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AUDITORY SUCCESSIVE CONDITIONAL DISCRIMINATION AND AUDITORY STIMULUS EQUIVALENCE CLASSES

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This paper describes an experimental demonstration of stimulus equivalence classes consisting entirely of auditory stimuli. Stimuli were digitized arbitrary syllables (e.g., "cug," "vek") presented via microcomputer. Training and testing were conducted with a two-choice auditory successive conditional discrimination procedure. On each trial, auditory samples and comparisons were presented successively. As each comparison was presented, a response location (a rectangle) appeared on the computer screen. After all stimuli for a trial were presented, subjects selected one of the response locations. Six subjects acquired the conditional discrimination baseline, 4 subjects demonstrated the formation of three-member auditory equivalence classes resulting from sample-S+ relations, and 1 subject demonstrated equivalence classes resulting from sample-S− relations. Four subjects received additional training and subsequently demonstrated expansion of the three-member classes to four members each.

Key words: auditory stimulus control, conditional stimulus control, successive discrimination, stimulus equivalence, screen touch, button push, humans

Sidman and Tailby's (1982) analysis of stimulus equivalence has been applied to data generated by several variations of matching-to-sample procedures (e.g., D'Amato, Salmon, Loukas, & Tomie, 1985; Dube, McIlvane, Maguire, Mackay, & Stoddard, 1989; Fields, Reeve, Adams, & Verhave, 1991; Hayes, Thompson, & Hayes, 1989; McIntire, Cleary, & Thompson, 1987; Pilgrim & Galizio, 1990; Saunders, Saunders, Kirby, & Spradlin, 1988). Sidman and Tailby proposed that conditional stimulus–stimulus relations are shown to be relations of equivalence if they exhibit the properties of reflexivity, symmetry, and transitivity. Sidman and Tailby also suggested behavioral tests for these properties that could be conducted in the context of a matching-to-sample baseline. Reflexivity is evaluated by tests for generalized identity matching; that is, matching each stimulus to itself (A to A, B to B, etc.) without explicit training. Symmetry is evaluated by tests for functional sample–comparison reversibility; that is, if AB matching (selecting comparison stimuli from Set B conditionally upon sample stimuli from Set A) is trained, then BA matching is tested. Transitivity tests require three sets of stimuli. If AB and BC matching are trained, for example, then transitivity is documented by tests for AC matching. When all three properties are demonstrated, relations of equivalence are shown to exist. Sets of stimuli related by equivalence are often referred to as equivalence classes.

Equivalence research has employed a wide variety of stimuli. Most often, studies have used auditory stimuli (e.g., dictated words) and visual stimuli (e.g., two-dimensional forms) that may be familiar (e.g., English names, representational pictures, and printed words; Sidman, 1971) or unfamiliar (e.g., Greek letters and their spoken names; Sidman, Willson-Morris, & Kirk, 1986) to subjects. Several recent studies have shown that equivalence methods can be extended to a broader range of auditory and visual stimuli. For example, Hayes and colleagues established equivalence classes whose members were letters of the alphabet, positions on a musical staff, piano keys, and specific fingers of the subject's hand (Hayes et al., 1989); Mackay and Ratti (1990) demonstrated classes that included positions on a

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matrix; and Dube and colleagues have investigated conditions under which reinforcing stimuli may become equivalence class members (Dube et al., 1989). Equivalence methods have been extended beyond auditory and visual stimuli to classes that also include gustatory stimuli (Hayes, Tilley, & Hayes, 1988).

To date, every demonstration of equivalence has included visual stimuli in the classes. The primary goal of the present experiment was to determine whether the equivalence formulation is applicable to conditional stimulus–stimulus relations that do not involve visual stimuli. A demonstration of equivalence classes consisting solely of auditory stimuli would extend the generality of Sidman and Tailby's (1982) analysis.

Methodological Issues

Our attempt to demonstrate auditory equivalence classes required a procedure suitable for establishing and evaluating conditional relations among auditory stimuli. Several intuitively reasonable procedures were rejected for this initial study because of potential complications in their adaptation for equivalence research. A brief discussion of some of those complications will serve as an introduction to and rationale for our procedure selection. For convenience, stimuli will be referred to as samples and comparisons, where "sample" refers to the first stimulus presented on each trial.

One type of procedure is a straightforward substitution of auditory stimuli for visual ones in delayed matching to sample. On each trial, an auditory sample stimulus is followed by auditory comparison stimuli presented simultaneously or in rapid alternation in different locations (e.g., Herman & Gordon, 1974). Although the trial sequence resembles that of visual matching to sample, the procedure imposes additional response requirements for the localization of stimuli, and it may result in interference or distortion of simultaneously presented stimuli. For this reason, we elected to use a successive conditional discrimination procedure with a single sound source.

"Go/no-go" procedures present two stimuli on each trial, one sample and one comparison (e.g., D'Amato & Colombo, 1985). For each sample, some trials present the correct comparison and responses are reinforced, and other trials present the incorrect comparison and responses are extinguished. For example, subjects trained to perform AB matching (selecting comparison stimuli B1 and B2 conditionally upon sample stimuli A1 and A2, respectively) might press a response key within 3 s on trials presenting A1-B1 or A2-B2 and not press for 3 s on trials presenting A1-B2 or A2-B1. Such procedures, however, may pose problems for equivalence tests in which performances with novel combinations of stimuli must be evaluated without differential consequences. For example, long response latencies have been observed on equivalence probe trials, particularly in the early stages of testing (Saunders, Wachter, & Spradlin, 1988). With go/no-go procedures, a potential measurement problem arises because no-go responses are recorded on trials in which response latencies exceed a certain value.

