STIMULUS CLASS FORMATION AND STIMULUS-REINFORCER RELATIONS

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This study examined stimulus class membership established via stimulus-reinforcer relations. Mentally retarded subjects learned conditional discriminations with four two-member sets of visual stimuli (A, B, C, and D). On arbitrary-matching trials, they selected comparison stimuli B1 and B2 conditionally upon samples A1 and A2, respectively, and C1 and C2 conditionally upon B1 and B2, respectively. On identity-matching trials, they selected all stimuli as comparisons conditionally upon identical stimuli as samples. Throughout training, correct selections of A1, B1, C1, and D1 were followed by one reinforcer, R1, and those of A2, B2, C2, and D2 were followed by another, R2. Subsequent tests documented the formation of two four-member stimulus classes, A1-B1-C1-D1 and A2-B2-C2-D2. The class membership of the A, B, and C stimuli could have been based on equivalence relations that resulted from the arbitrary-matching training. D1 and D2 had never appeared on arbitrary-matching trials, however. Their class membership must have been based on relations with R1 and R2, respectively. Results thus confirm a previous finding that stimulus classes can be expanded via stimulus-reinforcer relations. They also define more precisely the potential nature of those classes and the conditions under which class membership can be established.

Key words: conditional discrimination, matching to sample, stimulus classes, stimulus-reinforcer relations, pointing, mentally retarded adults

An operant is defined as a class of responses functionally related to a given consequence (Skinner, 1953, p. 65). Given appropriate context, such responses are mutually substitutable. For example, when deprived of water, one is likely to turn on faucets, open water bottles, ask for water, and so on. If a number of different stimuli each individually occasion a given response, then those stimuli can be members of a functional stimulus class. Paralleling response classes, the defining characteristic is mutual substitutability of class members within a given context (cf. Sidman, 1977; Spradlin, 1977). The stimulus class concept is especially appropriate when a variable applied to one class member subsequently affects other

members without explicit conditioning (e.g., de Rose, McIlvane, Dube, Galpin, & Stoddard, 1988; Galloway & Petre, 1968; Silverman, Anderson, Marshall, & Baer, 1986).

Current studies of stimulus class formation generally examine some form of conditional stimulus control (Sidman, 1986). The focus is typically on stimulus-stimulus relations involving conditional and discriminative stimuli in matching-to-sample procedures (Fields & Verhave, 1987; Sidman & Tailby, 1982; Stoddard & McIlvane, 1986). For example, subjects may be trained to select comparison (discriminative) stimuli B1 and B2 conditionally upon sample (conditional) stimuli A1 and A2, respectively (AB matching), and also to select comparison stimuli C1 and C2 conditionally upon samples B1 and B2, respectively (BC matching). The left portion of Figure 1 illustrates the four-term behavioral units established by this type of training (cf. Sidman, 1986); A1, A2, B1, B2, C1, and C2 represent arbitrary visual stimuli (e.g., Greek letters), and R1 represents a reinforcing stimulus (e.g., food). In representing these units, we show both the comparison stimulus selected and the one not selected. Without explicit tests, one cannot assume that the latter is irrelevant to

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Fig. 1. Training and testing paradigm for a demonstration of stimulus class formation. Nonspecific reinforcement contingencies are shown on the left, and performance-specific contingencies are shown on the right. The large letters A, B, and C represent two-member sets of arbitrary visual stimuli. Arrows point from samples to comparison stimuli. Solid arrows represent performances established through direct training; dashed arrows represent emergent matching performances. The smaller letters (A1, A2, etc.) show four-term behavioral units that may result from AB and BC training. Sample stimuli are shown to the left of the vertical lines, and simultaneously displayed comparison stimuli are shown to the right. Selections of a comparison are shown by an encircled "R" (for "response") to the right of the stimulus selected. Stimuli that follow selections are shown to the right of the encircled "R." See text for details.

stimulus control of the response (see McIlvane *et al.*, 1987; Sidman, 1987; Stromer & Osborne, 1982). In Figure 1, the trained performances are represented by solid arrows. If subjects then demonstrate BA, CB, AC, and CA matching performances without explicit training (as shown by the dashed arrows in Figure 1), then the formation of two stimulus classes is documented (A1-B1-C1 and A2-B2-C2). Stimulus class members are mutually substitutable with respect to their conditional (sample) and discriminative (comparison) stimulus functions.

