CONDITIONAL RELATIONS BY MONKEYS: REFLEXIVITY, SYMMETRY, AND TRANSITIVITY

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Two cynomolgous macaques categorized six colors into two groups of three after conditional discrimination training (zero-delay symbolic match-to-sample). The procedures resulted in the establishment of relations among the elements of each set—relations that were not specifically trained and that can be characterized by the properties of reflexivity, symmetry, and transitivity. Each set of colors was related to a characteristic pattern of responding: One response pattern involved temporal duration (press and hold the response keys); the second response pattern entailed repeated pressing and releasing of the response keys (fixed ratio 8). Six combinations of two colors were trained, three combinations from each set. After discriminative performance stabilized for each monkey, they were tested with 10 additional color combinations, all of which differed from the training combinations. The conditional relations established between test combinations can be characterized as stimulus equivalence. The training procedures were analogous to the procedure of using category names, and have implications for understanding the function of language in the formation of equivalence classes.

Key words: stimulus equivalence, conditional relations, discrimination training, reflexivity, symmetry, transitivity, key press, monkeys

The logical properties of reflexivity, symmetry, and transitivity underlie much of mathematics and are routinely taught to grammar school children as principles defining arithmetic operations on number systems. Transitivity requires a set of at least three elements. If element *a* bears a particular relation to element *b* (*aRb*) and the same relation is found between elements *b* and *c* (*bRc*), then transitivity requires that *aRc* be true. Symmetry requires two elements: If *aRb*, then *bRa*. Reflexivity or identity requires only one element: *aRa*. These three properties, formalized within the context of logic and mathematics, form the basis of larger systems that require them as basic operations. At least since Kant (1781/1929), logic systems have been proposed as rules explaining the interaction of people with their environments. An enduring question has

concerned the natural status of such logic systems when incorporated into behavioral theories. In the present case, we have posed the following question: Are reflexivity, symmetry, and transitivity purely formal, logical constructions, or do they develop in the absence of specific rule training as an organism responds in organized (or even preorganized) ways to sets of events in its environment? If the latter, what are the necessary and sufficient conditions for development of such relationships within an organism's repertoires?

There is a relation between certain discrimination-training procedures and the development of functional reflexive, symmetrical, and transitive stimulus relations by adult, child, nonhandicapped, and retarded human populations (Sidman, 1971; Sidman & Cresson, 1973; Sidman, Kirk, & Willson-Morris, 1985). During conditional discrimination training, if a consistent relationship *aRb* and *bRc* is established between three otherwise dissimilar stimuli, the relation *aRc* occurs in the absence of specific training, as does *cRa*, *cRb*, *bRa* and *aRa*, *bRb*, *cRc*. For example, assume stimulus *a* to be the written word "six," *b* to be "6," and *c* to be "XXXXXX." By establishing the relations, *six* → 6 and 6 → XXXXXX, using conditional discrimination-training procedures, the relation *six* → XXXXXX is established, as are the other untrained, and thus

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Fig. 1. Schematic of the relations that may emerge among a set of three stimuli as a result of conditional discrimination training. Implementation of the training procedure requires the use of at least one set of three stimuli.

“emergent,” relations indicated in Figure 1. By training two combinations of the three stimuli (aRb and bRc), all relations emerge apparently defined by the logical properties of reflexivity, symmetry, and transitivity. As all three stimuli stand in the same set of relationships with one another, they are mutually substitutable, or equivalent, under these conditions. Stimulus equivalence classes are thus formed when stimuli bear a consistent relationship with one another and are mutually substitutable as defined by reflexivity, symmetry, and transitivity. For example, one can substitute the spoken word “six” for the array XXXXXX or write the number 6 or six. Subsequently, this allows one to do arithmetic ($4 + 2 = 6$) and to write and talk about it (“four plus two equals six”). Not all possible combinations of stimuli need to be trained. Once a stimulus becomes an element in an equivalence class, the relationships of its use need not be taught if the relationships have been taught with respect to the other elements.