"Go-left/go-right" or "yes/no" variants of go/no-go procedures require a response on every trial (e.g., D'Amato & Worsham, 1974). For example, on trials presenting the sample and one comparison (e.g., A1 and B1), pressing a key on the right is reinforced; on trials with the sample and the other comparison (A1 and B2), pressing a key on the left is reinforced. AB training would establish the following (sample-comparison-correct key): A1-B1-right, A1-B2-left, A2-B2-right, A2-B1-left. Similarly, BC training would establish B1-C1-right, B1-C2-left, B2-C2-right, B2-C1-left. Go-left/go-right procedures, however, seem unsuitable for evaluating transitive properties of conditional relations because such training provides an explicit history of reinforcement for responses following all sample–comparison relations. To continue the example, responses to the left, the right, or both keys could be predicted on AC transitivity tests: On a trial that presented A1-C1, the training history of A1-B1-right and B1-C1-right would predict a response to the right (if A1-B1 and B1-C1, then A1-C1), whereas the A1-B2-left and B2-C1-left history would predict a response to the left (if A1-B2 and B2-C1, then A1-C1).

The present experiment was conducted with a modified successive conditional discrimination procedure (cf. Wasserman, 1976). Although the trial sequence was more elaborate than any of those outlined above, the procedure offered the advantages of (a) presenting auditory stimuli successively and individually to maximize discriminability, (b) requiring a response on every trial, and (c) allowing imple-

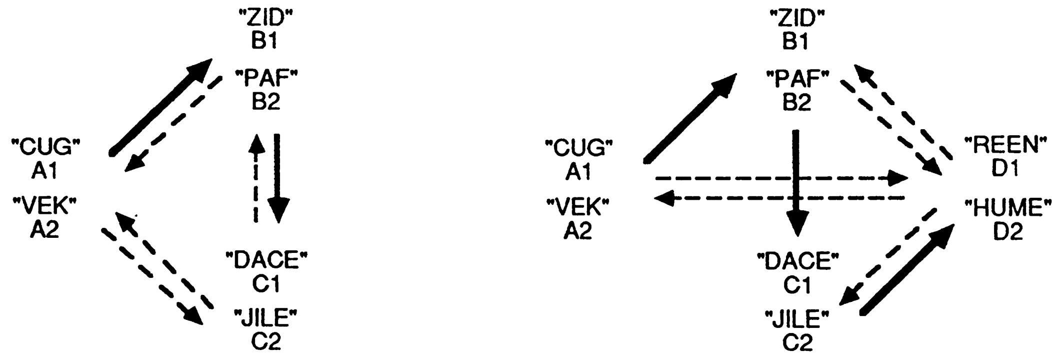

Fig. 1. Equivalence paradigm for the present experiment. The stimuli were digitized spoken words presented to the subject via computer. Solid arrows represent conditional relations that were explicitly taught. Broken arrows represent conditional relations that were tested after the others had been explicitly taught. The left portion shows initial training and testing. The right portion shows class-expansion training and testing.

mentation and interpretation of the full range of tests specified by Sidman and Tailby's (1982) equivalence paradigm. Thus, a secondary goal of the present study was to determine whether Sidman and Tailby's equivalence methods could be extended to a successive conditional discrimination procedure.

METHOD

An overview of the experimental design is presented in Figure 1. Subjects were trained to perform the conditional discriminations indicated by solid arrows in the left portion of the figure: to select B1 and B2 conditionally upon A1 and A2, respectively (AB), and to select C1 and C2 conditionally upon B1 and B2, respectively (BC). Test trials presented the conditional discriminations indicated by dashed arrows (CA, AC, BA, and CB), as well as reflexivity tests AA, BB, and CC (not shown in Figure 1). Subjects whose test results indicated the formation of three-member A-B-C equivalence classes were given the additional training (CD) and testing (DA, AD, DB, BD, CD) shown in the right portion of Figure 1.

Subjects

Seven normally capable subjects participated. Subjects ACM (female [f], chronological age 26) and FDK (f, 26) were employed as a teacher and administrative specialist, respectively, at a residential school for children with developmental disabilities. Subject NBR (f, 34) was an artist employed as a computer-graphic design and layout specialist. LWJ (f, 28) was a research technician in an area unrelated to behavior analysis or discrimination learning. SDN (male [m], 29) was an undergraduate student who participated as part of a summer independent study project. DYB (m, 15) and ZVR (m, 16) were high school students.

Apparatus and Stimuli

The apparatus was an Apple Macintosh® computer fitted with a MicroTouch® touch-sensitive screen (Dube & McIlvane, 1989). The Macintosh's audio output was connected to a small amplified speaker (Radio Shack MPS5) placed on the table next to the computer. Computer software controlled all stimulus presentations, procedural sequences, and response recording.

Stimuli were spoken arbitrary syllables, digitized and saved in disk-based files with a MacRecorder® digitizer and SoundEdit® software (Farallon Computing, 1989). Stimuli will be referred to by the letter-number designations shown in Figure 1.