At this level of analysis, response-reinforcer relations that define operants are rarely emphasized. Under some circumstances, however, relations of stimuli with reinforcers may be critical to complete analysis of stimulus classes. Such circumstances may occur when matching-to-sample procedures are programmed with performance-specific reinforcement contingencies (cf. Peterson, 1984; Trapold, 1970), as illustrated in the right portion of Figure 1. With performance-specific contingencies, correct selections of B1 and C1 are followed by R1 (e.g., food), and correct selections of B2 and C2 are followed by a different reinforcing stimulus, R2 (e.g., water).

With both types of procedures—nonspecific (Figure 1, left portion) and performance specific (Figure 1, right portion)—the resulting stimulus classes are defined by stimulus-stimulus relations among conditional and discriminative stimuli. However, with performance-specific procedures, one may ask if the classes also are defined by stimulus-reinforcer relations. If so, then the classes may be expanded to include new stimuli by establishing similar stimulus-reinforcer relations between the reinforcers, R1 and R2, and the new stimuli (Dube, McIlvane, Mackay, & Stoddard, 1987).

In the present study, we examined the expansion of stimulus classes with performance-specific reinforcement procedures like those represented in the right portion of Figure 1. This study was a systematic replication and extension of our earlier work with mentally retarded subjects (Dube *et al.*, 1987). Figure 2 illustrates the procedures of the present study, showing behavioral units that were established by baseline training and those that emerged on probe trials. (Procedures for our earlier study were similar to those in Figure 2. Differences will be noted below.) During training (Figure 2A), four pairs of visual stimuli were displayed on identity-matching trials (AA, BB,

CC, and DD matching). The A, B, and C stimuli were also displayed on arbitrary-matching trials; subjects were trained to perform AB and BC matching tasks. Performance-specific reinforcement contingencies were in effect throughout. Correct selections of A1, B1, C1, and D1 were followed by R1, and correct selections of A2, B2, C2, and D2 were followed by R2.

When the baseline performances were established, probe sessions tested for the emergence of new behavior that had not been explicitly conditioned (Figures 2B and C). Emergent arbitrary-matching performances with the A, B, and C stimuli (Figure 2B) were tested first. Emergence of these performances would indicate the formation of two stimulus classes (A1-B1-C1 and A2-B2-C2) similar to those shown in Figure 1. Such class formation might have at least two bases, either by itself sufficient and not mutually exclusive of the other. The first is the trained arbitrary-matching performances AB and BC. The formation of stimulus classes after these relations have been established among sample and comparison stimuli has been demonstrated many times before (e.g., Sidman & Tailby, 1982; Stoddard, 1986). The second basis for class formation is common relations between the stimuli in each class and the specific reinforcers (i.e., A1, B1, and C1 with R1; and A2, B2, and C2 with R2).

Emergence of the behavior shown in Figure 2C would indicate that the D stimuli were also members of classes with the A, B, and C stimuli. Class membership of the D stimuli would have to be based solely on specific stimulus-reinforcer relations, because the D stimuli had never been displayed simultaneously with the A, B, or C stimuli. Prior to the probe trials, the D stimuli had appeared only on DD identity-matching trials.

After the probe sessions were completed, we reversed the contingencies for the identity-matching trials with the D stimuli (not shown in Figure 2). Correct selections of D1 were now followed by R2 and those of D2 by R1. This reversal provided a stringent control for D stimulus class membership based on some variable other than the performance-specific reinforcement contingencies (e.g., primary stimulus generalization; cf. Sidman, 1987). If class membership of the D stimuli depended upon stimulus-reinforcer relations, a reversal

of those contingencies might disrupt—and perhaps reverse—that class membership (Dube et al., 1987). A new series of probe sessions examined this possibility.

As previously noted, the design of our earlier study (Dube et al., 1987) was similar to that shown in Figure 2. A major procedural difference involved the history of food reinforcers R1 and R2. In our previous study, the food items had explicitly defined discriminative functions, serving as matching-to-sample stimuli along with spoken names, printed symbols, and junk objects. Testing revealed that all stimuli, including the food items, were members of stimulus classes. The present study examined whether class membership based on stimulus-reinforcer relations depended on the restricted set of conditions of our previous study. Specifically, we asked whether such membership could be shown even if reinforcers had no explicit matching-to-sample functions.

