the same phenomenon as S− control. If only A1 and A2 appear as samples, "not A1" necessarily refers to "A2," and vice versa. However, to test control by exclusion and S− control, the testing

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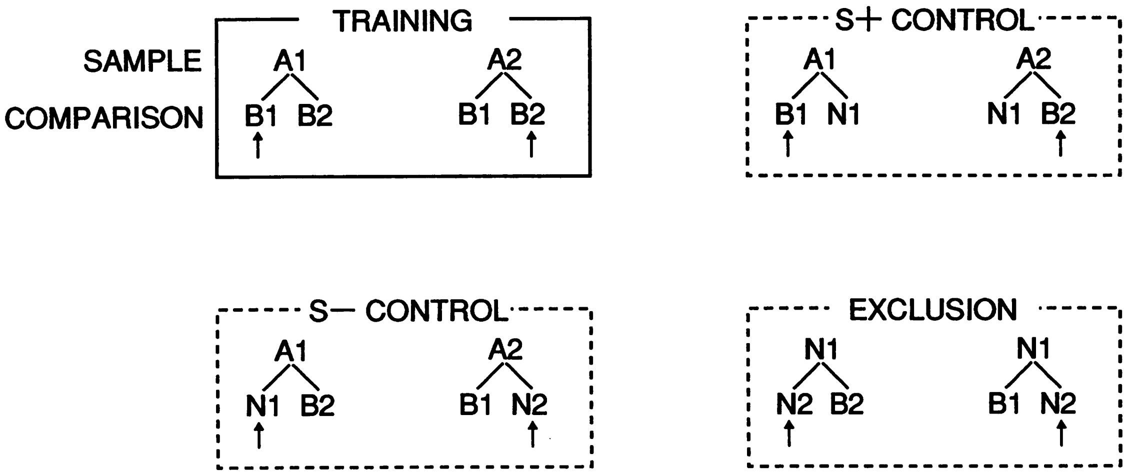

Fig. 1. Schematic diagrams of controlling relations in arbitrary matching to sample. The upper part of each panel indicates the sample stimuli. The lower pairs in each panel indicate the comparisons. Upward arrows indicate the comparisons to be selected.

paradigms are procedurally different from each other (as shown in Figure 1). In the S− control test, only the positive comparison is replaced by a novel stimulus, whereas in the exclusion test, the sample and one of the two comparisons are replaced by different novel stimuli. In both cases, appropriate control is evident by choice of the novel comparison stimulus.

The relations between the sample and the negative comparison actually control identity matching and arbitrary matching behavior in humans with normal ability and with mild and severe retardation (M. Dixon & Dixon, 1978; McIlvane et al., 1987; Stromer & Osborne, 1982; Stromer & Stromer, 1989). Control of arbitrary matching by exclusion also has been found in human subjects (L. Dixon, 1977; M. Dixon, Dixon, & Spradlin, 1983; McIlvane et al., 1987; McIlvane, Munson, & Stoddard, 1988; McIlvane & Stoddard, 1981; McIlvane, Withstandley, & Stoddard, 1984; Stromer, 1986). Although these studies used a variety of tasks (e.g., visual–visual and auditory–visual matching tasks), a variety of testing procedures (e.g., differential reinforcement and nonreinforcement testing), and a variety of stimuli (e.g., visual complex forms, letters, real objects, food items, and meaningful and meaningless spoken words for normal humans), the subjects consistently avoided trained comparisons and selected novel ones in the presence of the novel samples.

Some experiments have reported evidence for S− control or control by exclusion in animals. Zentall, Edwards, Moore, and Hogan (1981), for example, reported S− control in pigeons' conditional discriminations. However, their procedure was rather special, in that it biased the subjects in that direction. In animal language research, some groups have reported control of "language comprehension" by exclusion. For example, Schusterman, Gisiner, Grimm, and Hanggi (in press) reported that California sea lions exhibited control by exclusion in "comprehension" of gestures that indicated objects, and in standard conditional discrimination tasks in which geometric forms appeared as samples and objects appeared as comparisons.

The evidence described above, however, is exceptional; most of the literature on stimulus control of conditional discrimination in animals reports a lack of control by negative stimuli. For example, Cumming and Berryman (1961) trained pigeons on identity matching with colors. After acquisition training, they tested the transfer of identity matching to novel stimuli by substituting a novel comparison in the presence of an identical novel sample. The pigeons consistently selected familiar comparisons in the presence of novel samples. This result clearly indicated the lack of transfer of identity matching and also suggested the lack of control by exclusion. Carter and Werner (1978) and Cumming and Berryman (1965) claimed that pigeons could only learn sets of specific relations between the sample and the positive comparison.

In studies in which nonhuman primates (especially chimpanzees) served as subjects, a few experiments have investigated control by negative stimulus relations. In a research program on visual artificial language training with chimpanzees, Premack (1976) used procedures that were variants of learning by exclusion. He set newly introduced fruits (X) and names of newly introduced fruits ("X"), names of well-known fruits, "Mary(trainer)," "Sarah(chimpanzee)," and "give" before Sarah. Sarah was asked to produce the sentence, "Mary" "give" "X" "Sarah." Sarah showed good performance in such testing, which was weak evidence of learning by exclusion.

In our laboratory, Asano, Kojima, Matsuzawa, Kubota, and Murofushi (1982) reported a savings effect of learning by exclusion in the acquisition of "word naming," in which a conditional discrimination procedure was employed. After chimpanzees learned some sets of relations between geometrical forms (lexigrams) and real objects, the experimenters introduced a novel set of lexigrams and objects one after another. Although first-session performances with novel pairs was near chance in the early training phase, it gradually improved during repeated introductions of novel sets. In a more standard conditional discrimination paradigm, chimpanzees showed a tendency to avoid novel comparisons and select familiar ones in the presence of a novel sample (lack of control by exclusion), and performed randomly on trials with negative and novel comparisons in the presence of the familiar sample (lack of S− control). These chimpanzees also showed no evidence of emergence of symmetry when tested after testing of negative stimulus relations (Tomonaga, Matsuzawa, Fujita, & Yamamoto, 1991).