The conditions that are essential for development of equivalence classes remain unclear. It is possible that stimulus equivalence is simply an emergent property of conditional discrimination training procedures. A second possibility is that equivalence classes are related to verbal behavior and, as such, are probably limited to humans. These possibilities have been evaluated in a series of experiments that attempted to establish equivalence classes in monkeys (D’Amato, Salmon, Loukas, & Tomie, 1985; Sidman *et al.*, 1982). Except for one study showing that monkeys with “massive” exposure to conditional discrimination procedures demonstrate transitivity when transitive relations are reinforced during testing (D’Amato *et al.*, 1985), there is no evidence that monkeys formed equivalence classes. Inasmuch as procedures similar to those used with the monkeys result in the development of robust equivalence classes in children (Sidman *et al.*, 1982), this suggests that the formation of equivalence classes is a uniquely human characteristic.

It is, however, possible that the previous failures to develop robust equivalence classes in monkeys resulted from procedural rather than organismic limitations. If this is so, a procedure resulting in the establishment of stimulus equivalence in nonhumans may help clarify how humans form equivalence classes. Many studies of the establishment of equivalence classes in human subjects used verbal stimuli (spoken or heard by the subjects) during discrimination training and/or equivalence testing. Moreover, even in the studies that used only visual stimuli, the subjects may have devised their own linguistic codes for the stimuli. Stated simply, the subjects may have talked to themselves and created names for the nonsense figures, and those names may have helped the formation of equivalence classes. This suggestion is supported by observations of children creating names for nonsense stimuli used during discrimination training in the absence of specific instructions to do so (Lazar, Davis-Lang, & Sanchez, 1984).

Naming is a complex phenomenon, often involving social functions and social consequences. However, its basis involves the performance of some arbitrary response in the presence of a specific discriminative stimulus. It is possible that the discriminated emission of differential response topographies is itself of functional significance in the establishment

of stimulus equivalence. As such, organisms would be expected to form equivalence classes only to the extent that their behavioral repertoires allow them functionally to "name" stimuli. We report here that cynomolgous macaques, when given a simple two-word naming system, are capable of forming two three-element equivalence classes with the properties of reflexivity, symmetry, and transitivity.

METHOD

Subjects

Rang and Manley are female, wild-born cynomolgous macaques (*Macaca fascicularis*) approximately 15 years of age. Neither had been used for research for several years. They previously had been exposed to procedures involving the discrimination of response duration but had no experience with procedures similar to those of the present study. They were maintained at their preexperimental body weights of 3.2 and 4.0 kg, respectively. Both were fed daily rations of monkey biscuits in their home cages when sessions were completed.

Apparatus

Centered on one wall of the primate test chamber, approximately 10 cm above the grid floor, a small food hopper caught the raisins, currants, chopped dates, dried banana chips, carob bits, and occasional dried papaya that were presented in small amounts as reinforcers. Three translucent plastic response keys (3.0 cm diameter) were mounted in a horizontal line 30 cm above the food hopper. The circular keys were mounted flush with the wall, 10 cm apart. Approximately 0.15 N applied to the face of a key depressed it sufficiently (about 2.0 mm) to operate one or both of two series-connected microswitches. Stimuli were projected through the keys by lamps located behind each key. The chamber was constantly illuminated and the noise of the exhaust fan was always present. Stimuli were programmed and data were collected by solid-state digital logic located in an adjacent room.

Procedure

Sessions were conducted 4 to 6 days per week and a session lasted until a monkey stopped key pressing for approximately 5 min.

Fig. 2. A. The colors used as stimuli are ordered according to wavelength. The circled numbers adjacent to each color name are used in all discussions requiring reference to a specific color or combinations of colors. B. The color combinations used for the conditional discrimination training task. Color combinations requiring the Odd response are on the left and those requiring the Even response are on the right. C_{ij} indicates the comparison stimuli and S_{ij} indicates the corresponding samples. The arrows indicate which C_{ij} is the correct selection for each combination. In training, the lateral location of the comparison pairs was randomized for each sample. C. Schematic of the stimulus relations established by the conditional discriminations in Panel B.