METHOD

Subjects

Two moderately mentally retarded males (PN and JDB) served as subjects. They were 20 and 14 years old, respectively. On the Peabody Picture Vocabulary Test, their age-equivalent scores were 4.1 years and 3.8 years, respectively.

Apparatus and Setting

Two Macintosh® (Apple) computers were used. Their screens (19 by 14 cm) displayed stimuli, and the subject responded by touching them. One computer was fitted with a touch-sensitive screen (MicroTouch Systems, Inc.) that permitted automatic data recording (Dube & McIlvane, in press). Modula-2 programs controlled stimulus presentation and data collection.

Sessions were conducted 4 or 5 days per week in a quiet room of the residential school where both subjects lived. The Macintosh apparatus was placed on a table, and the subject sat facing it. The experimenter sat behind and slightly to one side, so that the subject could not observe the experimenter and the apparatus at the same time. Food reinforcers were delivered manually by the experimenter from a supply kept on a small table next to him.

With the apparatus that lacked a touch-sensitive screen, the experimenter recorded the

Fig. 2. Directly reinforced baseline behavioral units and emergent behavior for the present experiment. Sample stimuli are shown to the left of the vertical lines, and simultaneously displayed comparison stimuli are shown to the right. Selections of a comparison are shown by an encircled "R" (for "response") to the right of the stimulus selected. Stimuli that followed selections are shown to the right of the encircled "R." R1 and R2 are reinforcing stimuli. See text for details.

subject's responses. Whenever the subject touched a response area on the screen (see matching-to-sample procedures, below), the experimenter pushed a corresponding button on the computer's keyboard. When data recording was done manually, all sessions were videotaped to permit reliability assessment. Reliability scores (agreements/trials) were obtained for about one third of the sessions, and scores were always 98% or better. The manual recording method was used for all of PN's sessions and for about half of JDB's baseline sessions; JDB's remaining baseline sessions and all of his probe sessions were conducted with the touch-sensitive screen.

Reinforcer Preference Testing

This preliminary step determined two food reinforcers of approximately equal preference. Through such tests, we sought to avoid response biases that can influence responding when performance-specific reinforcers are used (Litt & Schreibman, 1981). Four food items were displayed two at a time in all possible

combinations; each combination was displayed four times. On every such preference-test trial, the experimenter said "Take one" and then recorded the subject's choice. For both subjects, two foods were about equally preferred: For PN, they were approximately 0.5 oz of cola (R1) and a cheese puff (R2); for JDB, they were cola (R1) and a piece of candy (R2). These tests also identified a third food item that each subject would take and eat reliably. These items, a fruit drop for PN and a pretzel for JDB, were used in a pretraining phase.

Matching-to-Sample Procedures

The matching-to-sample display consisted of five "keys," 4.5 by 4.5 cm white squares on a gray field. One key was centered on the computer's screen and one key appeared in each corner. Sample and comparison stimuli appeared on the center key and on the four corner keys, respectively.

Every trial began when a sample stimulus appeared on the center key. A required sample touch was followed immediately by the presentation of comparison stimuli on two of the four outer keys. The remaining keys were blank, and the locations of comparison stimuli varied unsystematically across trials. Additional touches of the sample, present throughout the trial, had no programmed consequences. A touch of a comparison stimulus was followed by the disappearance of all stimuli from the keys and consequences as follows.

Reinforcement Procedures

Continuous and intermittent reinforcement schedules were used at different points in the experiment. With continuous reinforcement, all correct selections were followed by melodic tones, a flashing display on the computer screen, and a food item. The tones and visual display presented with food item R1 had very different physical characteristics from those presented with R2. These stimuli, also performance-specific consequences, were judged to be highly discriminable from one another. A third visual display-tone complex followed correct selections during pretraining.

During the intertrial interval, all keys were blank. The experimenter initiated the next trial (by means of a hand switch) only after the subject had consumed the food (about 20 s for PN and 15 s for JDB). After incorrect selections, the screen went black for 5 s and the trial

ended. Thereafter, the keys were redrawn, and a 15- to 20-s intertrial interval began.

With intermittent reinforcement, about one fourth of the subjects' correct selections were followed only the intertrial interval (VR 1.3). Also, no blackout followed incorrect selections.