Yamamoto and Asano (1991) also trained a language-trained chimpanzee on a color-to-name matching task and then tested for symmetry. They used colored cards and cards on which names (lexigrams) were printed as stimuli. An experimenter sat facing the chimpanzee across a stimulus presentation platform. They trained three pairs of color-sample to name-comparison matching tasks and then tested the emergence of name-to-color symmetry. When the subject failed to show the emergence of symmetry, they trained one of the three pairs bidirectionally. After the subject again failed to show symmetry, one of the two remaining unidirectional pairs was trained bidirectionally. However, the subject showed no evidence of symmetry. In the last phase of testing, only one name-to-color relation was untrained so the subject could have selected the untrained color comparison bidirectionally on the basis of control by exclusion in the symmetry test trials. The results indicated a lack of control by exclusion.

Furthermore, among the three formal properties of stimulus equivalence relations—reflexivity, symmetry, and transitivity—that Sidman (1986) and Sidman and Tailby (1982) have formulated (known as Sidman equivalence), pigeons and monkeys show practically no signs of emergence of associative symmetry in conditional discriminations (D'Amato, Salmon, Loukas, & Tomie, 1985; Gray, 1966; Hogan & Zentall, 1977; Lipkens, Kop, & Matthijs, 1988; Sidman et al., 1982). For chimpanzees, although some experiments show weak but positive evidence (e.g., Kojima, 1984; Premack, 1976; Tomonaga, Matsuzawa, Fujita, & Yamamoto, 1991; Yamamoto & Asano, 1991), it is difficult to establish symmetry (Dugdale & Lowe, 1990; Yamamoto & Asano, 1991). Generally speaking, nonhuman animals such as pigeons, monkeys, and chimpanzees have shown only positive stimulus relations (Carter & Werner, 1978) and no strong signs of stimulus equivalence (Hayes, 1989) in conditional discriminations. This tentative conclusion leads us to assume that there may be some relationship between the establishment of Sidman equivalence and that of control by negative stimulus relations such as S− control and control by exclusion. To discuss the lack of Sidman equivalence relations (especially symmetry) in nonhumans, we should try to clarify how stimulus relations actually control an animal's conditional discrimination behavior.

Recently, we demonstrated that a chimpanzee could display emergence of symmetry with the standard testing procedure employed in experiments with humans (Tomonaga, Matsuzawa, Fujita, & Yamamoto, 1991). We trained three young chimpanzees on color-sample to shape-comparison arbitrary matching and tested for the emergence of associative symmetry in shape-to-color matching using red, green, a cross, and a circle as stimuli. One of

Table 1

Stimuli and stimulus relations employed in the present experiments.

	Colors	Shapes
Defined (trained in arbitrary matching)	Red (R) ⟷[a]	Cross (CR)
	Green (G) ⟷	Filled circle (CI)
	Yellow (Y) ⟷	Snake (SN)
	Light blue (LB) ⟷	Star (ST)
Undefined (untrained in arbitrary matching)	Dark blue (DB)	Inverted filled triangle (T)
	Purple (P)	Inverted U-shape (U)

[a] Bidirectional arrows indicate the trained sample-comparison relations.

the subjects displayed statistically significant emergence of symmetry in all three tests. The present experiments were aimed at clarifying the controlling relations of conditional discriminations in this "symmetry-emergent" chimpanzee.

In Experiment 1, the subject was given five series of exclusion tests using a novel sample and trained and novel comparisons. Humans have been found to be capable of learning new novel-sample novel-comparison relations or trained-sample novel-comparison relations after both differential-reinforcement testing (L. Dixon, 1977; McIlvane & Stoddard, 1981; McIlvane et al., 1984, 1988) and nonreinforcement testing (Stromer, 1986; Stromer & Osborne, 1982), whereas sea lions have not (Schusterman et al., in press). In the present experiment, arbitrary matching tests with a novel sample and two novel comparisons were arranged immediately after four of the five exclusion tests to assess learning of exclusion. In addition, S+ control of the conditional discrimination was tested by replacing the negative comparison with novel stimuli.

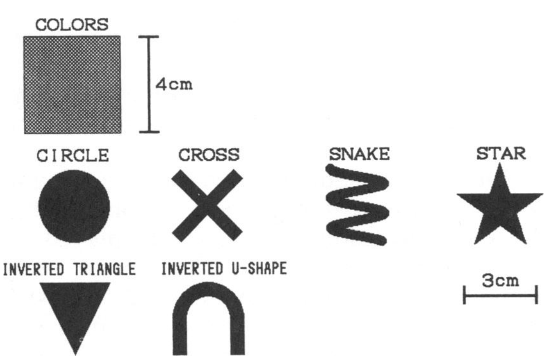

Fig. 2. Illustrations of stimuli employed in the present experiments. Top, color rectangle; middle, defined shape stimuli; bottom, undefined shape stimuli.

EXPERIMENT 1

METHOD

Subject

A 9-year-old female chimpanzee, Chloe, served as the subject during the present experiments. She had an extensive training history on matching-to-sample tasks, including tests for symmetry (Fujita & Matsuzawa, 1989; Tomonaga & Matsuzawa, 1992; Tomonaga, Matsuzawa, Fujita, & Yamamoto, 1991; Tomonaga, Matsuzawa, & Matano, 1991). She had no experience in language-like skill training.