* 1 → 1 and 2 → 2 reflexivity training were conducted so that Colors 1 and 2 would be presented as comparison stimuli during training and location/order effects would not affect later symmetry testing.

** Only Manley received this training for five sessions.

If fewer than 30 trials were initiated in a session, the session was often continued later the same day. The final schedule on which the monkeys were trained was a three-key conditional discrimination task using six colors projected onto the translucent response keys. The colors were not pure wavelengths, but to a human observer they were clearly discriminable as red, orange, yellow, green, blue, and pale violet. For purposes of description, the colors are numbered and will be discussed as shown in Panel A of Figure 2.

Discrimination training. A trial was initiated when the center key (the sample) was illuminated with one of the six colors (see Figure 3). The keylight remained illuminated until

Fig. 3. Beginning at the bottom with the intertrial interval (ITI), the sequence of events during a trial is shown schematically. The sample (S_{ij}) is presented and a response (R_{ij}) is emitted in its presence. An incorrect R_{ij} restarts the ITI. A correct R_{ij} turns off the S_{ij} and turns on the comparison keys (C_{ij}). An incorrect selection or an incorrect R_{ij} results in an ITI. Correct R_{ij} and C_{ij} selection results in a reinforcer on 65% of the trials and the initiation of the ITI on all trials.

one of two responses was emitted on the sample key. An “Odd” response was completed when a key was pressed and held continuously for 3.5 s. Any break in the continuity of the Odd response reinitiated timing of the 3.5-s duration requirement. An “Even” response was completed with the eighth key press, that is, the key had to be pressed and released seven times prior to the eighth press (fixed ratio 8). The Odd response was correct when the odd-numbered colors were present and the Even response was correct for even-numbered colors. If an incorrect response to the sample occurred, the keys were darkened for 4 s. Any key pressing during this intertrial interval (ITI) delayed the onset of the next trial until 4 s after pressing ceased. If a correct response occurred on the illuminated sample key, the key was darkened and the two side keys (comparisons) were illuminated. One of the comparison keys was an Odd color and one an Even color. The lateral arrangement of colors was random within each pair. When a monkey pressed either comparison key, the other comparison key was darkened and became inoperative. Thus, the monkey was forced to complete the trial on the comparison key that was initially selected. The selected comparison key re-

RELATIONS		RESULTS	
Odd	Transitivity	RANG	MANLEY
	Symmetry	19/19	14/14
	Reflexivity	16/17	20/21
	Sym X Trans	5/5	
		17/18	10/11
Even	Transitivity	12/12	5/5
	Symmetry	21/22	10/12
	Reflexivity	22/22	22/24
	Sym X Trans	7/7	
		17/17	12/12
Total trans		40/41	24/26
Total sym		50/51	42/45
Total refl		34/35	22/23
Total sym x trans		21/24	12/12
TOTAL EQUIVALENCE		145/151	100/106

Fig. 4. Stimulus combinations used during equivalence testing are listed on the left, adjacent to the name of the relationship that is tested by each combination. In testing, the lateral arrangement of comparison colors was randomized for each sample. Results of testing are shown in the right panel, and are presented as the number of correctly completed trials divided by the total number of trials of each combination presented to each monkey.

mained illuminated until either an Odd or an Even response was completed, regardless of key color. The completion of an Odd or Even response darkened all keylights, initiated the 4-s ITI, and presented a reinforcer when a trial was completed correctly. A correct trial required selecting the Odd comparison when an Odd sample had been present and emitting the Odd response in the presence of both Odd colors. Emission of the Even response in the presence of the Even sample and corresponding Even comparison key was also correct. All other combinations of stimulus selection and response emission resulted in the darkening of the keys and the initiation of the ITI. A reinforced trial may be construed as analogous to a human subject's pointing to the sample and correctly naming it, followed by pointing to the correct comparison and naming it the same. When performance stabilized on this schedule, reinforcers were presented following correct trials with a probability of .65.