Procedure

Experimental sessions were conducted in a quiet room. The apparatus was placed on a table before the subject. The experimenter remained in the room, behind the subject, for the first two to five trials of each session; thereafter, subjects completed the sessions alone. Session durations ranged from 13 to 139 min, with the majority between 30 and 60 min. Subject ACM had five sessions with a total of 196 min of contact with the experiment; FDK had six sessions, 202 min; NBR had five sessions, 141 min; LWJ had seven sessions, 274 min; SDN had four sessions, 214 min; DYB had eight sessions, 317 min; and ZVR had two sessions, 239 min.

Response definition. Subjects ACM and FDK responded by touching the computer's screen. The other subjects used the Macintosh mouse and responded by moving an on-screen cursor to the desired location and pressing the mouse button. For convenience, both types of responses will be referred to as "touching."

Auditory successive conditional discrimination. Auditory stimuli will be referred to as "samples" and "comparisons." One sample and two comparisons were presented on each trial, as in two-choice matching to sample. Although the two-choice procedure maximized the potential for variations in stimulus control (Carrigan & Sidman, 1992; Sidman, 1987), it was used for this initial study because it required subjects to remember a minimal number of successively presented stimuli per trial.

The successive conditional discrimination procedure is illustrated in Figure 2. Every trial included four auditory stimulus presentations, two of the sample and one of each comparison. Prior to each presentation, a round white spot 2.3 cm in diameter was displayed in the center of the screen. Each time the subject touched the white spot (hereafter called a key), it disappeared and an auditory stimulus was presented. The sample was presented first (Figure 2A), followed by one of the comparisons (Figure 2B). Then, to minimize the requirements for remembering that are inherent in successive discrimination procedures, the sample was repeated (Figure 2C), and it was followed by the other comparison (Figure 2D). As each comparison stimulus was presented, a gray rectangle (5.4 cm by 3.6 cm) was displayed in the upper left or right portion of the screen for 0.5 s. Following presentation of the second comparison, both rectangles (hereafter called keys) were presented simultaneously and remained displayed until the subject touched one of them (Figure 2E). During 1.5-s intertrial intervals (ITIs), no response keys were displayed (Figure 2F). One comparison was designated correct for each sample. Across trials, the sample presented, order of correct comparison presentation (first or second), and correct comparison response-key position (left or right) were counterbalanced and pseudorandom, with the restrictions that the same sample was not presented, and the response key on the same side was not correct, for more than three consecutive trials. Because of the counterbalancing, the visual stimuli (the left and right response keys) were irrelevant to the conditional discrimination.

Consequences. In *feedback* conditions, each experimentally defined correct response was followed by a computer beep and a 1-point increment of the score displayed in a window (3.5 cm by 1.8 cm) centered at the bottom of the screen (shown in Figure 2). Incorrect responses were followed only by the ITI. A correction procedure was in effect; if the subject made an error, the trial was repeated after the ITI.

In *no-feedback* conditions, the score was not displayed on the screen and no beeps sounded; all trials were followed only by the ITI. Before the first no-feedback condition, the following message was displayed on the screen: "In the next part of the experiment there will be times when you won't be able to see the score and you won't get any feedback after each selection. However, you will still earn points as before. Press the mouse button to continue." Following no-feedback conditions, the computer increased the score by an amount equal to 1 point for each correct response on baseline trials plus 1 point for every probe trial (except briefly for subjects FDK and ACM, see Discussion; see also stimulus equivalence tests, below) and displayed the score on the screen. The correction procedure was discontinued in no-feedback conditions.

After sessions, all subjects (except SDN) were paid at a rate of either $5.00 per hour or 1.5 cents per point, whichever was greater. Following his third session, Subject DYB approached the experimenter and negotiated an increase to $5.00 per hour plus 1 cent per point for subsequent sessions. Subject SDN received independent study course credit for participation.

Initial instructions to subjects. At the beginning of the first session, the following message was displayed on the computer screen:

> In this experiment, a white circle will appear on the screen. Each time it appears, touching it will produce a recorded sound. Then, you will have a choice between two gray squares. Touching one of the squares will earn a point, but touching the other square will earn nothing.