Stimuli

The lower left portion of Figure 2 illustrates the stimuli (approximately 2.5 by 2.5 cm) that were displayed on training and test trials. Stimuli used in pretraining were line drawings of common objects (e.g., car, house, etc.) or symbols (e.g., arrow, cross, etc., or Greek letters).

Matching-to-Sample Training Procedures

Two methods were used to teach matching-to-sample performances. One was a delayed prompting method (Sidman, 1977; Touchette, 1971) in which correct comparison selection was prompted by the disappearance of the incorrect comparison. Over trials, the prompt was delayed progressively by 0.5 s following each correct matching selection; incorrect selections decreased the delay by 0.5 s. For each arbitrary-matching performance, the learning criterion was 16 consecutive trials on which the subject responded correctly before the disappearance of the incorrect comparison stimulus.

The second method used stimulus fading and was modeled after one described by Rosenberger, Stoddard, and Sidman (1972). Correct comparison selections were prompted by displaying the incorrect comparison less distinctly. The apparent intensity of the S- stimulus was reduced by masking out an evenly distributed portion of its pixels; on successive program steps 0%, 25%, 50%, 75%, and finally 100% of the pixels were displayed. The program advanced one step after three consecutive correct selections; the program backed up to the previous step following any error. Again, the learning criterion was 16 consecutive unprompted selections.

Pretraining

In introductory sessions, a simple discrimination task was used to teach the subjects to scan and to touch stimuli on the screen. These procedures, modeled after those of Sidman and Stoddard (1966), have been described extensively elsewhere (Dube & McIlvane, in press).

Subjects next learned simultaneous identity matching with pretraining stimuli. Every selection of the comparison stimulus that was identical to the sample was followed by the pretraining reinforcer. PN's identity-matching performances were accurate immediately, but JDB's were not. For the latter, the delayed prompting procedure was used to establish identity matching. Identity-matching training continued until subjects performed errorlessly for at least one session.

Baseline Training

Identity matching to sample. Subjects first performed identity matching with all stimuli (Sets A-D). Reinforcer-specific contingencies were in effect on a continuous-reinforcement schedule. All correct selections of A1, B1, C1, and D1 were followed by R1, and those of A2, B2, C2, and D2 were followed by R2.

Arbitrary matching to sample. After four (for PN) or three (for JDB) sessions of identity matching, subjects were taught the arbitrary-matching performances. On AB trials, A1 and A2 were sample stimuli and B1 and B2 were comparison stimuli. Selections of B1 and B2 conditionally upon A1 and A2, respectively, were followed by R1 and R2, respectively. On BC trials, B1 and B2 were samples and C1 and C2 were comparisons. Selections of C1 and C2 conditionally upon B1 and B2, respectively, were followed by R1 and R2, respectively.

After the arbitrary-matching performances were learned, AB and BC trials were intermixed with identity-matching trials (AA, BB, CC, and DD trials), and the intermittent-reinforcement schedule was introduced. A possible advantage of intermixing trial types was to establish a context in which there were two bases on which comparison stimuli could be selected, identical physical features or arbitrarily defined relations with the sample. This context might prove helpful when D stimuli were presented on arbitrary-matching trials for the first time (see below).

Stimulus Class Probes

A series of probe sessions tested for formation of two stimulus classes: A1-B1-C1-D1 and A2-B2-C2-D2. Two probe procedures were used; they will be termed the "repeated-probe" and the "unique-probe" procedures. Subject PN received seven repeated-probe ses-

Table 1

Results of baseline training. Where more than one trial type is reported on a single line (e.g., AA, BB, CC), the number of trials of each type is equal. The number of training trials is shown, but not included in the correct/error (C/E) totals.

Subject	Sessions	Relation	C/E	Training trials
PN	1-4	AA, BB, CC, DD	143/1	28 delayed cue
		AA, BB, CC	37/3	
	5-8	DD	20/0	
		AB	100/4	
		AA, BB, CC	42/0	
		DD	58/0	
		AB	78/0	
		BC	116/8	
JDB	1-3	AA, BB, CC, DD	144/0	18 stimulus fading
		AA, BB, CC	24/0	
	4-7	DD	24/0	
		AB	133/11	
		AA, BB, CC	42/0	
		DD	58/0	
		AB	92/0	
		BC	126/0	
	8-14			18 stimulus fading

sions. Results of these sessions led to the development of the unique-probe procedure; this procedure was used for PN's remaining probe sessions and all of JDB's probe sessions. Further details and the rationale for the change will be explained with the results. Additional baseline sessions were programmed occasionally as a review (e.g., when several days elapsed between experimental sessions).