After the experiments on symmetry, Chloe was trained on the shape-to-color matching tasks, which appeared in the symmetry tests, with differential reinforcement, and she was also given a new set of color-to-shape and shape-to-color matching tasks using yellow, light blue, a snake, and a star as stimuli (see Table 1 and Figure 2). The steady-state training of identity matching and arbitrary matching tasks continued for approximately 6 months until the onset of the present experiments. Performance on each task, averaged over 10 sessions just prior to the present experiments, was 100% for identity matching, 96.7% for color-to-shape arbitrary matching, and 95.4% for shape-to-color arbitrary matching.

Chloe lived in a cage (with sun rooms) together with the three young chimpanzee cagemates. She maintained her free-feeding weight without special deprivation throughout the present experiments.

Apparatus

The experimental booth for the chimpanzee (2.4 m by 2.0 m by 1.8 m) had a 14-in. CRT color monitor with an optical touch panel (Minato Electronics, Inc., TD-301). Touching the screen was defined as a response. A BASIC software program divided the monitor screen into 12 areas (four columns and three rows). Colored computer-graphic stimuli could be presented in each area. A food tray was installed to the right of the monitor. A universal feeder (Davis Scientific Instruments, UF-100) could deliver a variety of foods (apples, pineapples, raisins, peanuts, etc.) into this tray. The equipment was controlled by a personal computer (NEC, PC-9801 F2).

Stimuli

Table 1 and Figure 2 show the stimuli that Chloe had been trained on in matching-to-sample tasks and the novel stimuli introduced in the present experiments. As shown in Figure 2, colors were squares (4 cm), and shapes were white on black backgrounds (3 cm by 3 cm).

Hereafter, the term *undefined stimuli* refers to the stimuli that have no preestablished arbitrary relationship with any other nonidentical stimuli, whereas the term *defined stimuli* refers to the stimuli used for training in arbitrary relation with some nonidentical stimuli. This is a slight modification of the terminology of McIlvane et al. (1987).

Procedure

The left column of Table 2 shows the test series conducted in Experiment 1. The number of sessions for each test series is also shown. The center column indicates the nonfeedback probe trials that appeared in each test. The selection of the comparison described on the left was defined as the "correct" selection on the probe trials.

General procedure: Matching-to-sample training. As noted above, Chloe was trained on identity and arbitrary matching with colors and shapes for 6 months with a trial-based continuous reinforcement schedule.

In all the present training and testing, a typical trial proceeded as follows. After a 3-s intertrial interval, the sample was presented on one of the four areas of the top row of the monitor screen. Three responses to it resulted in the termination of the sample and presentation of the two comparisons on two of the four areas of the bottom row. When the subject responded to either of the comparisons, they immediately disappeared. A response to the positive comparison was followed by the presentation of a 1-s chime and food reinforcement, whereas a response to the negative one resulted in a 0.5-s buzzer and a 3-s timeout. If the subject made an error, correction trials were given until she made the correct selection. In the correction trials, the same sample and comparisons as in the original trial appeared in different areas.

Sessions consisted of 96 trials. Four types of tasks—identity matching with colors, identity matching with shapes, color-to-shape arbitrary matching, and shape-to-color arbitrary matching—each appeared 24 times per session. In each task, each sample appeared six times, and the relative left–right positions of positive comparisons were counterbalanced. Red and green, cross and circle, yellow and light blue, and snake and star were presented as comparison pairs. Other pairs (e.g., red and star, snake and circle) never appeared. Trials were randomized, with the restriction that the same sample, the same comparisons, and the same absolute positions of comparisons never appeared in succession, and that the same relative left–right correct positions never appeared in more than four consecutive trials. The position of the sample was also randomized from trial to trial.

Training with intermittent reinforcement. To minimize disruption of performance by the insertion of nonreinforcement probe trials, a trial-based 67% intermittent reinforcement schedule was introduced to the baseline training before shifting to the test series. The correct selection was reinforced with food in two trials out of three. Trials with reinforcement were randomized in each three-trial block. On trials without reinforcement, no chime, buzzer, timeout, or food was given to the subject. Two sessions of baseline training with intermittent reinforcement were given to Chloe. The variable 67% reinforcement schedule was maintained throughout the following test series.

Preliminary test: Identity matching with undefined stimuli. The subject was initially given two preliminary tests after the intermittent-reinforcement baseline training. In the first test, transfer of identity matching to undefined stimuli was tested with nonfeedback probe trials. This test session consisted of 112 trials. Four types of probe trials appeared four times (center column of Table 2). These 16 probe trials were randomly interspersed among the

Table 2

Series of tests, types of probe trials, and the number of correct selections in Experiment 1.

Test	Probe trials: Sample	Probe trials: Comparisons +/−	Correct/Total	
Pretest series				
Identity test	DB	DB/P	4/4	8/8**
[1]	P	P/DB	4/4	
	T	T/U	4/4	8/8**
	U	U/T	4/4	
Arbitrary test	DB	T/U	2/4	4/8
[1]	P	U/T	2/4	
	T	DB/P	0/4	4/8
	U	P/DB	4/4	
Exclusion test series				
Exclusion test (1)	DB	T/CR, CI, SN, ST	6/8	12/16*
[4 (2/2)]	P	U/CR, CI, SN, ST	6/8	
	T	DB/R, G, Y, LB	2/8	9/16
	U	P/R, G, Y, LB	7/8*	
Arbitrary test (1)	DB	T/U	0/4	4/8
[2]	P	U/T	4/4	
	T	DB/P	0/4	4/8
	U	P/DB	4/4	
Exclusion test (2)	DB	T/CI	8/8**	16/16***
[4]	P	U/CR	8/8**	
	T	DB/G	1/8	9/16
	U	P/DB	8/8**	
Arbitrary test (2)	DB	T/U	0/4	3/8
[2]	P	U/T	3/4	
	T	DB/P	0/4	4/8
	U	P/DB	4/4	
Exclusion test (3)	DB	T/CR	3/8	10/16
[4]	P	U/CI	7/8*	
	T	DB/R	4/8	12/16*
	U	P/G	8/8*	
Arbitrary test (3)	DB	T/U	1/4	4/8
[2]	P	U/T	3/4	
	T	DB/P	1/4	5/8
	U	P/DB	4/4	
Exclusion test (4)	DB	U/CI	7/8*	14/16**
[4]	P	T/CR	7/8*	
	T	P/R	8/8*	9/16
	U	DB/G	1/8	
S+ control test	R	CR/T	8/8**	16/16***
[4]	G	CI/U	8/8**	
	CR	R/P	6/8	14/16**
	CI	G/DB	8/8**	
Exclusion test (5)	DB	U/CR	7/8*	15/16***
[4]	P	T/CI	8/8*	
	T	P/G	3/8	11/16
	U	DB/R	8/8*	
Arbitrary test (4)	DB	U/T	2/4	4/8
[2]	P	T/U	2/4	
	T	P/DB	4/4	5/8
	U	DB/P	1/4	
Matching from	DB	CI/CR	1/8	8/16
undefined sample to	P	CR/CI	7/8*	
defined comparison	T	R/G	0/8	7/16
[4]	U	G/R	7/8*	