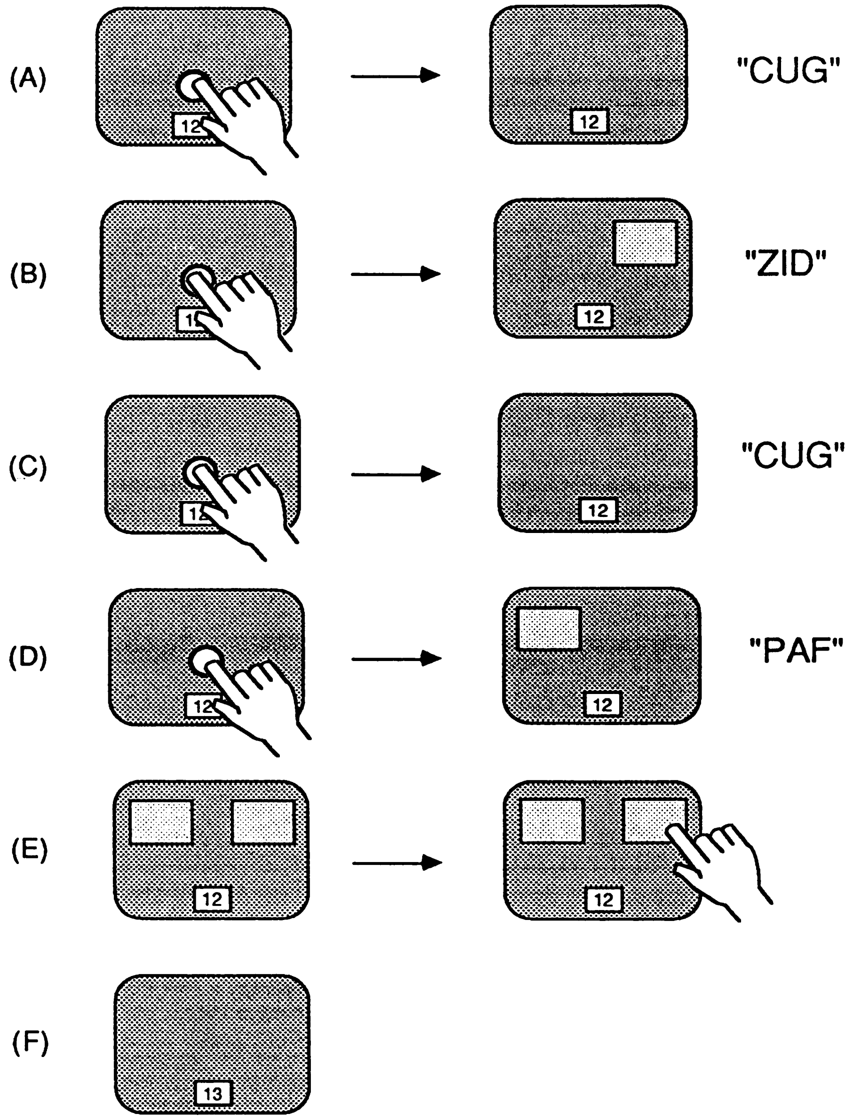

Fig. 2. The auditory successive conditional discrimination procedure; the example shown is an A1-B1 trial. The trial began when a white circular key appeared on the screen. When this white key was touched (A), it disappeared and the sample was presented. The white key then reappeared and the second touch (B) was followed by presentation of the first comparison and one rectangular gray response key. The third touch to the white key (C) was followed by a repetition of the sample. The fourth touch to the white key (D) was followed by presentation of the second comparison and the other response key. Finally, both response keys were presented together (E). A touch to the response key that was presented with the correct comparison (E, right) was followed by a beep and a 1-point increment of the score that was displayed in a small window at the bottom of the screen. A touch to the incorrect key (not shown) was followed only by the ITI. See text for further details.

The window at the bottom of the screen will show you how many points you have earned. Later, you will be paid at a rate of 1.5 cents per point. Press the mouse button to continue.

Baseline training. Conditional discrimination training was conducted with differential reinforcement contingencies (i.e., "trial and error") to an acquisition criterion of 16 consecutive correct responses. First, subjects were trained to perform the AB discrimination, that is, to touch the response keys paired with comparisons B1 and B2 on trials that presented samples A1 and A2, respectively (see Figure

1). Then, the BC discriminations were trained. Next, AB and BC trials were intermixed by alternating blocks of 16 trials of each, then blocks of eight trials, and finally irregular alternation of trial types within blocks of 16 trials to produce the AB/BC baseline. If accuracy fell below 93% (less than 15 of 16 or 8 of 8) during this phase of training, the inaccurate discrimination was repeated in blocks of 16 trials until accuracy recovered.

Subjects who did not meet the AB acquisition criterion within 400 trials with differential reinforcement were given AB training with a stimulus-control shaping procedure that manipulated the availability of the incorrect response key (Bush, Sidman, & de Rose, 1989; Dube et al., 1989; cf. McIlvane & Dube, 1992; Terrace, 1963). The procedure was the same as before with one exception: After both response keys were presented at the end of the trial (Figure 2E), the key paired with the incorrect comparison disappeared, leaving only the correct key available for a response. Initially, the incorrect key was displayed for 0.1 s. Thereafter, the incorrect key's display duration increased on the trial following a correct selection and decreased on the trial following an error. When the duration was 2.0 s or less, the increase or decrease was 30% of the current value (with a lower limit of 0.1 s); when duration exceeded 2.0 s, the increase or decrease wa a constant 0.5 s per trial. The acquisition criterion was 16 consecutive correct responses prior to the disappearance of the incorrect key.

Subject LWJ, who failed to meet the AB acquisition criterion with differential reinforcement or the shaping procedure, was given printed instructions prior to continued training with differential reinforcement contingencies. The instructions were presented on the computer screen, and the experimenter asked her to read them aloud: "If 'CUG' is the first word you hear, then select the square that appears with 'ZID.' If 'VEK' is the first word you hear, then select the square that appears with 'PAF.' "

Stimulus equivalence tests. After meeting the 93% accuracy criterion with the AB/BC baseline in both feedback and no-feedback conditions, subjects were given a series of tests for equivalence class formation. All subjects received a minimum of nine tests given in the following order: CA (combined symmetry and transitivity), AC (transitivity), BA, CB (symmetry), AA, BB, and CC (reflexivity), followed by a repetition of the first four tests. CA, AC, BA, and CB tests consisted of eight probe trials interspersed among 16 baseline trials, all with no feedback. The reflexivity test consisted of four probe trials each of AA, BB, and CC interspersed among 16 baseline trials, all with no feedback. Prior to every test, the AB/BC baseline was reviewed in a block of 16 trials with feedback; if necessary, this review was repeated until the subject met the 93% accuracy criterion.