Repeated-probe sessions. In each such session, six unreinforced probe trials were interspersed among 42 intermittently reinforced baseline trials. Baseline trials included 13 AB, 13 BC, and 16 identity-matching trials. In probe sessions in which only A, B, and C stimuli were displayed on probe trials, identity-matching trials included two AA, two BB, two CC, and 10 DD trials; in probe sessions in which D stimuli were also displayed on probe trials, only 16 DD identity-matching trials were included. All probe trials in a session tested potentially emergent relations involving only one set of samples and one set of comparisons. In a CA probe session, for example, C1 and C2 were sample stimuli on three probe trials each, and A1 and A2 were comparison stimuli on all six trials. A given relation was considered demonstrated when all of the subject's probe selections within a session were class consistent (i.e., three selections of A1 when C1 was the sample and three selections of A2 when C2 was the sample).

Unique-probe sessions. In these sessions, a given probe trial display appeared only once, and thus each probe trial tested a different emergent relation. For example, PN's first unique-probe session tested for the following emergent relations: B1A1, B2A2, A1C1, A2C2, C1A1, and C2A2. Probe sessions could contain two, four, or six probe trials. Probe trials were interspersed among 42 to 46 intermittently reinforced baseline trials which included 14 to 16 AB trials, 14 to 16 BC trials, and two AA, two BB, two CC, and eight DD identity-matching trials. The criterion for demonstrating probed relations was either six of six or seven of eight consecutive class-consistent responses for each emergent arbitrary-matching task. With the unique-probe procedure, of course, this criterion could be met only across sessions.

Reversed Reinforcement Contingencies for D Stimuli

As outlined previously, the performance-specific reinforcement contingencies were reversed on all DD identity-matching trials. Correct selections of D1 were followed by R2, and those of D2 by R1. All other contingencies remained as before. Thus, the baseline consisted of AA, BB, CC, AB, and BC trials with the original performance-specific contingencies, and DD identity-matching trials with reversed contingencies. Reinforcement was con-

tinuous for the first session and intermittent in the second and subsequent sessions. After three additional baseline sessions, stimulus-class probe sessions were conducted using the unique-probe procedure.

RESULTS

Pretraining

Both subjects learned the simple discrimination without error in the first session. In two identity-matching sessions, PN responded correctly on 76 of 80 trials. He met the pretraining criterion in his second session. Subject JDB made six errors on 14 identity-matching trials in his first pretraining session. The delayed prompting method was then used to teach the performance directly, and he met the criterion in his fifth pretraining session. He then was given 16 sessions of additional identity-matching pretraining.

Baseline Training

Identity matching to sample. The upper portion of Table 1 summarizes the baseline training. Both subjects displayed generalized (from pretraining) identity matching with the experimental stimuli, performing virtually errorlessly in four (PN) and three (JDB) sessions.

Arbitrary matching to sample. PN learned the AB task in Sessions 5 through 8 and the BC task in Sessions 9 through 12, receiving 28 and 34 delayed prompting trials, respectively. Intermittent reinforcement was introduced in Session 13. During baseline development, PN responded correctly on 178 of 182 unprompted AB trials and on 116 of 124 unprompted BC trials. He performed without error in Sessions 13 through 15.

JDB's arbitrary-matching training was conducted with the stimulus fading procedure. He learned the AB task in Sessions 4 through 7 and the BC task in Sessions 8 through 10, both after 18 fading trials. Intermittent reinforcement was introduced in Session 12. During training, JDB responded correctly on 225 of 236 unprompted AB trials and on each of 126 unprompted BC trials. He performed without error in Sessions 12 through 14.

Stimulus Class Probes

Subject PN was given seven repeated-probe sessions, 17 unique-probe sessions, and six ad-

Table 2

Results of repeated-probe sessions with Subject PN. For each session, the type of probe trial displayed is given in parentheses (see text for details). For each probe trial, the plus (+) or minus (−) indicates that a response was consistent or inconsistent, respectively, with stimulus class formation.