Note. R = red, G = green, CR = cross, CI = circle, Y = yellow, LB = light blue, SN = snake, ST = star, DB = dark blue, P = purple, T = inverted triangle, U = inverted U-shape.

The number in brackets indicates the number of sessions given to the subject in each test.

Asterisks were given if the numbers of selections of correct comparisons were statistically significant at 5% (*), 1% (**), and 0.1% (***) in binomial tests.

96 baseline trials. Reponses in the probe trials produced no feedback.

Preliminary test: Arbitrary matching with undefined stimuli. The second preliminary test session was designed to check for stimulus preferences among undefined comparisons in the presence of an undefined sample. Chloe was given four types of arbitrary matching probe trials with an undefined sample and two other comparisons. The session consisted of 96 baseline trials and eight color-to-shape and eight shape-to-color arbitrary matching probe trials.

Training of identity matching with undefined stimuli. After the completion of the two preliminary test series, Chloe was trained on identity matching with undefined color and shape stimuli. This training was conducted in order to eliminate the tendency to avoid novel (nonreinforced) stimuli in subsequent testing (e.g., Farthing & Opuda, 1974). In a session consisting of 144 trials, each of the four undefined stimuli appeared 12 times, interspersed with 96 baseline trials. In subsequent testing, eight identity matching trials with differential reinforcement and with undefined stimuli (twice for each sample) were added to the 96 baseline trials with the previously defined stimuli.

Exclusion tests. As shown in the left column of Table 2, five test series for the assessment of control by exclusion were given to Chloe. Each test consisted of four sessions, each of which had 104 baseline trials and eight exclusion probe trials without feedback. Undefined-sample undefined-comparison relations were never changed during a four-session test. These relations were kept compatible bidirectionally. For example, if the sample triangle was followed by purple as a comparison in an exclusion probe trial, a purple sample had to be followed by a triangle comparison in another trial. An undefined color comparison was always accompanied by a defined color comparison, and an undefined shape comparison always accompanied a defined shape comparison.

In the first exclusion test, undefined comparisons were paired with all the possible defined comparisons (center column of Table 2). The session in which undefined comparisons were paired with red, green, a cross, and a circle and the session in which they were paired with yellow, light blue, a snake, and a star were given twice alternately to the subject.

In the following four exclusion tests, undefined comparisons were paired only with red, green, a cross, and a circle. Unlike the first test, both the undefined-sample undefined-comparison relations and the defined comparisons with which the undefined comparisons were paired were held constant during testing (see the center column of Table 2). There were two possible combinations of undefined samples and comparisons and two possible combinations of undefined and defined comparisons, yielding four combinations of undefined samples, undefined comparisons, and defined comparisons. These combinations appeared in each test. Each undefined sample appeared twice in a session.

Arbitrary matching tests with undefined stimuli. Immediately after each exclusion test (except the fourth), an arbitrary matching test with undefined stimuli was conducted for two sessions. This test assessed control of arbitrary matching by the undefined-sample undefined-comparison relations presented in the exclusion test. Sessions consisted of 104 baseline trials and four color-to-shape and four shape-to-color arbitrary matching probe trials.

S+ control test. After the fourth exclusion test, Chloe was given a four-session test for control by defined-sample positively defined-comparison relations. In the probe trials, a defined sample was followed by positive and undefined comparisons. Each session had 104 baseline and eight probe trials. Four types of probe trials appeared twice in a session.

Tests for matching from undefined sample to defined comparison. When Chloe completed the five exclusion test series, she was then given a four-session test in which the defined comparisons followed the undefined sample to clarify the stimulus preference between defined comparisons in the presence of each undefined sample. Four types of probe trials were interspersed twice in the 104 baseline trials.

RESULTS

Chloe performed perfectly in the two-session variable 67% intermittent-reinforcement training. The right column of Table 2 presents the number of correct selections for each type of probe trial in each test. As noted in the Procedure section, the correct selection is defined as the selection of the comparison listed first in the center column of Table 2. The right column of Table 2 indicates the total number of correct selections in the probe trials with