Class-expansion training and testing. Subjects who demonstrated the formation of A-B-C equivalence classes were given additional training and testing to expand the classes to include new stimuli (as in Sidman & Tailby, 1982). Subjects learned to perform the CD discrimination (see Figure 1), and then CD trials were intermixed with AB/BC baseline trials by alternating blocks of 16 and eight trials in a manner analogous to that described above. When AB/BC/CD baseline accuracy was at least 93% without feedback, subjects were given 10 tests in the following order: DA, DB (combined symmetry and transitivity), AD, BD (transitivity), DC, and DD (symmetry and reflexivity), followed by repetition of the first five tests. DA, DB, AD, BD, and DC tests consisted of eight probe trials interspersed among 16 AB/BC/CD baseline trials, all without feedback; the DD test consisted of four probe trials added to the first DC test. As in previous testing, the AB/BC/CD baseline was reviewed in a block of 16 trials with feedback before every test.

RESULTS

Baseline Training

Table 1 shows the number of trials required to meet the acquisition criterion (16 consecutive correct selections) for AB and BC successive conditional discriminations. With exposure to differential reinforcement contingencies, Subjects ACM, FDK, SDN, and ZVR all met the AB criterion; DYB, NBR, and LWJ responded at chance accuracy levels for 400 trials.

Subjects DYB, LWJ, and NBR were given AB discrimination training with the stimulus shaping procedure. DYB met the acquisition criterion in 176 trials, and then went on to do so with the BC discrimination in 19 trials with

Table 1
Number of training trials for AB, BC, and CD discriminations.

Discrim	Subject ACM	FDK	SDN	ZVR	DYB	NBR	LWJ
AB	48	206	27	20	400[a]	400[a]	400[a]
					176[b]	440[b]	144[b]
							16[c]
BC	17	36	21	16	19		19
CD	17		20	17			20

[a] Subject did not meet acquisition criterion with differential reinforcement.
[b] Stimulus shaping procedure.
[c] Printed instructions.

differential reinforcement only. Subjects NBR and LWJ did not meet the criterion in 440 and 144 trials, respectively, and NBR elected to withdraw from the experiment at that point.

LWJ was given the printed instructions ("If 'CUG' is the first word you hear . . ."), and she met the AB acquisition criterion without error in 16 trials. She met the BC acquisition criterion in 19 trials without instructions.

Following AB and BC acquisition, all subjects (except DYB) were virtually errorless in the transition from separate blocks of AB and BC trials to the AB/BC baseline and subsequent baseline testing with no feedback. On DYB's first block of AB trials following BC acquisition, accuracy fell to 3 of 16 correct and then improved to 14 of 16 and 15 of 16 as the AB block was repeated twice. As alternating blocks of AB and BC trials continued, it was necessary to repeat blocks six times because of failures to maintain accuracy of at least 93%. His performance became reliably accurate after 12 blocks of trials, and he was errorless for the final three blocks of AB, BC, and mixed AB/BC trials. DYB was also errorless on his first test of the AB/BC baseline without feedback.

Stimulus Equivalence Tests

For convenience, equivalence test results will be characterized as positive or negative, where positive refers to tests with at least seven of eight probe responses consistent with equivalence classes A1-B1-C1 and A2-B2-C2. According to this criterion, positive outcomes were obtained with 4 of the 6 subjects who received equivalence tests.

Figure 3 shows that all test results for Subject ACM were positive, and that those for ZVR were positive with one exception. Results for Subjects SDN and LWJ became consistently positive with the third test, a test for BA symmetry. Accuracy on AB/BC baseline trials remained above 90% correct throughout testing for these 4 subjects.

Subject DYB's test results did not document equivalence. All CA, AC, and BA tests were negative. CB symmetry tests were positive in Tests 4, 9, and 11, but were negative in Test 15. Reflexivity test results were negative in Test 5 and became positive in Test 10. Accuracy on no-feedback AB/BC baseline trials began to deteriorate during Test 15. Following Test 16, accuracy scores on baseline review trials with feedback did not meet the criterion for continued testing (15 of 16) for three consecutive blocks of 16 trials. At that point, DYB withdrew from the experiment.

Subject FDK's data may be summarized in three phases. The first phase included Tests 1 through 8. Figure 3 shows that accuracy on no-feedback baseline trials during these tests remained perfect, symmetry tests were positive, and CA, AC, and reflexivity tests were perfectly negative (0 of 8 and 0 of 12). In the second phase (Tests 9 through 15), both no-feedback baseline accuracy and test results were highly variable. For example, baseline accuracy was 14 of 16 correct in Test 12 (CA) but fell immediately to 3 of 16 in Test 13 (BA). As another example, in AC Test 11, baseline accuracy was high (15 of 16) and probe responses were negative (2 of 8); however, in the next AC test (Test 15), baseline accuracy was 0 of 16 correct and probe responses were perfectly positive (8 of 8). In the third phase (Tests 16 through 19), FDK touched the right-hand response key on virtually all baseline and probe trials. The experimenter ended her participation at this point because of the consistent