Probe session (type)	Probe trial					
	1	2	3	4	5	6
1 (CA)	+	+	+	+	+	+
2 (BD)	+	+	+	−	+	+
3 (BD)	+	+	+	+	+	−
4 (BD)	+	+	+	−	+	−
5 (DB)	+	+	+	−	+	−
6 (CB)	+	−	+	+	+	−
7 (CA)	+	+	+	+	−	+

ditional baseline sessions. JDB was given 14 unique-probe sessions and two baseline sessions. During the probe sessions, both subjects responded virtually without error on baseline trials.

Subject PN: Repeated-probe sessions. Results of PN's repeated-probe sessions are shown in Table 2. In Table 2, a plus (+) or minus (−) indicates a probe response that was consistent or inconsistent, respectively, with stimulus class formation. For example, class-consistent probe responses were selections of A1 and A2 conditionally upon C1 and C2, respectively; class-inconsistent responses were selections of A2 or A1 conditionally upon C1 and C2, respectively. The first probe session included six CA probes, and all probe responses were class consistent. Emergent CA matching provided evidence for the formation of the A-B-C classes. Four subsequent sessions examined the status of the D stimuli, which had so far appeared only on identity-matching trials. Initial tests examined potential BD and DB relations. Table 2 (Probe Sessions 2–5) shows that PN did not consistently select D1 and D2 conditionally upon B1 and B2, respectively, and vice versa. Thus, these results did not document D stimulus class membership. Moreover, results of subsequent CB and CA sessions (Table 2, Sessions 6 and 7) were also not perfectly consistent with class formation.

Data analysis suggested that the inconsistent responding may have been an unintended result of our probe methods. The left portion of Table 2 shows that 20 of 21 selections on the first three probe trials of each session were

Fig. 3. Results of unique-probe sessions for Subjects PN and JDB. Each bar represents the percentage of probe responses that was consistent with stimulus class formation. Letters below each bar show the emergent performance tested (sample comparison). Numbers in parentheses below each bar show the number of probe trials for each performance. See text for details.

class consistent. However, only 13 of 21 trials were class consistent on the final three probes (Table 2, right portion). These data suggested shifts in stimulus control as the session progressed, perhaps because probe selections were never reinforced. The unique-probe method was devised to circumvent this apparent problem in measurement. We reasoned that effects of nonreinforcement might be reduced if each probe display was presented only once in a session.

Subject PN: Unique-probe sessions. In the first four unique-probe sessions, probe trials displayed only A, B, and C stimuli; probes displaying the D stimuli were included in subsequent sessions. PN's probe results are shown in the upper portion of Figure 3. The bars show percentage of class-consistent selections; the total number of probe trials given is shown in parentheses below each bar. Class consistency was shown on 77 of 80 probe selections. Thus, the results documented formation of the A-B-C classes and expansion of those classes to include the D stimuli.

Subject JDB. The lower portion of Figure 3 shows Subject JDB's probe results, all obtained with the unique-probe procedure. In the first five sessions, probe trials displayed only A, B, and C stimuli; probes displaying

the D stimuli were included in subsequent sessions. With one exception, results for all probed relations immediately met the criteria for class formation (six of six or seven of eight consecutive class-consistent selections). The exception occurred on his first eight CD probes, when only six of eight selections were class consistent. The final eight CD probe trials were presented in a baseline in which the proportion of trials displaying C stimuli was increased (two AA, two BB, 10 CC, eight DD, 10 AB, and 12 BC trials per session); all responses were class consistent on these probes. In all, Figure 3 shows that 74 of 78 selections were class consistent, documenting class formation and expansion.

Reversed Reinforcement Contingencies for D Stimuli

Both subjects were errorless in the first three baseline sessions following reversal of the performance-specific contingencies on DD identity-matching trials. Subject PN received 19 probe sessions and three additional baseline sessions. JDB received 15 probe sessions and three additional baseline sessions. Baseline performances remained virtually errorless throughout probing. Probe session results for Subjects PN and JDB are shown in the upper and lower portions, respectively, of Figure 4. For both subjects, responses on BA, CB, AC, and CA probes remained class consistent.