A correction procedure was intermittently

Table 1
Equivalence responses/trials for each monkey during test sessions.

Test session	Rang				Manley			
	Refl	Sym	Tran	T × S	Refl	Sym	Tran	T × S
1			2/2		2/2	2/2	2/3	
2			8/8				2/2	
3			3/3				5/5	
4			4/4				2/2	
5	10/10				5/5			
6		15/15			6/7			
7	4/4					1/1		
8	5/6	5/6	7/8			5/5		
9	3/3	3/3	3/3			5/6		
10	1/1	3/3	3/3			4/5		
11		6/6				9/9		
12		6/6					7/7	
13	3/3	4/4	3/3				6/7	
14	5/5	4/4	4/4		9/9			
15	3/3	4/4	3/3			7/7		
16				3/3		9/10		
17				4/5				7/7
18				5/5				5/5
19				5/6				
20				4/5				
Total	34/35	50/51	40/41	21/24	22/23	42/45	24/26	12/12

used during training sessions. When the correction procedure was in effect, an incorrect trial was repeated after the ITI until it was completed correctly. The order of presentation of the training combinations was quasi randomized on punched paper tape with the restriction that no trial was repeated unless an error had occurred.

The color combinations used as sample and comparison stimuli on the final conditional discrimination procedure are shown in Panel B of Figure 2. Additionally, Panel C of Figure 2 shows in schematic form the color relations that were established by the training combinations.

Equivalence testing. After each monkey's performance stabilized on the training schedule, equivalence test sessions were conducted one to three times per week. During test sessions, stimulus combinations were presented that had not occurred during training. These test combinations were selected to reveal the presence of conditional relations not specifically trained. Equivalence testing sessions were procedurally the same as training sessions with the following exceptions: First, errors on a comparison stimulus never caused a trial to be repeated. Second, the probability of reinforce-

ment for correct completion of a trial involving stimulus combinations that had been used during training was increased to .80. Third, one in seven stimulus combinations, on average, was a test combination that never had been present during training conditions. Additionally, and importantly, test combinations were never followed by reinforcement. Figure 4 shows the color combinations introduced during equivalence testing sessions.

Correctness during equivalence testing was evaluated using the same criteria that were used during training: The proper comparison must be selected and the proper response emitted in its presence. Testing the symmetry relations required placing Colors 5 and 6 on the sample key for the first time. During testing, Samples 5 and 6 were repeated until a correct sample response was emitted. Test sessions were interspersed among the continuing training sessions.

RESULTS

Rang received 2,162 trials and Manley 5,536 trials of shaping prior to exposure to the conditional discrimination task. Rang received 3,104 trials of conditional discrimination

Fig. 5. A. Schematic of relations established between stimulus elements and naming responses during discrimination training. B. Schematic of proposed relations responsible for the establishment of equivalence classes.

training prior to equivalence testing and Manley received 3,073 training trials. In the final three training sessions prior to equivalence testing, Rang performed at 95% accuracy (241/254) and Manley performed at 87% (278/319). Figure 4 shows that both monkeys performed as accurately on the test color combinations as they did on the color combinations used during training. Both Rang and Manley demonstrated conditional discrimination performance based on reflexivity (97%, 96%), symmetry (98%, 93%), and transitivity (97%, 92%). Additionally, both monkeys demonstrated equivalence with a test pair that required a combination of symmetry and transitivity (87%, 100%). These equivalence performances were stable over 18 and 20 testing sessions distributed over 5 and 8 weeks for Manley and Rang, respectively. Hence, once the equivalence classes were established, the emergent relations were robust and stable in the absence of reinforcement. Table 1 shows the equivalence performance for each monkey during each test session.