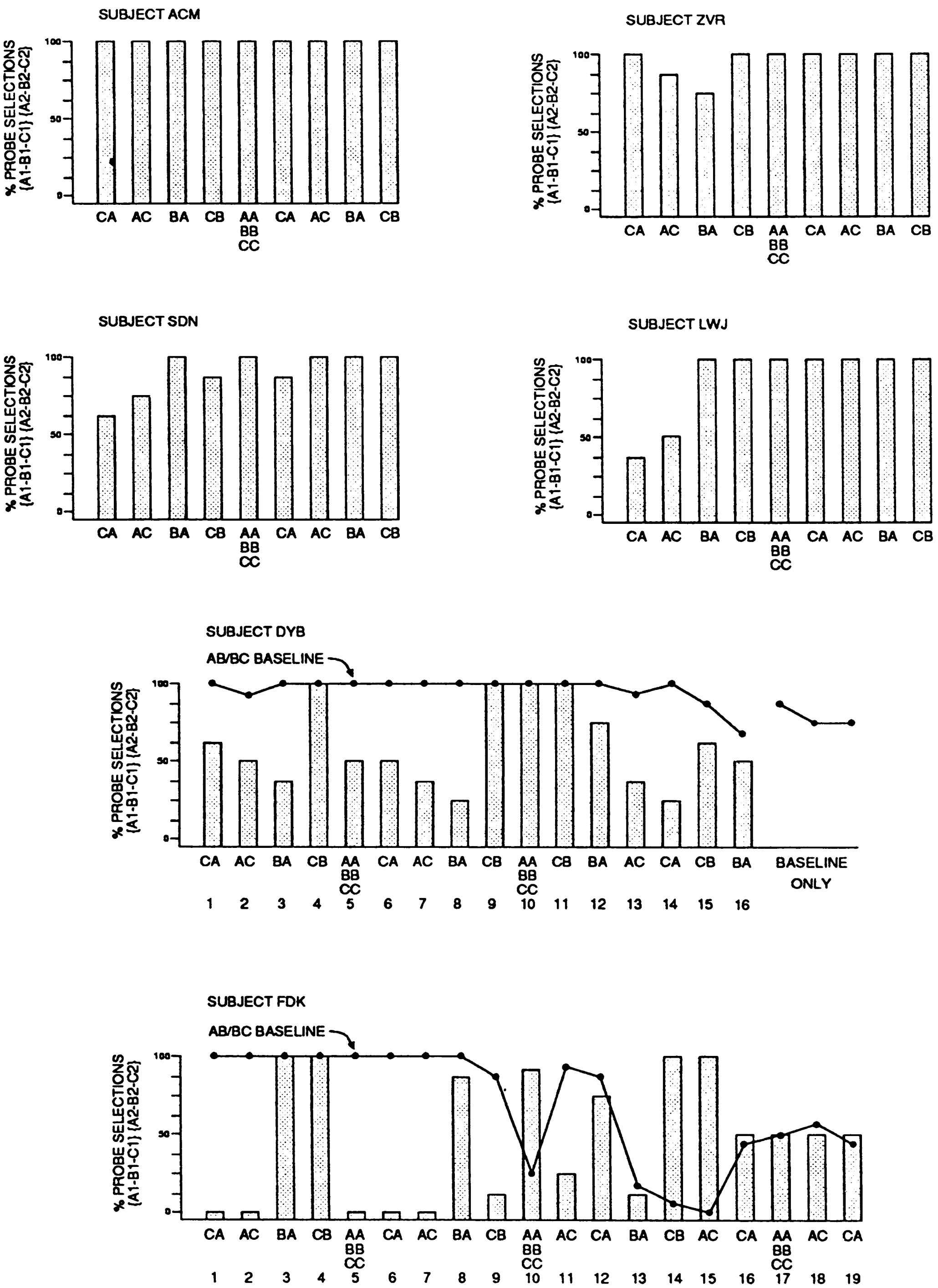

Fig. 3. Gray bars show the percentage of responses on test trials consistent with equivalence classes A1-B1-C1 and A2-B2-C2. Bars labeled AA BB CC show results of 12 probe trials; all other bars show results of eight probe trials. For Subjects DYB and FDK, points show percentage correct on the 16 no-feedback baseline trials in each test; the final three points for DYB show percentage correct in blocks of 16 baseline trials with feedback.