Results of D stimulus class probes are plotted as the percentage of selections that were consistent with the reversed stimulus-reinforcer relations (e.g., selecting D1 and D2 conditionally upon A2 and A1, respectively). Each bar is divided in two. The left and right portions show results from equal numbers of probe trials in early and later probe sessions, respectively. For both subjects, initial probe results showed immediate disruption of previous D stimulus class membership. (Maintained class membership would have produced 0% consistency with the prevailing D stimulus-reinforcer relations.) Moreover, as probing continued, results became increasingly more consistent with reversed D stimulus class membership. The right portions of the bars in Figure 4 show class consistency on 30 of PN's 32 selections and on all 24 of JDB's selections. PN's DA and DC performances were exceptions initially, as suggested by the larger number of probe trials that were given. In each

case, the final eight probe trials were given in a baseline that was changed to increase the number of trials displaying A and C stimuli, respectively (for DA probes: 12 AA, one BB, one CC, 10 DD, six AB, and six BC trials per session; for DC probes: one AA, one BB, 12 CC, 10 DD, six AB, and six BC trials per session).

DISCUSSION

This study systematically replicates and extends our earlier work on stimulus classes and performance-specific consequences (Dube et al., 1987). Stimulus-reinforcer relations served as the basis for stimulus class membership in a context in which the reinforcers had no explicitly developed sample or comparison functions. Thus, such class membership does not depend on the restricted set of procedures of our previous study. Indeed, findings from other areas of our research program suggest that these results may be only one example of a much broader phenomenon (cf. de Rose et al., 1988; de Rose, McIlvane, Dube, & Stoddard, 1988).

The reversal of D stimulus class membership provided a stringent control for artifactual results due to primary stimulus generalization (cf. Sidman, 1987) or arbitrary class assignment (Saunders, Saunders, Kirby, & Spradlin, 1988; Stromer, 1986). When performance-specific reinforcement contingencies for the D stimuli were reversed, subsequent probe results showed that the stimulus class membership of those stimuli also reversed. This result strongly supports a conclusion that D stimulus class membership depended on specific stimulus-reinforcer relations. The reversal procedure used here can be contrasted with the more typical control for stimulus-reinforcer relations wherein stimuli and reinforcers are randomly (procedurally) associated (Rescorla, 1967). One may ask whether the latter may offer an advantage, that of demonstrating conditions under which reinforcers do and do not become class members. The random control condition is not straightforward in matching-to-sample contexts, however. In the present experiment, for example, it would require correct selections of D1 or D2 on identity-matching trials to be followed equally often by R1 and R2 (cf. Litt & Schreibman, 1981). Such nonspecific contingencies would provide no ba-

Fig. 4. Results of probe sessions for Subjects PN and JDB following reversal of specific reinforcement contingencies for D stimuli on baseline trials. Each bar represents the percentage of probe responses that was consistent with stimulus class formation (see text). Letters below each bar show the emergent performance tested (sample comparison). Numbers in parentheses below each bar show the number of probe trials for each performance. Bars divided in two show results of the first half (left portion) and second half (right portion) of the probe trials. See text for details.

sis for selection on subsequent probe trials—trials which nonetheless demand some response. Consistent conditional behavior could emerge based on primary stimulus generalization or arbitrary assignment. However, the random condition could be very useful in analyzing stimulus classes that were defined originally by performance-specific reinforcement contingencies. Also, a design that included both (a) alternation of specific and nonspecific reinforcement conditions and (b) repeated reversals of specific reinforcement contingencies may be useful for the analysis of stimulus class membership that is conditional upon prevailing stimulus-reinforcer relations.

The present study also defined more precisely the classes established via the performance-specific reinforcement procedure. Our previous study did not document the formation of equivalence classes, because the use of auditory stimuli in training precluded some tests necessary to document equivalence according to criteria outlined by Sidman and Tailby (1982); the use of all-visual stimuli in the present study permitted the full complement of tests, as follows. Typical stimulus-equivalence

research has used matching-to-sample methods to show that the relations (r) among class members possess the logical properties of reflexivity (e.g., ArA), symmetry (e.g., if ArB , then BrA), and transitivity (e.g., if ArB and BrC , then ArC). According to these criteria, the A-B-C classes were clearly equivalence classes. Both subjects displayed generalized identity matching with the experimental stimuli, a test of reflexivity. Both subjects given AB and BC training then proved immediately capable of BA and CB performances, tests of symmetry. The same training also established the basis for the AC performance, a test of transitivity, and its symmetric counterpart, CA.