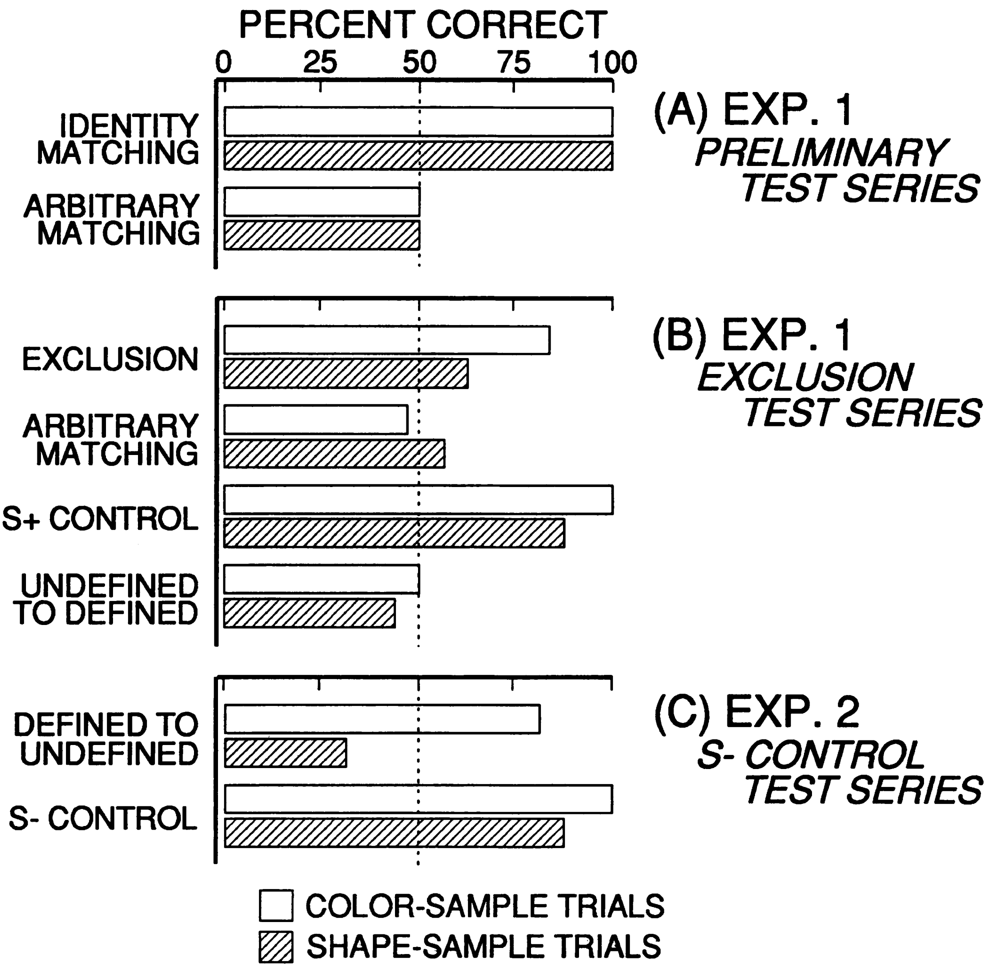

Fig. 3. Mean percentage correct for each test in Experiments 1 and 2. (A) Preliminary tests in Experiment 1. (B) Exclusion and other tests in Experiment 1. (C) S− control tests in Experiment 2. Data were averaged across five series for exclusion tests, four series for arbitrary tests in Experiment 1, and two series for S− control tests in Experiment 2. White bars indicate the mean percentage correct of the color-sample probe trials. Shaded bars indicate that of the shape-sample probe trials. Dotted lines indicate chance level (50%).

the same sample dimensions (color or shape). Each number of correct selections was analyzed with a binomial test.

The upper part of Figure 3 represents the mean percentage of correct selections for preliminary tests and exclusion, arbitrary matching, S+ control, and undefined-sample defined-comparison matching tests. White bars indicate the mean percentage correct of the color-sample trials, and shaded bars indicate the mean percentage correct of the shape-sample trials. The mean accuracies on the baseline trials across all test sessions were 100% for identity matching, 99.0% for color-to-shape arbitrary matching, and 98.6% for shape-to-color matching tasks.

Preliminary Tests

Chloe performed perfectly in the identity matching test with undefined stimuli. On the other hand, she showed position preference in the color-to-shape trials and showed preference for purple in the shape-to-color trials of the arbitrary matching test with undefined stimuli, irrespective of the sample.

Training of Identity Matching with Undefined Stimuli

Chloe was given seven sessions of training in identity matching with undefined stimuli. She made no errors during this training.

Exclusion Tests

In the first exclusion test, Chloe "excluded" the defined comparisons and selected the undefined comparisons in the color-sample probe trials ($p < .05$, binomial test). On the other hand, she selected purple ($p < .05$) and avoided dark blue in the shape-sample trials.

In the following four exclusion tests, Chloe consistently selected undefined shape comparison in the color-sample probe trials ($.001 < p < .05$) except in the third test (62.5% correct). However, no strong evidence of control by exclusion was obtained in the shape-sample trials: She selected the undefined color comparisons only in the third test ($p < .05$). In the purple comparison trials, she excluded the defined comparisons ($p < .01$), whereas she selected dark blue on 43.8% of the dark blue comparison trials.

Arbitrary Matching Tests with Undefined Stimuli

In the four arbitrary matching tests conducted immediately after the first, second, third, and fifth exclusion tests, Chloe selected the comparison in the presence of an undefined sample that was related to it in the previous exclusion tests on 51.6% of the total trials. She showed a preference for purple in the shape-sample probe trials ($p < .001$), which was consistent with the preliminary arbitrary matching test. Unlike preliminary arbitrary matching, in which Chloe showed position preference, she consistently selected the U shape in the color-sample trials ($p < .01$), irrespective of samples.

S+ Control Test

In the S+ control test conducted after the fourth exclusion test, the subject consistently selected the positive comparison both in the color-sample and shape-sample probe trials ($p < .01$).

Test for Matching from Undefined Sample to Defined Comparison

Chloe selected the cross in the color-sample probe trials ($p < .01$), and selected green in the shape-sample trials ($p < .001$).

Discussion

Chloe exhibited a significant degree of control by color-to-shape arbitrary matching by exclusion in four of five exclusion tests. On the other hand, in the shape-to-color arbitrary matching, she showed statistically significant control by exclusion only in the third test. During the exclusion test series, she showed significant selection of purple, whereas she showed a difference in selection of dark blue from test to test. The results on shape-sample trials suggest that the apparent degree of control by exclusion was affected by the combination of stimuli (Zentall et al., 1981). Consequently, the relations between selections of undefined comparisons and the combination of stimuli presented on a trial were analyzed further using data from probe trials, except those from preliminary tests.