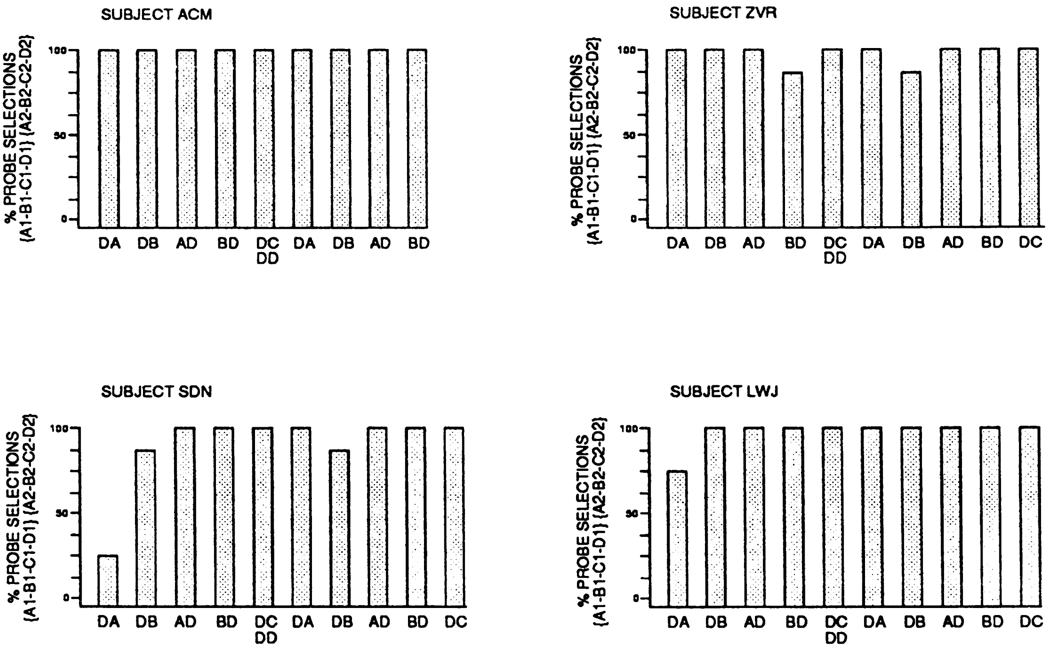

Fig. 4. Percentage of responses on test trials consistent with equivalence classes A1-B1-C1-D1 and A2-B2-C2-D2. Bars labeled DC DD show results of 12 probe trials; all other bars show results of eight probe trials.

and apparently stable position preference. Notably, throughout all testing, FDK's accuracy remained virtually perfect on the blocks of 16 baseline trials with feedback that preceded every test.

Class-Expansion Training and Testing

Table 1 shows that Subjects ACM, ZVR, SDN, and LWJ all acquired the CD discrimination rapidly with differential reinforcement. Figure 4 shows that probe results for all 4 subjects documented expansion of the three-member classes established earlier to four members each: A1-B1-C1-D1 and A2-B2-C2-D2. Subjects ACM and ZVR's probe responses were positive immediately, and SDN and LWJ's became positive in the second test.

DISCUSSION

Results of this experiment extend the generality of Sidman and Tailby's (1982) stimulus equivalence methodology by providing an experimental demonstration of equivalence classes consisting entirely of auditory stimuli. Visual stimuli (the response keys) controlled aspects of response topography only. The left and right positions of the response keys were irrelevant to the conditional discrimination, and thus they were not members of the equivalence classes.

Subjects ACM, SDN, ZVR, and LWJ

Equivalence test results for Subjects ACM and ZVR were immediately consistent with equivalence classes A1-B1-C1 and A2-B2-C2. For SDN and LWJ, results of the initial CA and AC tests were negative, the symmetry tests BA and CB that followed were positive, and then CA and AC were positive when they were retested. A similar outcome was reported by Sidman et al. (1986): Following DE and DF training with all-visual stimuli, several subjects failed initial combined tests for symmetry and transitivity, EF and FE. After those subjects had passed symmetry tests ED and FD (or, in one case, ED and FD discriminations were trained explicitly), they then passed the combined tests. On class-expansion tests in the present experiment, data for SDN and LWJ showed a similar pattern in the early two- and one-node tests (Fields, Verhave, & Fath, 1984). The initial two-node DA test was negative, the one-node DB test that followed was positive, and then the two-node AD test and all subsequent tests were positive. Similar findings were reported by Sidman and Tailby (1982) and Sidman, Kirk, and Willson-Morris (1985). Thus, data from all-auditory equivalence tests for 2 subjects in the present experiment are consistent with previous interpretations of initial failures to document equivalence as due to missing prerequisites (Sidman et al., 1985, 1986). The present data also seem consistent with analyses of nodal distance effects (Fields, Adams, Verhave, & Newman, 1990).

Intersubject differences in AB training history appear to be unrelated to differences in initial equivalence test performances. Subjects ACM, SDN, and ZVR all met the AB acquisition criterion following exposure to the initial instructions and trial-and-error training, but initial equivalence tests were positive for ACM and ZVR and negative for SDN. Also, results for LWJ and SDN were similar, although LWJ was given instructions describing specific stimulus–stimulus relations ("If CUG . . . then select . . . ZID," etc.) and SDN was not (cf. Green, Sigurdardottir, & Saunders, 1991).

Subject DYB

Results of Subject DYB's tests for reflexive, symmetric, and transitive properties of the AB and BC conditional relations were either negative or inconsistent, although baseline performance remained accurate for 14 test blocks. Apparently, his baseline performance was controlled by "if . . . then" conditional relations that were not relations of equivalence (Carter & Werner, 1978; Sidman & Tailby, 1982). DYB was the only subject with this pattern of results. Two aspects of DYB's training history differed from those of the other subjects: He was the only subject to meet the AB acquisition criterion with the stimulus-control shaping procedure after failure with differential reinforcement, and he was the only one to make a substantial number of errors when AB and BC discriminations were first presented within the same block of trials. DYB's data raise questions for further study: Is there a relation between failures to demonstrate equivalence and (a) different types of training procedures or (b) performance stability as the complexity of the baseline increases?