The difficulty in establishing discriminative control prior to testing is evident in the relatively large number of shaping and training trials required prior to the introduction of the test combinations. It is probable that stimulus location and/or temporal order, in addition to wavelength and response topography, were sources of discriminative control. (Evidence for

this was not quantified because of equipment limitations.) However, it was clear that many responses to the test combinations were of a different latency and/or duration than the predictable, steady responding in the presence of the training combinations. Additionally, testing symmetry relations required placing Colors 5 and 6 on the sample key for the first time. Rang apparently generalized to Sample 5 (blue) from Sample 4 (green) and emitted several Even responses in the presence of Sample 5 prior to emitting Odd responses. Manley had an analogous problem with Sample 6 (orange), apparently generalizing to it from 1 (red) or 3 (yellow). It is possible that this additional source of control affected Rang's accuracy on the symmetry $\times$ transitivity test involving Sample 6.

DISCUSSION

Establishing differential response patterns that appear to share properties with a two-word naming system (Odd-Even) resulted in the establishment of equivalence classes where previous procedures had met with limited success. These findings indicate the potential importance of differential response topography in the ontogeny of equivalence classes and the emergence of reflexivity, symmetry, and transitivity. The use of the language metaphor in our description of the monkeys' performances is not intended to imply complete similarity to human language. A metaphor, like all equivalence classes, is conditional. However, an explanation for the development of equivalence classes in the present study may provide insight into analogous functions performed by human language. The conditional discrimination task used here required the monkeys to respond correctly to 12 patterns of training stimuli, combined with two very distinctive patterns of responding. If the monkeys had simply learned configurations of colors or stimulus-stimulus associations, they would not be expected to form equivalence classes. Additionally, learning all possible stimulus-response sequences is not a very efficient way of performing this task. A much simpler and more efficient strategy would be to relate each element of each stimulus class (the colors) with the appropriate response topography, as shown in Figure 5; that is, name each stimulus as it appears.

Once the responses were clearly differentiated and the stimuli were discriminated,

stimulus events related to the emission of the first naming response set the occasion for a subsequent naming response of the same type. This process can account for our results and is consistent with previous observations that some complex discriminative performance may be facilitated or mediated by the emission of topographically distinct "coding" responses (see Carter & Werner, 1978). It is possible that the use of names by humans shares functional properties with the differential responses emitted by the monkeys in our study. Names may become functionally related to sets of otherwise dissimilar stimuli and result in the formation of equivalence classes, that is, conditional relations. Consequently, the formation of equivalence classes, hence of reflexivity, symmetry, and transitivity, may arise from the use of a functional naming system.

Although the above interpretation requires direct testing, there are some relevant results from early work on mediated association. Birge (1941) showed that naming can be an effective mediator for children who learned the names of four boxes with distinctive designs on the top. Two boxes shared one name and two boxes shared another. After the child learned the names of the boxes, one pair with contrasting names was repeatedly presented with candy under one of them. The child was then presented with the other pair of boxes and told to guess which one had candy under it. Under these conditions, performance was essentially at the chance level. However, when the child was required to name the boxes as they were being selected, there was substantial facilitation of correct selections. This procedure, although not a conditional discrimination task, is in several respects similar to the procedure used in the present experiment.

Of course, a simple homogeneous naming chain such as that used here is not the only interaction possible between verbal operants and the formation of stimulus classes. Indeed, the complexities of children's verbal behavior during discrimination training (Lazar et al., 1984) indicate the rapidity with which heterogeneous verbal sequences may develop. However, the simple homogeneous response chains used here may constitute a relatively simple mechanism upon which complex relations are established. For example, use of Odd-Even and Even-Odd response chains might have facilitated Rang's and Manley's performances as effectively as the Odd-Odd

and Even-Even chains used in the present study.

It is questionable whether any set of training procedures will greatly increase Rang's or Manley's equivalence sets or the number of equivalence sets they demonstrate. However, pongids, which are capable of emitting a large number of different manual signs (Gardner & Gardner, 1975; Patterson, 1981), would be expected to be relatively adept at forming equivalence classes. In the wake of the ape-language controversy, it may be profitable to readdress the issues of comparative development from the beginning, including naming (Terrace, 1985) and stimulus equivalence.

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