The right four columns of Table 3 show the number of selections for each comparison in the probe trials of the five exclusion tests with the various combinations of undefined samples and undefined and defined comparisons. The left two columns indicate the number of selections for each defined comparison in the presence of the undefined sample obtained from the test for matching from undefined sample to defined comparison, and those for each undefined comparison in the presence of the undefined sample obtained from the four arbitrary matching tests. If the results of exclusion trials can be explained by the stimulus preferences shown in Table 3, it would follow that Chloe did not exhibit "true" control by exclusion.

In the presence of undefined color samples, Chloe selected the cross or avoided the circle ($p < .005$) and selected the U shape or avoided the triangle ($p < .001$, Table 3), whereas in the presence of undefined shape samples, she consistently selected green and purple ($p < .001$) regardless of the samples (Table 3). These results indicate that if the sample had not acquired control of the selection of a specific comparison stimulus, the subject's selection came under the control of experimentally uncontrolled preference, which might be established outside the context of the present experiments even when the comparison stimuli were defined. On the basis of the stimulus preference account, although direct measurement was not conducted in the present experiments, we can say tentatively that if the comparisons were preferred and nonpreferred ones, she should select the preferred comparison in the presence of the undefined sample. One more tentative hypothesis about a stimulus preference account was assumed; if the nonpreferred

Table 3

Numbers of selections of comparisons in various combinations of defined and undefined stimuli in Experiment 1.

Type of pairs	Comparisons					
	Preference (arbitrary matching) tests		Exclusion tests: Pairs of preferred and nonpreferred comparisons		Exclusion tests: Pairs of both preferred or both nonpreferred comparisons	
Color-to-shape probe trials			+ −	+ −	+ −	+ −
Sample	*CR*/CI[a]	T/*U*[b]	T/*CR*	*U*/CI	T/CI	*U*/*CR*
DB	*7*/1	3/*13*	4/*6*	*7*/1	10/0	*7*/*1*
P	*7*/1	4/*12*	7/*1*	*9*/1	8/0	*8*/*2*
Total	*14*/2	7/*25*	11/7	*16*/2	18/0	*15*/*3*
% selection of preferred comparison			63.9			
% selection of undefined comparison			75.0		91.7	
Shape-to-color probe trials			+ −	+ −	+ −	+ −
Sample	R/*G*[a]	DB/*P*[b]	*P*/R	DB/*G*	DB/R	*P*/*G*
T	0/*8*	1/*15*	*8*/0	1/*9*	6/4	*3*/*5*
U	1/*7*	1/*15*	*10*/0	1/*7*	8/0	*10*/*0*
Total	1/*15*	2/*30*	*18*/0	2/*16*	14/4	*13*/*5*
% selection of preferred comparison			94.4			
% selection of undefined comparison			55.6		75.0	

[a] Data from the test for matching from undefined sample to defined comparison.

[b] Data from the arbitrary matching tests with undefined stimuli. Symbols in italics are preferred stimuli in these two tests.

comparisons or highly preferred ones were paired together, the subject would not show as strong preference for one of the comparisons as in the preferred-nonpreferred comparison trials.

On color-sample trials, if the performances on the exclusion probe trials were controlled only by these stimulus preferences, she should consistently select the U shape in the presence of the circle and U shape comparison pair, and select the cross in the presence of the cross and the triangle. When the comparisons were circle and triangle and cross and U shape, Chloe would not show strong preference for either comparison. However, Chloe consistently selected the undefined comparison when the comparisons were circle and triangle, both of which were less preferred, and cross and U shape, both of which were highly preferred (mean percentage correct was 91.7%, $p < .001$). When the comparisons were cross (preferred) and triangle (less preferred), she would select the cross if only stimulus preferences controlled her probe-trial performance, but Chloe showed a tendency to select the less preferred triangle. Further evidence comes from the comparison with the S+ control test (see Table 2). In the S+ control test, Chloe consistently selected the cross (defined) when it was paired with the triangle (undefined) in the presence of red as sample, and selected the circle (defined) when it was paired with the U shape (undefined) in the presence of green. Chi-square tests revealed that these changes were statistically significant (cross-triangle, $\chi^2 = 8.46$, $p < .005$; circle-U shape, $\chi^2 = 14.92$, $p < .001$). This result further supported the conclusion that when the sample was undefined, comparison selection was more firmly controlled by exclusion than by stimulus preference.

On shape-sample exclusion probe trials with undefined shape samples, results were complicated by the effect of stimulus preferences. On exclusion trials with preferred and nonpreferred comparison stimuli, preference was consistent with the stimulus preference account; she indeed selected green in the presence of green (preferred) and dark blue, and selected purple in the presence of red and purple (preferred) ($p < .001$). Mean percentage of selections of green and purple (percentage selection of preferred comparison) on these trials was 94.4%. On the other hand, when the comparisons were green and purple (both highly preferred comparisons) or red and dark blue (both nonpreferred comparisons), the subject selected the undefined comparison 72.2% of the time in purple-green comparison trials ($p < .05$) and 77.8% of the time in dark blue-red comparison trials ($p < .05$). The mean percentage of selections of undefined comparisons in these probe trials was 75%, significantly above chance ($p < .005$). In comparison with results of the S+ control test, selection of purple against red (exclusion trials) significantly changed to selection of red against purple (S+ control test, $\chi^2 = 13.58$, $p < .001$).