Were the D stimuli also members of the equivalence classes? Apparently, they were. Generalized DD identity matching demonstrated reflexivity. Although no arbitrary-matching performances involving the D stimuli were trained directly, the emergent matching performances indicate stimulus equivalence. All relations between the D stimuli and the A-B-C class members were symmetric. No cases were seen in which, for example, ArD did not imply DrA . Further, the relations were always transitive. No cases were seen in which, for example, ArB and BrD did not imply ArD .

Given the preceding facts, one is led next to ask about the status of the reinforcers R1 and R2 in the A-B-C-D equivalence classes. Some status must be inferred, because D stimulus-class membership depended on relations with those reinforcers. Because reinforcers were never displayed as sample or comparison stimuli, the usual tests for equivalence were not possible. Nonetheless, it may be meaningful to infer that the reinforcers were also members of the equivalence classes. The inferential path parallels that for combined tests of symmetry and transitivity in sample-comparison relations (Sidman & Tailby, 1982). Such tests examine the status of, for example, BC and CB relations after the AB and AC relations are established by direct training. Emergence of the transitive BC performance requires ArB symmetry: If BrA (ArB symmetry) and ArC (established by the training contingencies), then BrC (transitivity). Similarly, emergence of CB requires ArC symmetry: if CrA (ArC symmetry) and ArB (established by the training contingencies), then CrB (transitivity). Note that these tests never present the A stimuli as

comparison stimuli; BrA and CrA relations are derived from the emergence of BC and CB performances. Now consider the emergent AD and DA conditional performances in the present experiment. The relevant history was, of course, the relations of the A and D stimuli with the performance-specific reinforcers (R). One may express these as relations ArR and DrR . By the logic of transitivity, the AD performance seems to require relations ArR and RrD (the symmetric counterpart of the directly conditioned DrR). By the same reasoning, the DA performance would seem to require relations DrR and RrA (the symmetric counterpart of the directly conditioned ArR). Thus, the emergence of AD and DA performances indicates that the ArR and DrR were both symmetric and transitive; similar cases may be made with respect to BrR and CrR in relation to DrR . Viewed in this way, the stimulus-reinforcer relations meet the requirements for equivalence relations, even though the reinforcers never appeared as matching-to-sample stimuli.

One implication of stimulus-reinforcer equivalence relations is that they might have provided a sufficient basis for all of the emergent arbitrary-matching performances that we observed. Applying the reasoning outlined in the preceding paragraph, the AA, BB, CC, and DD identity-matching performances and the specific consequences by themselves might have established the A-B-C-D classes; the AB and BC training might have been redundant. However, one can argue plausibly that AB and BC training might have been critical to the emergent arbitrary-matching performances, including those that involved D stimuli. It is possible that it was necessary to establish the A-B-C equivalence classes first and only then could the D stimuli be added via the stimulus-reinforcer route. It is also possible that the AB and BC training was necessary because it established the arbitrary-matching context. Had the subjects experienced only identity matching with specific consequences, then the probe trials would for the first time display samples and comparison stimuli that were all physically dissimilar from one another. (This second possibility might indicate only the need for a recent history of arbitrary matching with any stimuli, and not necessarily with those used for the experimental tests.) Further study will be necessary to clarify these issues.

Mackay and Sidman (1984) have suggested that studies of stimulus classes and equivalence relations can help in formulating an account of some types of linguistic processes. The present line of inquiry may prove relevant to this enterprise, because of a possibly important parallel with functional analysis of verbal behavior (Skinner, 1957). We refer to the distinction between mands and tacts. A mand characteristically specifies its consequences (e.g., "Give me water"), but the tact does not (e.g., "That's water"). Our work suggests that equivalence-class membership can be based on common relations with specific consequences. Do such classes differ qualitatively from those established with nonspecific reinforcement procedures? If so, behavioral processes underlying the reported functional independence of mands and tacts (Lamarre & Holland, 1985) might be amenable to analysis with conditional-discrimination procedures. Moreover, stimuli can be members of different classes in different contexts (cf. Lazar & Kotlarchyk, 1986; Wulfert & Hayes, 1988). It seems possible that a member of a class defined by specific consequences could at other times be a member of a class that was not so defined. If so, then analyses of processes underlying functional interdependence of mands and tacts (Skinner, 1957, p. 188) would also be feasible.

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