Subject FDK

FDK's initial probe results (Tests 1 through 8) are consistent with Carrigan and Sidman's (1992) analysis of a conditional discrimination stimulus-control topography in which the controlling stimulus–stimulus relation involves the sample and the S−, that is, the comparison that is not touched. For example, on a trial with sample A1 and comparisons B1 and B2, the subject can satisfy the reinforcement contingencies by "rejecting" B2 (e.g., McIlvane, Withstandley, & Stoddard, 1984; Sidman, 1987). In such a case, stimulus control involves A1 and B2, even though the subject touches the response key that was presented with B1. If this sample-S− or "reject" relation (×) controlled AB and BC baseline training, then the performance may be described as follows: A1 × B2, that is, given sample A1, then reject B2 and touch the key that appeared with B1; A2 × B1, that is, given sample A2, reject B1 and touch the key that appeared with B2; and so forth for B1 × C2 and B2 × C1. Further, if the "reject" relation was one of equivalence, then the following examples of test outcomes would be predicted: On a reflexivity test, A1 × A1; that is, if sample A1, then reject comparison A1 and touch the key that appeared with A2. On a symmetry test, if A2 × B1 then B1 × A2; that is, given sample B1, reject comparison A2 and touch the key that appeared with A1. On a transitivity test, if A1 × B2 and B2 × C1, then A1 × C1; that is, given sample A1, reject C1 and touch the key that appeared with C2. On a combined test, if C1 × B2 (symmetry) and B2 × A1 (symmetry), then C1 × A1; that is, given sample C1, reject A1 and touch the key that appeared with A2. Test outcomes would be the same as those for sample-S+ ("select") relations on symmetry tests and completely reversed on reflexivity, transitivity, and combined symmetry-and-transitivity tests; this pattern describes FDK's probe results in Tests 1 through 8. Her data support a conclusion that baseline training established equivalence classes defined by sample-S− ("reject") relations; these classes were A1-B2-C1 and A2-B1-C2. This conclusion brings the total number of subjects displaying auditory equivalence classes to 5.

After the final experimental session, subjects were asked to complete a written questionnaire that included the following: "If you made up any rules, please quote them here." Although such postexperimental reports cannot be taken as accurate descriptions or explanations of within-session behavior (e.g., Perone, 1988; Shimoff, 1986), we note that FDK's answer to this question was consistent with the sample-S− analysis. She wrote, "The 'Z' sound [B1] was paired with the 'J' [C2] and another 'Z' sound [A2, which she called 'zek']. The 'C' [A1] and 'P' [B2] were paired, as was the 'P' [B2] and 'D' sound [C1]. Choose the opposite of the above rule when the score was shown. When the score was hidden choose the right side only." In a subsequent interview, FDK was asked, "What did you mean when you wrote 'choose the opposite'?" She pointed to the first portion of her written answer quoted above and said, "If the left side was one of these pairs [A1-B2, B2-C1, A2-B1, B1-C2] then I chose the opposite side, the right side. If the right side was a pair, then I chose the left."

A final point on FDK's data concerns a possible reason for the change in probe responding following Test 8. In her postexperimental interview, she was asked "Did you always choose the right side when the score was hidden?", and she answered, "Early on, I applied this rule [indicating her written answer 'choose the opposite'] when the score was hidden, but I didn't get all the points so I went to the right side only." Her comments referred to a programming error in the score display for her and Subject ACM, who were the first 2 participants. Following probe blocks, the amount added to the score was equal to the number of correct baseline trials but did not include a point for each probe trial. This error was corrected for all other subjects.

Implications for Further Study

The present results indicate that conditional stimulus–stimulus relations established by a successive auditory conditional discrimination procedure may meet Sidman and Tailby's (1982) criteria for relations of equivalence. One area for further study is continued extension of the range of procedures that will produce equivalence classes. The inadvertent establishment of sample-S− stimulus control with Subject FDK illustrates one disadvantage of two-choice procedures for equivalence studies (Carrigan & Sidman, 1992; Sidman, 1987). Extension to three choices in future work may, however, increase the complexity of trial sequences. For example, a three-choice version of the present study's procedure would require six stimulus presentations per trial.

With successive go/no-go procedures, an increase in the number of stimuli in each stimulus set increases the number of different trial types, but the number of stimulus presentations per trial remains constant at two. Because of this possible advantage for programming a go/no-go version of three-choice matching, go/no-go procedures merit consideration despite the potential measurement problem due to increased response latencies on initial equivalence tests (described in the introduction). In the present study, mean response latencies for the first eight probe trials (CA probes) for Subjects ZVR, SDN, and LWJ were six, nine, and 14 times longer, respectively, than mean latencies for the interspersed baseline trials; latencies for ACM and FDK were no different on baseline and probe trials. The extent to which similar changes in response latency would occur following go/no-go training and testing in a go/no-go baseline is an empirical question. Further study might also examine development of equivalence classes including visual stimuli with successive discrimination procedures like those of the present study and with go/no-go procedures.

Further development of methods for establishing all-auditory equivalence classes may help to extend the range of subject populations included in equivalence research. Such extensions could include nonhuman species whose performance on auditory discriminations is superior to visual discrimination, as well as humans with both limited verbal repertoires and visual impairments. The feasibility of experimentation with subject populations less capable than that of the present study, however, will depend upon the extent to which appropriate auditory conditional discrimination baselines can be established.

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