Analysis of the results on color-sample trials strongly implies that the selections of undefined shape comparisons by Chloe were actually controlled by exclusion. On shape-sample trials, control by stimulus preference was relatively stronger than on color-sample trials, especially when dark blue and green were presented as comparisons. When, however, the highly preferred comparisons or nonpreferred ones were paired together, Chloe usually selected the undefined color comparisons.

Our conclusion must be tentative because direct measurement of preferences among highly preferred or nonpreferred stimuli was not conducted in the present experiment. In pigeons, preference for a specific position or a specific stimulus often controls the subject's behavior in the early phase of acquisition of conditional discrimination (e.g., Carter & Werner, 1978). This is also the case with primate subjects; such preferences were frequently observed in our laboratory. One must consider the effects of preferences in interpreting an animal's conditional discrimination behavior, especially under testing without reinforcement, with new situations as in the present experiments.

The fact that control by stimulus preferences was more potent than control by exclusion on shape-sample trials compared to color-sample trials might suggest relatively weaker control by defined color comparisons compared to defined shape comparisons. Difference in performances between color- and shape-sample exclusion trials might have resulted from the difference in training history between color-to-shape and shape-to-color baseline arbitrary matching with red, green, the cross, and the circle. Chloe had been trained on the color-to-shape arbitrary matching for approximately 6 months longer than on the shape-to-color arbitrary matching in order to test the emergence of symmetry in the previous experiment (Tomonaga, Matsuzawa, Fujita, & Yamamoto, 1991). Therefore, it is possible that even if the accuracies of both color-to-shape and shape-to-color baseline trials were kept nearly 100% correct during exclusion testing, the degree of stimulus control between them would differ to some extent.

In humans, the nonreinforced exclusion testing can establish sample–comparison relations that were not trained explicitly when tested on trials in which only undefined sample and comparisons appeared (Stromer, 1986; Stromer & Osborne, 1982). In the present experiments, arbitrary matching tests with undefined sample and comparisons immediately followed the exclusion tests. However, Chloe consistently showed preferences for the specific comparisons (see Tables 2 and 3), even when she reliably selected the undefined comparison in the presence of the undefined sample in the previous exclusion test trials. This outcome indicates that the undefined sample–comparison relations presented in the previous exclusion testing did not acquire control over her conditional discrimination behavior. Such a lack of "learning by exclusion" was also observed in sea lions (Schusterman et al., in press). Although Chloe might have experienced too few trials with undefined stimulus relations for reliable stimulus relations to be established, the present results suggest that Chloe's exclusive selections of undefined comparisons were "by-products" that resulted from the relations between the undefined samples and the excluded comparisons (cf. McIlvane et al., 1987). These results also suggest a difference between humans and chimpanzees in the controlling relations of conditional discriminations. In the present experiments, however, the selections of undefined comparisons in the exclusion trials were not differentially reinforced. If such exclusive selections were reinforced, as McIlvane and his colleagues did with humans (McIlvane & Stoddard, 1981; McIlvane et al., 1984, 1988), learning by exclusion might occur in Chloe. This possibility must be examined further.

In conclusion, Chloe showed reliable control by exclusion on color-sample trials, though less

Table 4

Series of tests, types of probe trials, and the number of correct selections in Experiment 2.

Test	Probe trials: Sample	Comparisons + −	Correct/Total	
Matching from defined sample to undefined comparison [4]	R	U/T	8/8**	13/16*
	G	T/U	5/8	
	CR	P/DB	5/8	5/16
	CI	DB/P	0/8	
S− control test (1) [4]	R	T/CI	8/8**	16/16***
	G	U/CR	8/8**	
	CR	DB/G	6/8	14/16**
	CI	P/R	8/8**	
S− control test (2) [4]	R	U/CI	8/8**	16/16***
	G	T/CR	8/8**	
	CR	P/G	8/8**	14/16**
	CI	DB/R	6/8	

Note. See Table 2 for explanation of symbols.

consistently on shape-sample trials. This is the first demonstration of control by exclusion in a nonhuman primate's conditional discriminations.

EXPERIMENT 2

In Experiment 2, the same subject was given two series of S− control tests with a defined sample followed by negatively defined and undefined comparisons. The subject was also given a preference test with defined samples and undefined comparisons before the S− control testing.

Method

Subject, Apparatus, and Stimuli

Chloe also served as subject in Experiment 2. Experiment 2 started after the completion of all tests in Experiment 1. The same equipment and stimuli as in Experiment 1 were also used.

Procedure

The general procedure was identical to that employed in Experiment 1. In Experiment 2, three tests (including a preliminary one) were given to Chloe, as shown in Table 4. Baseline trials were the same as those in Experiment 1. In the probe trials, red, green, a cross, and a circle were used as defined stimuli.

Preliminary test: Matching from defined sample to undefined comparison. In this test, stimulus preferences between undefined comparisons in the presence of a defined sample were investigated. Sessions consisted of 104 baseline and eight probe trials without feedback. Each type of probe trial appeared twice. Four sessions were given to the subject.

S− control test. Two series of four-session S− control tests were successively given to Chloe (Table 4). In these tests, a defined sample was followed by negatively defined and undefined comparisons. These two tests exhausted the possible combinations of negatively defined and undefined comparisons. Sessions consisted of 104 baseline and eight probe trials.

Results and Discussion

The right column of Table 4 shows the number of correct selections in each test. Figure 3 presents the mean percentage correct of preliminary and S− control tests. Mean accuracies on baseline trials during test sessions were 100% for identity matching, 99.7% for color-to-shape arbitrary matching, and 99.7% for shape-to-color matching.

In the test of matching from defined sample to undefined comparison, Chloe consistently selected the U shape in the presence of red as the sample and selected the triangle in the presence of green on 62.5% of the green-sample trials. Chloe therefore showed statistically significant one-to-one correspondence between the specific sample and comparison in the color-sample probe trials ($p < .05$). On the other hand, she generally selected purple in the shape-sample probe trials ($p < .05$). Therefore, when the sample was changed from undefined to defined, preferences for U shape and purple were not changed from those obtained in arbitrary matching tests in Experiment 1 (U shape, $\chi^2 = 0.13$; purple, $\chi^2 = 2.83$).

In the following two S− control tests, Chloe avoided negatively defined comparisons both in the color- and shape-sample probe trials ($.001 < p < .01$). Avoidance of dark blue (as shown in Experiment 1) disappeared: She selected dark blue on 75% of dark blue comparison trials ($p < .05$).

Chloe avoided negatively defined comparisons in the S− control tests. Viewed together with the results of the S+ control test in Experiment 1, her conditional discrimination behavior was controlled by both positive and negative stimulus relations, as is the case for humans.

The preliminary tests of stimulus preferences between undefined comparisons in the presence of defined samples did not affect her avoidance of negative comparisons during the five control tests, unlike in the exclusion tests. It suggests that the two types of negative stimulus relations (control by exclusion and S− control), which were logically the same in the two-choice conditional discrimination, had different degrees of control over behavior under the same experimental situations. Note that one of the sample–comparison relations that appeared in probe trials of S− control tests had been differentially trained during baseline training (i.e., defined sample, negatively defined comparison), whereas no relations were explicitly trained, even when one of the comparisons was a defined one, in exclusion testing. This difference in training history of stimulus relations could account for the difference between exclusion and S− control.

GENERAL DISCUSSION

The present experiments were conducted to clarify the controlling relations in arbitrary matching in a "symmetry-emergent" chimpanzee. Previous studies on conditional discrimination in animals, especially in nonhuman primates, generally support the view that their conditional discrimination behavior is controlled only by sets of relations of specific samples and positive comparisons and that relations between the sample and the negative comparison or "same-different" relations between sample and comparison acquire control over behavior only in limited experimental situations (Carter & Werner, 1978; Cumming & Berryman, 1965; Fujita, 1983; Wright, Cook, Rivera, Sands, & Delius, 1988; Zentall et al., 1981). The present results, however, show that Chloe's conditional discrimination behavior was controlled by relations between the sample and the positive comparison, by relations between the sample and the negative comparison, and by exclusion, especially on color-to-shape trials.

McIlvane et al. (1988) have offered two hypotheses to explain the origin of such negative stimulus relations. In one of their experiments (Experiment 2), 9 normal preschoolers were trained on several sets of conditional discriminations in which spoken words appeared as the sample and pictures appeared as comparisons. After baseline training, the subjects were tested on probe trials that were the same as the S− control test trials in the present experiments, in which positive comparisons were replaced by undefined ones. Only 2 of 9 subjects, however, perfectly selected undefined comparisons, whereas all subjects in exclusion tests in another experiment exhibited perfect exclusion. Their results from normal children thus are inconsistent with the present results from a chimpanzee; Chloe showed better performance on S− control trials than on exclusion trials, especially when shapes were presented as samples. The two hypotheses suggested by McIlvane et al. (1988) to account for the emergence of control by exclusion were a novelty account and a stimulus class account. The novelty account suggests that the subjects excluded the defined comparison merely because it was not novel, that is, "novel samples and novel comparisons go together" (McIlvane et al., 1988, p. 491). However, the present results could not be explained by this account because Chloe reliably excluded the negatively defined comparisons in the presence of defined samples on S− control test trials. Furthermore, the undefined stimuli in the present experiments were no longer novel because they were differentially reinforced on identity matching trials during the testing. The other account, the stimulus class account, suggests that the subjects excluded any comparison that was not in the same stimulus class as the sample. This is a more generalized version of the S^X rule proposed by M. Dixon et al. (1983). Dixon and colleagues expanded Cumming and Berryman's (1965) S^D rule—"if A, then select B"—into more general but complex form—"if A, then select B *and* if not A, then not select B." The present positive results on S+ control and S− control tests (and even on the color-sample exclusion test) suggest that Chloe's behavior was consistent with S^X rules during conditional discrimination training. However, if the S^X rule was generalized into McIlvane et al.'s stimulus class account, it would have difficulty explaining the results of the S− control testing in the present experiments for the same reason described above. In S− control testing, as McIlvane et al. (1988) noted, if the stimulus class account were true, Chloe should have excluded *both* negatively defined and undefined comparisons because they were not members of the same stimulus class as the defined sample. Furthermore, this account also does not explain other results obtained with human subjects (Stromer & Osborne, 1982).

If an S^X rule is one of the necessary conditions of a stimulus class, the establishment of exclusion would imply the formation of a stimulus class. Subjects who show emergence of equivalence relations—evidence of a stimulus class—should exhibit control by negative stimulus relations and vice versa. Attempts to establish stimulus equivalence in nonprimates have consistently failed to show the emergence of Sidman equivalence relations (Gray, 1966; Hayes, 1989; Hogan & Zentall, 1977; Lipkens et al., 1988). However, primates are exceptional in that they consistently show transitivity (D'Amato et al., 1985; Savage-Rumbaugh, Rumbaugh, Smith, & Lawson, 1980; Yamamoto & Asano, 1991), and even some evidence for emergence of symmetry (cf., Kojima, 1984; Premack, 1976; Tomonaga, Matsuzawa, Fujita, & Yamamoto, 1991). As noted earlier, Chloe was a chimpanzee who showed significant emergence of symmetry in arbitrary matching using standard testing procedures for humans (Tomonaga, Matsuzawa, Fujita, & Yamamoto, 1991). The present results suggest that the emergence of Sidman equivalence relations and control by negative stimulus relations are actually correlated in Chloe as in humans. In the future, we must identify the environmental variables common to the establishment of both the Sidman equivalence relations and control by negative stimulus relations, as well as exclusion and the S^X rule. It is also important to compare the controlling relations of conditional discriminations between humans and nonhumans in order to explore the characteristics and origins of stimulus equivalence.

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